Rare Plant Surveys and Vegetation Monitoring in Camp Grayling Pine Barrens Management Area

Prepared By:

Tyler J. Bassett, Julie B. McLaughlin, and Paul R. Schilke
Michigan Natural Features Inventory, Michigan State University Extension
P.O. Box 13036
Lansing, MI 48901-3036

Prepared For:

Michigan Department of Military and Veterans Affairs

November 19, 2024

MNFI Report Number 2024–36

Michigan Natural Features Inventory

MICHIGAN STATE UNIVERSITY | Extension

Suggested Citation:

Bassett, T.J., J.B. McLaughlin, and P.R. Schilke. 2024. Rare Plant Surveys and Vegetation Monitoring in Camp Grayling Pine Barrens Management Area, Report Number 2024-36, Lansing, MI.

We collectively acknowledge that Michigan State University occupies the ancestral, traditional, and contemporary Lands of the Anishinaabeg – Three Fires Confederacy of Ojibwe, Odawa, and Potawatomi peoples. In particular, the University resides on Land ceded in the 1819 Treaty of Saginaw. We recognize, support, and advocate for the sovereignty of Michigan's twelve federally recognized Indian nations, for historic Indigenous communities in Michigan, for Indigenous individuals and communities who live here now, and for those who were forcibly removed from their Homelands. By offering this Land Acknowledgement, we affirm Indigenous sovereignty and will work to hold Michigan State University more accountable to the needs of American Indian and Indigenous peoples.

Cover Photo: A good example of canopy heterogeneity in Frog Lake Barrens in subunit 2C of the Pine Barrens Management Area.

All photos by Tyler J. Bassett.

ACKNOWLEDGEMENTS

Funding for this project was provided by Department of Military and Veteran Affairs. We express our gratitude to the numerous DMVA staff at Camp Grayling that helped administer and guide this project, in particular Cullen Haesler and Matt Kleitch. We appreciate insightful conservations with DNR-FRD regarding the management of the PBMA, especially fire managers Mike Janisse and Lee Osterland and forester Joan Charlebois. We especially thank Phyllis Higman for laying the botanical groundwork at Camp Grayling and for sharing her passion for the plants of the area with us.

This report relies on data collected by many former Michigan Natural Features Inventory field scientists, especially Dennis Albert, Josh Cohen, Pat Comer, Phyllis Higman, Mike Kost, Mike Penskar, and Bradford Slaughter. Former MNFI botanist Elizabeth Haber contributed significantly to 2021 study design and data collection. Former AmeriCorps intern Diana Digges and current GIS Specialist Courtney Ross also assisted in the field in 2021. Nicole Smith and Courtney Ross provided GIS support for generating random points for plot sampling. Mike Monfils provided edits that improved this report, and Jesse Lincoln offered valuable advice on the presentation of management recommendations. For their administrative support and assistance throughout this project, we thank our MNFI colleagues Ashley Adkins, Sarah Carter, Kraig Korroch, Mike Monfils, Deb Richardson, Rebecca Rogers, and Hope Wolcott.

Phyllis Higman investigating Alleghany plum (*Prunus umbellata*) in subunit 2C of the Pine Barrens Management Area along Stephan Bridge Rd.

EXECUTIVE SUMMARY

The Pine Barrens Management Area (PBMA) occupies 2,026 ha (5,007 acres) in north-central Crawford County, MI. The PBMA is co-managed by the Michigan Department of Natural Resources Forest Resources Division and Michigan National Guard Camp Grayling Joint Maneuver Training Center. Surveys by Michigan Natural Features Inventory (MNFI) documented a high-quality pine barrens natural community and several rare plant and animal species within the PBMA. MNFI also conducted rare species monitoring and completed a management plan for the PBMA in 2000. The plan subdivided the PBMA into management units and subunits, and outlined objectives including reintroducing prescribed fire, reducing the density of jack pine (*Pinus banksiana*) and other canopy tree species, and increasing native species diversity and rare species abundance. The plan also suggests regular vegetation monitoring. To that end, MNFI was contracted in 2021 to conduct rare plant species surveys in the PBMA, and collect monitoring data to track the effects of future management on rare plant species and the pine barrens ecosystem.

We conducted meander surveys from 2021-2023 for four rare plant species: pale agoseris (*Agoseris glauca*, State Threatened), Hill's thistle (*Cirsium hillii*, Special Concern), rough fescue (*Festuca altaica*, Special Concern), and Alleghany plum (*Prunus umbellata*, Special Concern). We documented Hill's thistle and rough fescue in most subunits of the PBMA, an estimated 453 and 25,332 individuals, respectively. One existing occurrence of Alleghany plum was redocumented, comprised of at least five individuals. No pale agoseris was observed.

We established long-term monitoring plots for Hill's thistle and rough fescue. In these plots, we marked 64 individuals of Hill's thistle in three plots, and 39 rough fescue individuals in two plots. In these plots, we recorded demographic data in 2021, specifically the number and width of rosettes, the length of the longest rosette leaf, the number of fertile culms, the height of the tallest culm, and the width of the flowerhead for Hill's thistle; and plant width and number of fertile culms for rough fescue. We resurveyed marked individuals in 2022 and 2023 to better understand demographic changes in populations of both species. We also documented associated plant species composition in both rough fescue plots. We observed minor fluctuations in demographic parameters over time, but few differences were statistically significant.

We collected data on ecosystem structure and plant community composition to track how the pine barrens ecosystem changes in response to management and plant community succession. These data also allowed us to compare contemporary structure and composition across a jack pine canopy cover gradient. First, we delineated three cover types within the PBMA – prairie (~<10% tree cover), savanna (10-80%), and forest (>80%). Then, we sampled vegetation in 45 ecosystem plots distributed among cover types (prairie, n= 17; savanna, n= 16; forest, n=12). We sampled vegetation across three vertical strata in ecosystem plots, including the structure, density and composition of the tree and shrub layers, and composition and abundance of ground layer vegetation. We also sampled ground layer vegetation in both of the rough fescue rare plant monitoring plots. Ecosystem structure differed among cover types, with canopy basal area and live stem density highest in the forest and lowest in the prairie cover type. These structural differences among cover types translated into differences in plant community composition but not diversity among cover types. Woody plant species and mosses were abundant in forest plots, heliophytic (sun-loving) forbs and graminoid species were abundant in prairie plots, while savanna plots supported a mix of both "forest" and "prairie" species.

Pine barrens is a fire-dependent ecosystem. Historically, Indigenous people applied fire frequently as a way of life in the pine barrens landscape, and the ecosystem and its inhabitants evolved with frequent fire. However, the droughty conditions and dense stands of jack pine present a contemporary wildfire risk. We recommend the reintroduction of low-intensity fire as a primary management tool in the PBMA for restoring and maintaining the heterogenous canopy structure and distinct biodiversity of the pine barrens ecosystem. Low-intensity fire can reduce the risk of crown fires by thinning out dangerous ladder fuels and conditioning trees to withstand more intense fires. The reintroduction of fire can help maintain a pine barrens ecosystem that supports biodiversity over the long-term. We look forward to conducting subsequent monitoring after the application of low-intensity fire in the PBMA.

Frog Lake Barrens, view south over intermittent wetland in subunit 2C of the Pine Barrens Management Area..

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Diana Digges (USFWS, former MNFI AmeriCorps intern) and Elizabeth Haber (USFWS, former MNFI botanist) conducting a rare plant survey at the Pine Barrens Management Area.

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INTRODUCTION

The Pine Barrens Management Area (PBMA) occupies 2,026 ha (5,007 acres) in north-central Crawford County, MI in the Michigan Department of Natural Resources Forest Resources Division (DNR-FRD) Grayling Forest Management Unit (Figure 1). The PBMA is co-managed by DNR-FRD and the Michigan National Guard Camp Grayling Joint Maneuver Training Center (hereafter, Camp Grayling). Michigan Natural Features Inventory (MNFI) was contracted in 2021 to conduct rare plant species surveys in the PBMA, and collect monitoring data to track the effects of management on rare plant species and the pine barrens ecosystem.

Landscape Context

The Regional Landscape Ecosystems of Michigan (Albert et al. 1995) categorizes landscapes based on climate, glacial landform, soil, and vegetation. This system offers a framework for placing natural communities, species, and their ecological relationships in a comprehensive context. Michigan's geological history is shaped by the Wisconsin advance of the Laurentide ice sheet during the Pleistocene epoch, which ended approximately 10,000 years ago. Camp Grayling is located entirely within the Grayling Outwash Plain sub-subsection (VII.2.2) of the Highplains subsection (VII.2) of Section II (Figure 2). The Highplains subsection is primarily

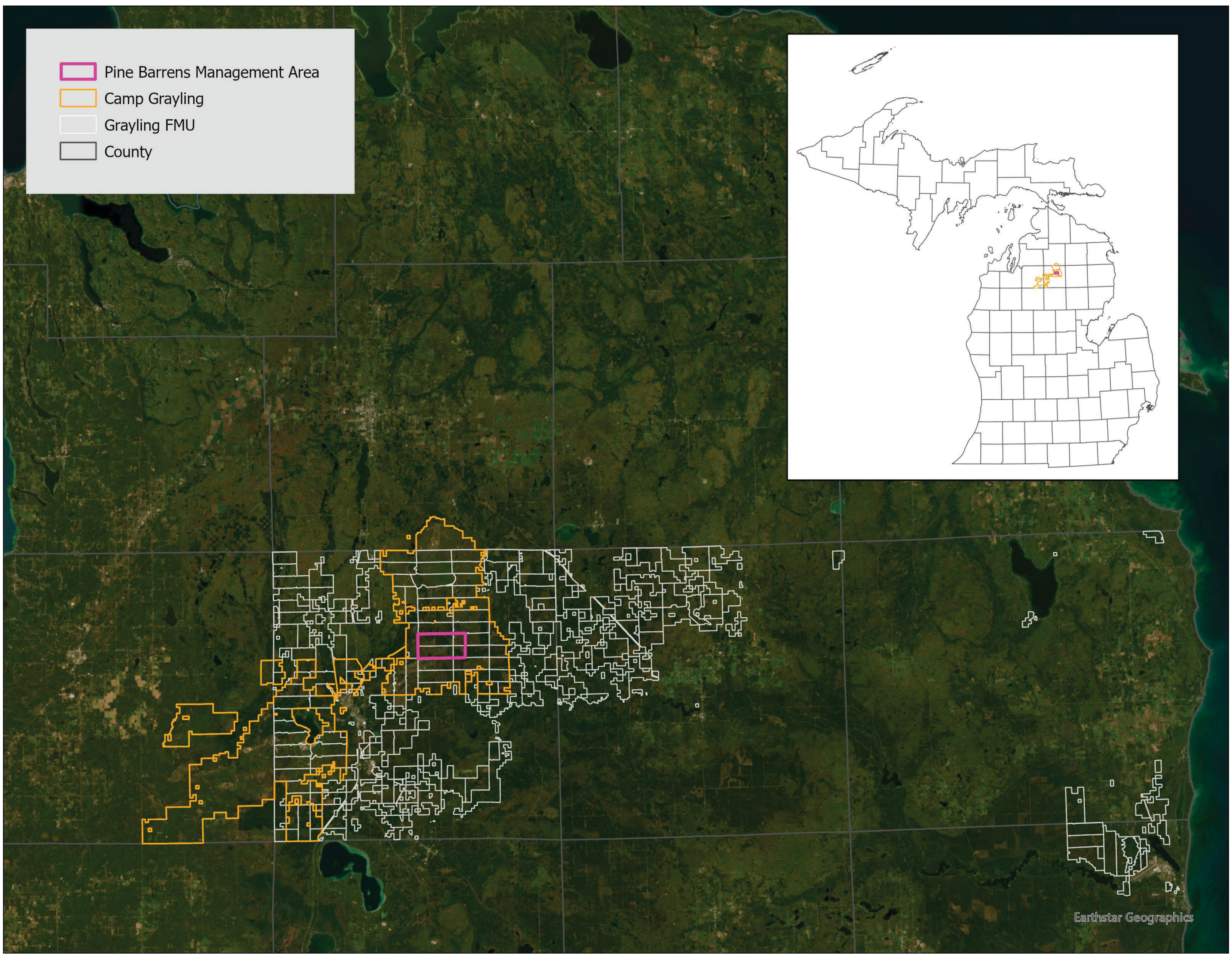

Figure 1. The Pine Barrens Management Area within Camp Grayling.

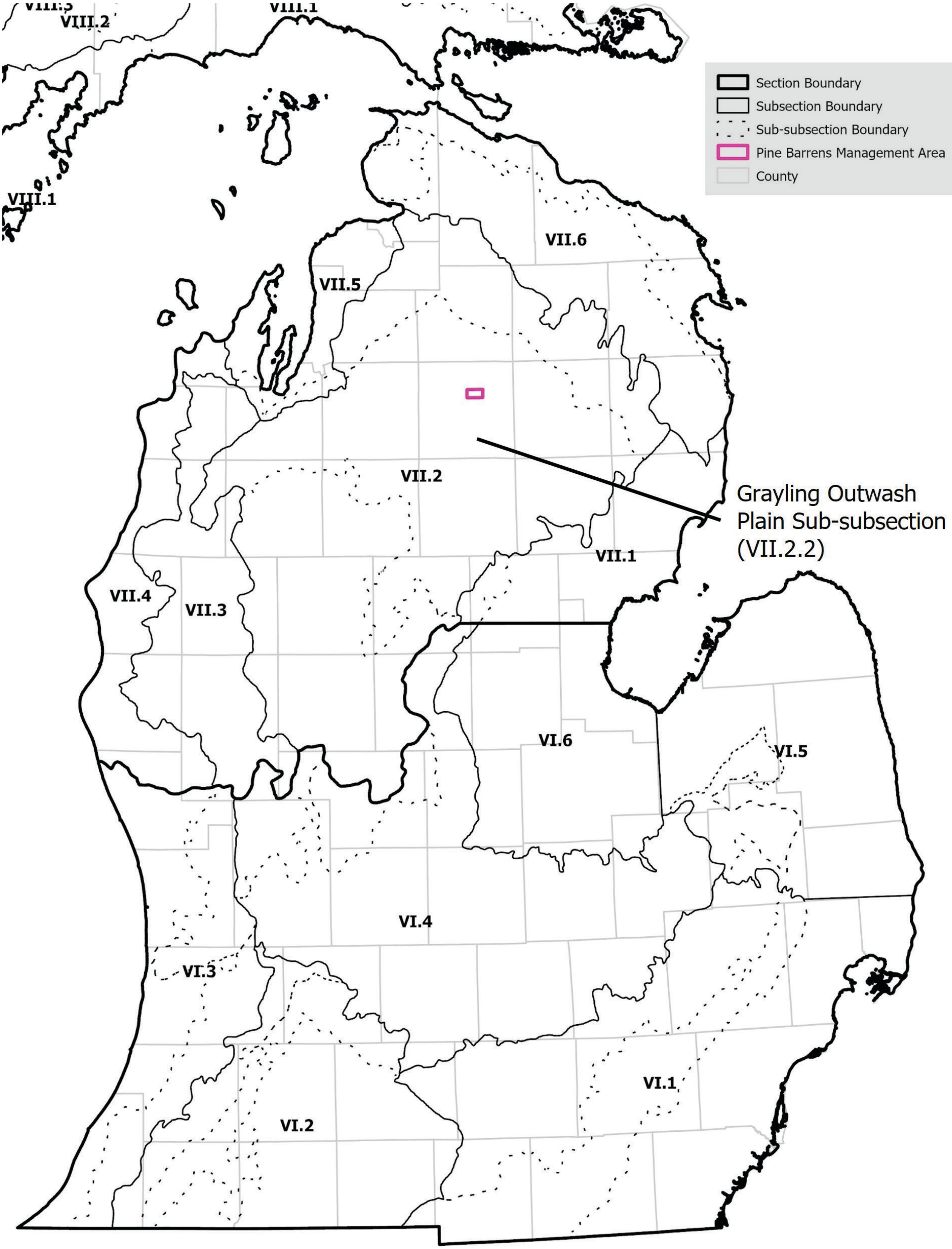

Figure 2. Regional landscape ecosystems of Michigan (Albert 1995).

a high plateau characterized by glacial outwash and end moraines, cut through by the Manistee and Au Sable rivers. Most of the subsection has sandy, excessively drained soils. The boundaries of the Grayling Outwash Plain are similar to other landcover classifications, including the EPA Level III ecoregions (as the Mio Plateau; Omernik and Griffith 2014) and the Physographic Regions of Michigan (as the High Plains section; Schaetzl et al. 2013).

Due to its distance from the Great Lakes and high elevation, the Highplains subsection has the most extreme climate in the Lower Peninsula (Albert 1995). It has the shortest growing season, experiences late spring freezes and mid-summer frosts, and frost pockets that form in kettle holes are prevalent. Vegetation circa 1800 of the outwash plains included forests of jack, red, and white pine (*Pinus banksiana*, *P. resinosa*, and *P. strobus*); savannas (barrens) dominated by jack pine but including Hill's and white oak (*Quercus ellipsoidalis* and *Q. alba*) and a supercanopy of white and red pine; and occasional thin-canopied grasslands concentrated in frost pockets (Comer et al. 1995) (Figure 3). In the late 1800s, this area experienced heavy logging followed by massive wildfires, which reduced the abundance of red and white pine in the supercanopy. Red pine plantations were established across this part of the state, starting in the 1930s with the Civilian Conservation Corps, and continuing today in accordance with State (DNR) and Federal (USFS) policy (Higman et al. 1994). Jack pine plantations to support populations of the globally rare Kirtland's warbler (*Setophaga kirtlandii*) have been frequent on the landscape since the late 1950s (Huber et al. 1996).

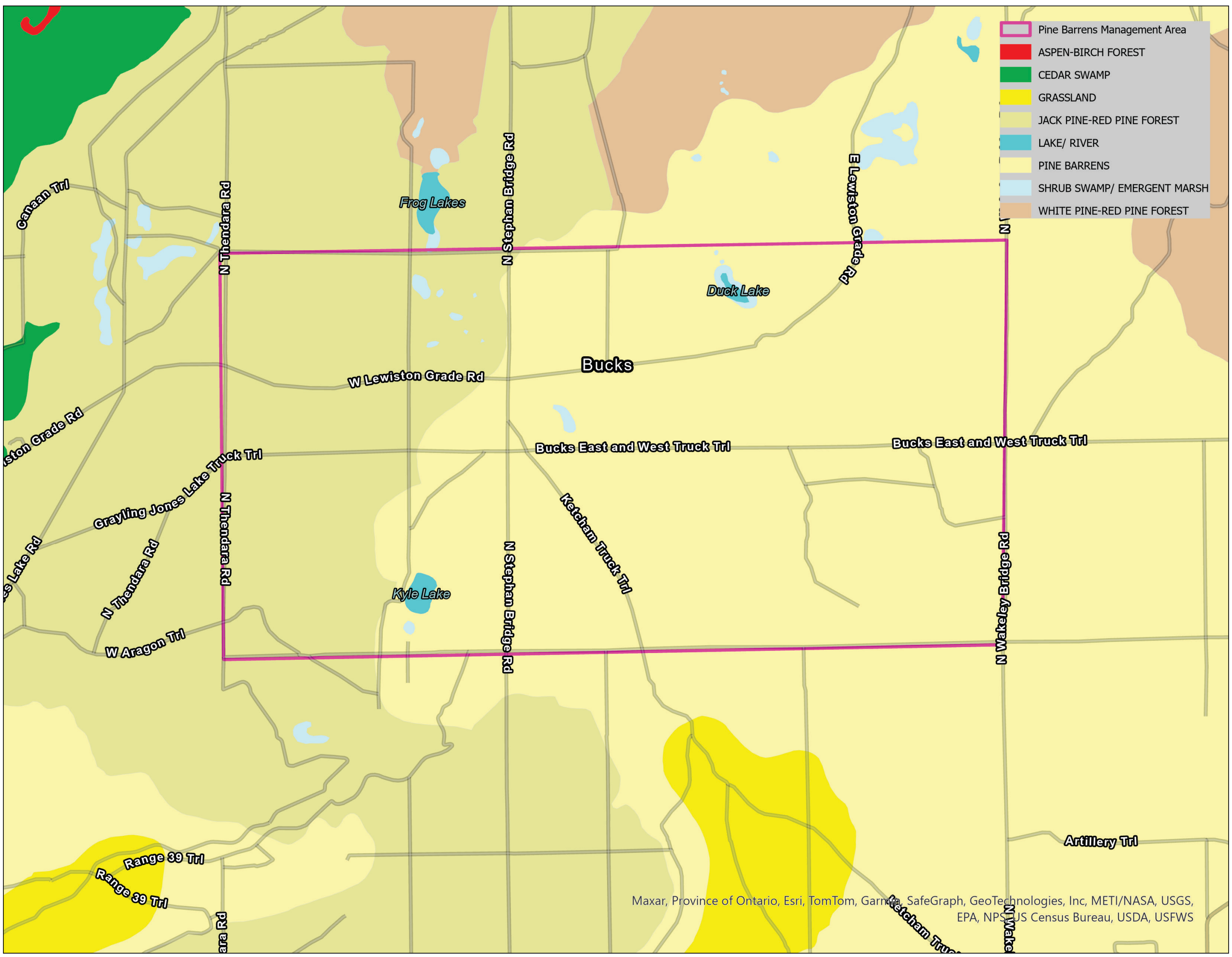

Figure 3. Vegetation circa 1800 of the PBMA.

Pine Barrens Natural Community Description

The central natural feature of the PBMA is Frog Lake Barrens, a high-quality example of a pine barrens natural community (Figure 4). Pine barrens is a fire-dependent savanna that occurs across the northern Lower Peninsula of Michigan and in scattered locations in the Upper Peninsula (MNFI 2024). Pine barrens is characterized by heterogenous canopy structure, generally dominated by jack pine with red and white pine present or subdominant in the canopy or super-canopy (Comer 2010). Topography is flat to gently rolling, and soils are highly to moderately acidic (pH 4.5-6.0) and excessively drained Grayling sands (Zimmerman 1956, Comer 2010). Fire was historically the predominant factor shaping plant community composition and ecosystem structure, maintaining open conditions by limiting woody species encroachment that would lead to succession to closed-canopied conditions. Historically, pine barrens burned frequently. Fire return interval estimates range from 9 to 55 years (Simard and Blank 1982, Cleland et al. 2004, Stambaugh et al. 2024), and several historic and contemporary fires were thousands of acres in size (Simard and Blank 1982). Although historic fires were often high-intensity, stand-replacing events, recent studies suggest a wide range of intensity and seasonality, including low-intensity fires (Simard and Blank 1982, Jolly et al. 2016, Stambaugh et al. 2024). Frequent fire encourages recruitment of jack pine seedings by triggering their serotinous cones to open and disperse seed, as well as creating patches of bare ground while limiting dominance of the mat-forming sedge Pennsylvania sedge (*Carex pensylvanica*), allowing for the

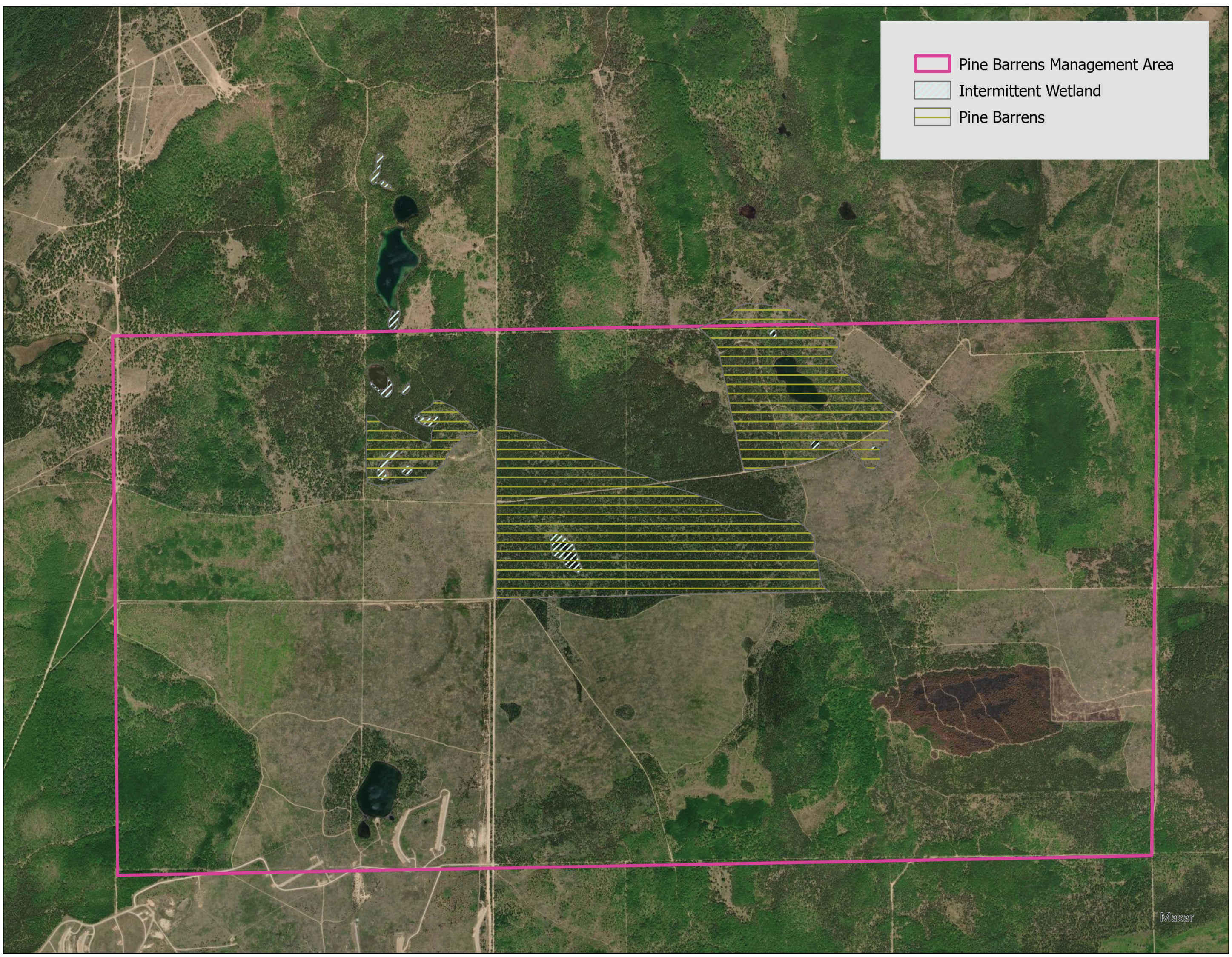

Figure 4. Natural community element occurrences of the PBMA.

maintenance of a diversity of grasses and forbs (Comer 2010). Where barrens have succeeded to forests, herbaceous and low-shrub ground cover and diversity that are characteristic of barrens is limited (Kost et al. 2000). Fire suppression over the last century has led to an increase in closed-canopy natural jack pine forest, in addition to many acres of intentionally established pine plantations.

Portions of the pine barrens in the PBMA are of state-wide conservation significance. Elements of biodiversity, which include rare plant and animal species and high-quality examples of natural communities, are documented as element occurrences (EOs) in the Michigan Natural Heritage Database (MNFI 2024). Global and subnational (i.e., state-level) conservation ranks (G-rank and S-rank) are used to assess the conservation value of each element. Conservation ranks range from critically imperiled (G1 and S1) to secure (G5 and S5), and may include additional ranks (e.g., GU, or globally unrankable [NatureServe 2002]; Table A1, A2). The status of each EO is assessed with EO Ranks, which range from A (Excellent estimated viability/ecological integrity) to D (Poor estimated viability/ecological integrity; Table A3). For natural communities, condition is based upon several biotic (e.g., species composition and diversity, forest canopy closure and dominant tree age, biological threats such as invasive species and threats) and abiotic (e.g., soil characteristics, hydrology, slope, and aspect) factors that may vary among different natural communities. Pine barrens is ranked S2/G3 (imperiled in Michigan/globally vulnerable). Nearly 110,000 hectares (270,000 acres) of pine barrens existed in the state of Michigan in the 1800s prior to widespread European colonization (Comer et al 1995). Currently, there are only 1,624 hectares (4,012 acres) of high-quality pine barrens documented in Michigan as EOs, representing 1.5% of historical extent. Of the 25 individual EOs, only 4 are of excellent to good viability (EO Rank A to B; Lincoln et al 2024). The third-largest (233 hectares [575 acres]) remnant pine barrens in the state, Frog Lake Barrens, is located within the PBMA, and ranked as good or fair estimated viability (BC) (MNFI 2024). This EO was down-ranked from a rank of B in 2020 after a portion northwest of the Stephan Bridge Rd-Bucks East West Trail intersection (the southeast corner of subunit 1B) was clearcut to provide a "machine-gun alley" for training purposes.

History of the Pine Barrens Management Area

The PBMA occurs in a historically 64,750-hectare (160,000-acre) mosaic of pine barrens and jack pine-red pine forest (Comer et al. 1995; Figure 3). Notes from the General Land Office surveys in the 19th century describe the PBMA as "gently rolling burnt land," emphasizing the fundamental role of fire in this habitat (General Land Office 1890). The contemporary vegetation of the PBMA includes young dry northern forest dominated by jack pine, pine barrens, open sand prairie, and a deciduous cover types dominated by either Hill's oak or aspen (*Populus grandidentata and P. tremuloides*), ranging from second growth forest to shrub lands (Kost et al. 2000).

MNFI conducted a comprehensive inventory of the flora, fauna, and natural communities for the Camp Grayling Military Reservation in 1992 and 1993 (Higman et al. 1994). The study was initiated for compliance with the Land Condition Trend Analysis (LCTA) project implemented by Camp Grayling staff. This study provided baseline data for the Camp, including documentation of 18 natural community types (nine types ranked high quality), 866 vascular plant taxa (including 15 listed plant species), and nine occurrences of two listed animal species, secretive locust (*Appalachia arcana*, Special Concern) and eastern massasauga (*Sistrurus catenatus*, Federally and State Threatened). This inventory also highlighted two natural community occurrences as focal areas or units for conservation, restoration, and management. Both units also support a high concentration of rare plant and animal species. Frog Lake Barrens formed the backbone of one unit along with an associated intermittent wetland EO (Figure 4). The other unit, the Portage Lake Complex, is structured around a wet-mesic sand prairie EO (Lincoln and Cohen 2022).

Focused surveys for rare plant and animal species were conducted in 1998 and 1999 (Kost et al. 2000). Only Hill's thistle (*Cirsium hillii*, Special Concern) and rough fescue (*Festuca altaica*, Special Concern) were found within the PBMA. While rough fescue was found in large colonies, Hill's thistle was observed infrequently and at low density (Kost et al. 2000). Bird point counts documented 24 species, with no listed species and low abundance. Insect surveys targeted three rare species. Secretive locust and red-legged spittlebug (*Prosapia ignipectus*, State Delisted) were documented, but no occurrences of blazing star borer moth (*Papaipema beeriana*, Special Concern) were observed (Kost et al. 2000).

In 2005, MNFI mapped landcover of the PBMA based on the U.S. National Vegetation Classification (USNVC; Cohen et al. 2005). Eight plant alliances were described, with the most dominant ones being the Jack Pine Forest Alliance (36%), the Jack Pine – (Northern Pin Oak, Black Oak) Forest Alliance (28%), and the Jack Pine – (Red Pine) Wooded Herbaceous Alliance (22%). MNFI also re-assessed the status of rare and declining species and natural communities throughout Camp Grayling (Kost and Cohen 2005). This included the ~10-acre Frog Lake Complex intermittent wetlands, located within the PBMA.

Rare plant and animal species

Several rare and declining plant and animal species utilize or require pine barrens and the landscapes where they occur. These include at least five plant species, four bird species, eleven insects, and one reptile. Kirtland's warbler (*Setophaga kirtlandii*, State Threatened and Federal Delisted) is a noteworthy species for its dependence on large, dense stands of young jack pine (ca. >80 acres) for breeding (Beylich et al. 1976). Several rare and declining plant and animal species have been documented in the PBMA. Prior to the beginning of this study in 2021, there were nine element occurrences documented within the PBMA (Table 1). In addition to pine barrens and intermittent wetland natural communities, there was a single EO each of Hill's thistle, rough fescue, Alleghany plum (*Prunus umbellata*, Special Concern), Kirtland's warbler, eastern massasauga, secretive locust, dusted skipper (*Atrytonopsis hianna*, Special Concern), and cobweb skipper (*Hesperia metea*, Special Concern) (MNFI 2024). Most of these species depend upon the patchy canopy conditions associated with pine barrens and are threatened by the closed-canopy conditions resulting from fire suppression and jack pine plantations for Kirtland's warbler (Tucker et al. 2016). In addition, significant populations of Hill's thistle and rough fescue are located within

Table 1. Natural community and rare species element occurrences in the PBMA as of 2021.

EO ID	Scientific name	Common name	G/S Rank	First Observed	Last Observed	EO Rank
	Plants					
615	*Cirsium hillii*	Hill's thistle	G3/S3	1992	2023	BC
1888	*Festuca altaica*	Rough fescue	G5/S2S3	1992	2023	A
14571	*Prunus umbellata*	Alleghany plum	G5/S3	2004	2023	BC
	Animals					
4145	*Appalachia arcana*	Secretive locust	G2G3/S2	1993	2023	AC
9373	*Appalachia arcana*	Secretive locust	G2G3/S2	1999	2021	AC
14529	*Atrytonopsis hianna*	Dusted skipper	G4G5/S3	2004	2021	AC
24179	*Hesperia metea*	Cobweb skipper	G4/S4	1993	2021	E
11180	*Setophaga kirtlandii*	Kirtland's warbler	G3/S3	1971	2023	E
12282	*Sistrurus catenatus*	Eastern massasauga	G3/S3	1950	1950	X?
	Natural communities					
9538	Intermittent Wetland	Intermittent Wetland	G2/S3	1993	2020	B
16049	Pine Barrens	Pine Barrens	G3/S2	2006	2020	BC

active military ranges. Factors associated with military training, such as the use of tracked vehicles, presents a potentially conflicting land use, whereas other factors may benefit these and other rare species, such as restricted access for non-military uses and the lack of conversion to pine plantations. Perhaps most importantly, there is a history of incidental fires associated with the use of live ammunition, dating as far back as the 1940s, that may be at least in part responsible for the persistence of these fire-dependent species.

Rare plant species descriptions
Hill's thistle is a globally vulnerable (G3) perennial thistle of pine barrens, oak savanna, prairie, and forest openings. The Highplains region of Michigan is a global stronghold for this species, which is considered vulnerable (S3) to critically imperiled (S1) throughout its range Iowa, Illinois, Indiana, Minnesota, Wisconsin, Michigan, and Ontario, and extirpated from Missouri (NatureServe 2024). Of the 192 EOs observed since 2000, 100 occur in the Highplains subsection (Albert 1995, MNFI 2024). Hill's thistle is referred to *C. pumilum* by some authors, as subsp. or var. *hillii* (Voss and Reznicek 2012). Young plants persist as a basal rosette for 1-2 years, and then produce single, large, purple to pink flower heads on short (25-60 cm tall) stalks. Flowering occurs from June to August and requires openings for flowering. This species has poor seedling establishment where lack of fire has allowed litter to accumulate (Higman and Penskar 1996). Higman et al. (1994) reported several large metapopulations of Hill's thistle within the PBMA. In 1999, unit 2C contained an occurrence of 61 individuals (Kost et al. 2000).

Rough fescue is a stout (50-80 cm tall) bunchgrass that in Michigan is exclusively found in the sandy plains and pine barrens of the Highplains region, where it is isolated from its stronghold in British Columbia, Yukon, and Alaska (Voss and Reznicek 2012, NatureServe 2024). Of the 38 EOs observed since 2000, 35 occur in the Highplains subsection, 23 in Crawford County (Albert 1995, MNFI 2024). It is shade-intolerant, thrives after moderate grazing or fire, and flowers between July and September. In 1993, 23 populations were documented in the state, with only two occurrences in the PBMA (Higman et al. 1994). In follow-up surveys in 1999 it was present in 41% of plots within the PBMA (Kost et al. 2000). Five new occurrences were reported in 2004.

Alleghany plum is a small, straggly shrub (up to 3 m tall) of dry, open forests, barrens, and prairies. Michigan populations of *Prunus umbellata* are disjunct from the core range in the southeastern United States. Of the 38 EOs observed since 2000, 23 occur in the Highplains subsection (Albert 1995, MNFI 2024). This species has also been referred to *Prunus allegheniensis*, in which case Michigan populations are *P. allegheniensis* var. *davisii* and are disjunct from the core *P. allegheniensis* range in eastern North America. It is similar in appearance to other members of the genus, especially Canada and American wild plum (*P. nigra* and *P. americana*), but can be more easily identified during flowering and fruiting (Voss and Reznicek 2012). In 1992, two occurrences were seen along roads south of the PBMA (Higman et al 1994). One new occurrence was documented along Stephan Bridge Road in 2003 (Higman et al. 2005).

Pale agoseris (G4G5/S2) is disjunct in Michigan from its core range in the prairies and mountains of the western U.S. and Canada (NatureServe 2024). Restricted to four contiguous counties in Michigan (Otsego, Montmorency, Crawford, and Oscoda), all 18 of the EOs documented and all 9 observed since 2000 occur in the Highplains subsection (Albert 1995, MNFI 2024). In the Asteraceae family, pale agoseris has characteristics similar to the common dandelion, such as a single, large, yellow flower head. However, pale agoseris has a basal rosette of toothless, glaucous leaves, and produces leafless flower stalks 20-40 cm tall. It flowers and fruits in June and July. The fruits have long silky hairs (pappus) to aid in wind dispersal (Higman and Penskar 1996). Despite this species being a pine barrens specialist in Michigan and occurring in the nearby Shupac Lake pine barrens (~ 10 km to the north-northeast), none has ever been located within the PBMA (Higman et al. 1994, Kost et al. 2000, Cohen et al. 2005, Kost et al. 2005, MNFI 2024).

Hill's thistle (*Cirsium hillii*). In pine barrens habitat (*below*); *clockwise from lower left*: rosette prior to bolting, seed-dispersing individual, flowering individual.

Rough fescue (*Festuca altaica*). Dense, golden seed heads in Unit 4 (*above*), flowering individual (*below left*), and sterile individual (*below right*).

Alleghany plum (*Prunus umbellata*). Straggly growth form (*above*), flowering individual (*below*), and leaf shape (*right*).


Pale agoseris (*Agoseris glauca*). Flowering head (*upper left*), individual with both flowering and fruiting stalks (*upper right*), fruting individual with associates low sweet blueberry (*Vaccinium angustifolium*) and sand cherry (*Prunus pumila*) (*lower left*), and fruiting individual showing resemblance to dandelion (*lower right*).


Previous Management Recommendations

The PBMA area is divided into seven management units based on vegetation and firebreaks. Several units are further divided into sub-units (Figure 5). Management recommendations for different units and habitats were provided in the 1994 and 2000 reports (Higman et al. 1994, Kost et al. 2000). The results of surveys and monitoring contained in this report are intended to enhance those and other previous surveys, and provide data that support or modify these and other recommendations.

The 1994 report included broad management suggestions, such as retaining large red and white pine trees, introducing fire into jack pine communities, using camp personnel to conduct a rotating pattern of prescribed burns, and thinning plantations to create uneven-aged stands (Higman et al. 1994).

The vision for management in 2000 was to restore "a pine barrens with large expanses of open grassland with scattered patches of uneven-aged jack pine, red pine, white pine, northern pin oak, and aspen. Ideally, the open grassland would harbor a diverse array of native grasses, sedges, forbs, and woody species" (Kost et al. 2000, page 10). The following management objectives were included in the 2000 report: reintroduce fire to the system; reduce jack pine cover within the unit to 30% (+/- 10%); decrease jack pine patches to <10% of the overall acreage; plant red and white pine; reduce exotics plant species like spotted knapweed (*Centaurea stoebe*); increase native animal species diversity; maintain/increase native ground-layer diversity; and maintain/increase rare species abundance.

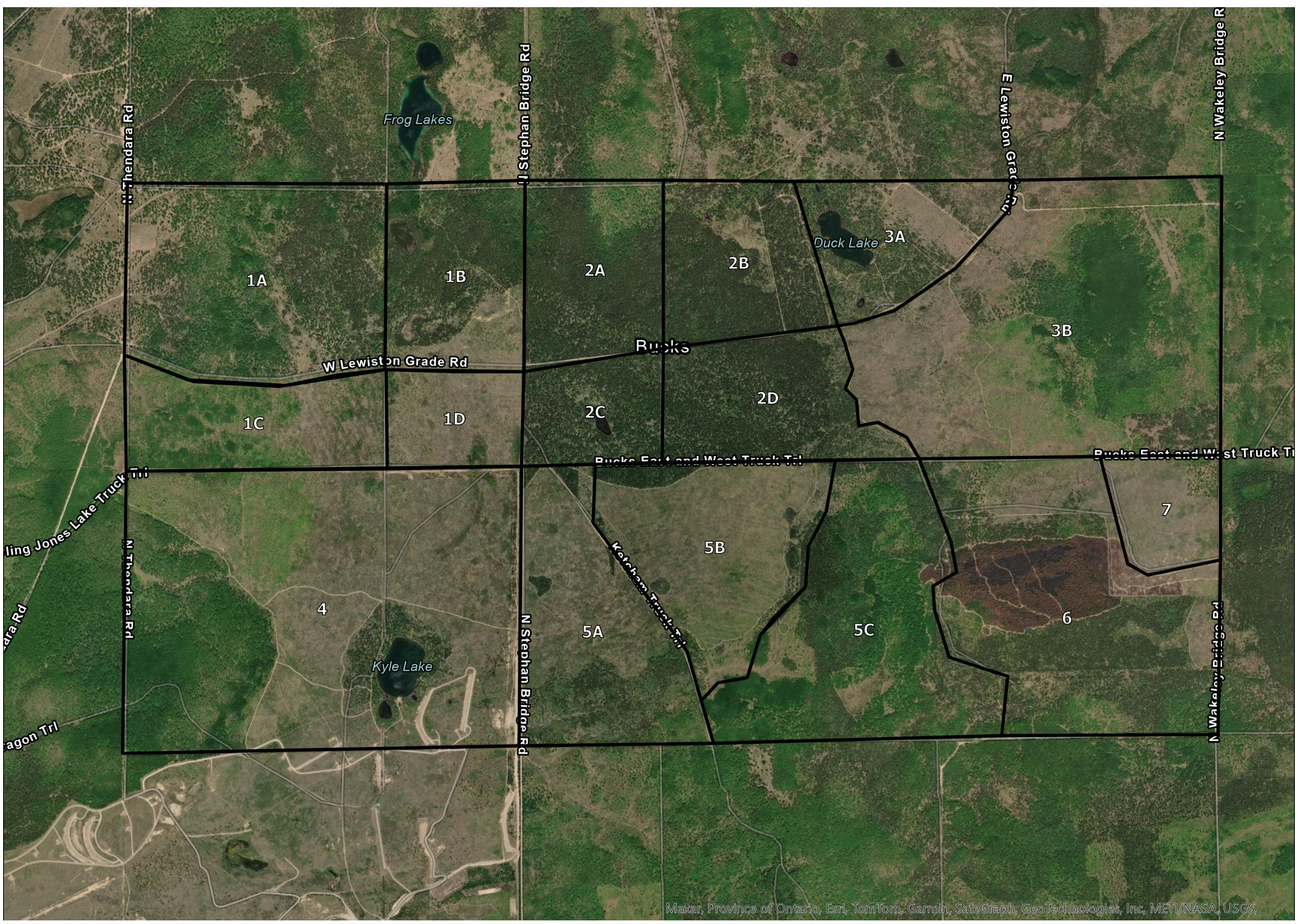

Figure 5. Subunits of the PBMA.

Rare Plant Surveys

We conducted meander surveys from 2021-2023 for four rare plant species: pale agoseris, Hill's thistle, rough fescue, and Alleghany plum. Surveys were conducted annually during the peak flowering period for pale agoseris, Hill's thistle, and rough fescue of late June and early July, to maximize detection probability. We conducted surveys for Alleghany plum in early- to mid-May, the peak flowering period for that species.

Surveys units consisted of approximately one-third of the PBMA in each year. We conducted surveys in subunits 2A-D and 5A-B in 2021; in the eastern approximately two-thirds of Unit 4 and all of Unit 1 (subunits 1A-D) in 2022; and in Units 3, 5C-D, 6, and 7 in 2023 (Figure 5). In each unit, surveys focused on suitable pine barrens habitat, especially grass- and sedge-dominated openings and areas dominated by jack pine. Surveys avoided areas of unsuitable habitat, particularly those with a canopy dominated by deciduous trees (e.g., Hill's oak and aspen), and an understory dominated by bracken fern (*Pteridium aquilinum*). Prior to 2021, several observations had been documented of both Hill's thistle and rough fescue in the PBMA (Table 1). A single EO of Hill's thistle (EOID 615) contained observations described as "scattered north and south of E Lewiston

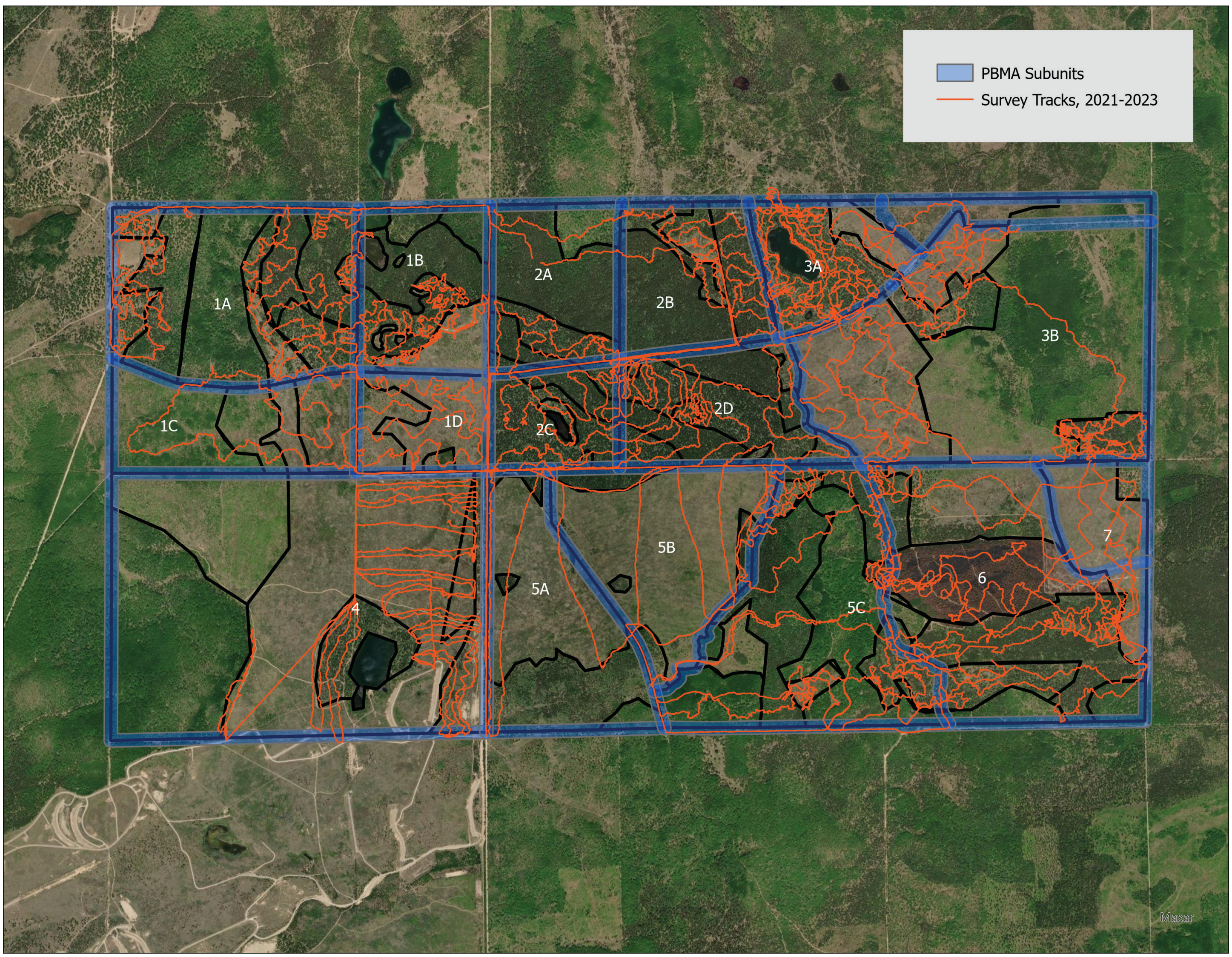

Figure 6. Survey tracks from rare plant surveys.

Grade Rd. and east and west of Stephan Bridge Road," suggesting Units 1-3, but mapped in the Natural Heritage Database only in Unit 1 (MNFI 2024). A single EO of rough fescue (EOID 1888) contained observations described as "scattered throughout Pine Barrens Management Area from west of Kyle Lake to north of Duck Lake to North Wakely Bridge Road," suggesting occurrences in much of the PBMA. A single small occurrence of Alleghany plum had been documented in the PBMA prior to 2021, representing a single EO (EOID 14571). No occurrences of pale agoseris had been documented.

We mapped rare plant species observations using the Avenza application on a Samsung Galaxy A tablet or an Android smart phone. After delineating survey units in ArcGIS Pro, we generated georeferenced PDF maps for data collection. Spatial data collection included survey tracks (Figure 6) and GPS point data (5-meter accuracy) marking rare plant locations. Data collection differed by species. For rough fescue, we estimated the number of individuals at each GPS point in broad categories (1, 5, 10, 25, 50, 100, 1000). At each point documenting Hill's thistle, we recorded the number of individuals by each of the following phenological stages: sterile rosette, in bud, in flower, and in fruit. We documented the number of individuals associated with the previously documented Allegheny plum occurrence at a single point. No individuals of pale agoseris were documented during the surveys.

Rare Plant Monitoring

In August 2021, we conducted long-term monitoring for Hill's thistle and rough fescue (Figure 7). First, we located areas where each species occurred at high density, then we marked individuals of Hill's thistle or rough fescue using numbered metal tags and pins and recorded demographic data. Plot design and marking protocol differed between species and is described below. We also documented associated plant species composition in rough fescue plots (see below under *Ecosystem monitoring*). We resurveyed marked plants in June 2022 and July 2023 and again recorded demographic data. Blank datasheets are provided in Appendix B (Figures B1a and B1b).

Rough fescue monitoring occurred in two, 200 m X 100 m plots, one in Unit 5B (FESALT01 in Figure 7) and one spanning Units 2C and 2D (FESALT02 in Figure 7). We established ten, 100 m long transects at random starting points along a 200 m baseline, and perpendicular to that baseline (Figure C1). We marked plants encountered within 1 meter of transect until we reached a total of 20 individuals per plot. To avoid spatial aggregation of marked plants, we marked every fifth plant encountered, and up to a maximum of 10 individuals per transect. We recorded the following demographic parameters on each marked plant to estimate changes in population viability due to management and plant community succession: width (cm) of the widest part of the base of the plant to estimate biomass; number of flowering or fruiting stems (culms) to estimate fecundity; and categorized rank of stem density as sparse, medium, or dense.

We used a plotless design for Hill's thistle, and instead conducted meander surveys to locate individuals for demographic monitoring. Hill's thistle grows in tightly aggregated clumps, so the random transects did not consistently intersect individuals that we could select for monitoring. We surveyed for and marked Hill's thistle plants within and in the vicinity of each rough fescue plot, plus an additional third survey area in subunit 2C (Figure 7). We marked a total of 24 plants among 5 clusters in CIRHIL01 (subunit 5B; = FESALT01). In CIRHIL02 (subunits 2C and 2D; = FESALT02), we marked a total of 20 individuals among 3 clusters. To increase the spatial distribution of marked plants, we initially marked every third individual encountered for the first 12 marked plants, then every second individual thereafter. In CIRHIL03 (subunit 2C), we marked a total of 20 individuals in six clusters, initially marking every second individual for the first 11 marked plants, then every fifth individual thereafter. As with rough fescue, we recorded similar demographic parameters on Hill's thistle. We estimated biomass by measuring the number of rosettes per individual (rosettes were attributed to the same individual if the rosette width

Figure 7. Long-term rare plant monitoring plots for rough fescue (FESALT) and sites for Hill's thistle (CIRHIL). Inset:(*upper left*) measuring width of medium-density rough fescue; (*lower right*) marked Hill's thistle rosette.

overlapped), the length of the longest rosette leaf, and the width of the rosette at the widest point. We estimated fecundity by measuring number of flowering and fruiting culms, the height of the tallest culm, and the width of the flowerhead if present.

Ecosystem Monitoring

We collected data on ecosystem structure and plant community composition to track changes to ecological integrity in response to management and plant community succession, and to compare structure and composition across a jack pine canopy cover gradient. First, we mapped coarse cover types in ArcGISPro through aerial photograph interpretation using 2018 NAIP imagery. We classified individual polygons as *prairie* (<10% jack pine canopy), *savanna* (10-80% canopy), *forest* (>80% canopy), and *other* (aspen- or oak-dominated canopy). Next, we generated random points using the Create Random Points tool in ArcGIS Pro. For each cover type in each subunit, we generated one point for every five acres but no less than five points regardless of area. We buffered each subunit to prevent the generation of points within 40 meters of subunit boundaries. Finally, we randomly selected one sampling point for each barrens covertype (prairie, savanna, forest) in each subunit (Figure 8). In some cases where a subunit did not contain a particular covertype, we substituted for the missing cover type adding an additional plot in an adjacent subunit (e.g., no prairie cover in 2A resulting in two prairie plots in 2C). Other anomalies in this sampling approach

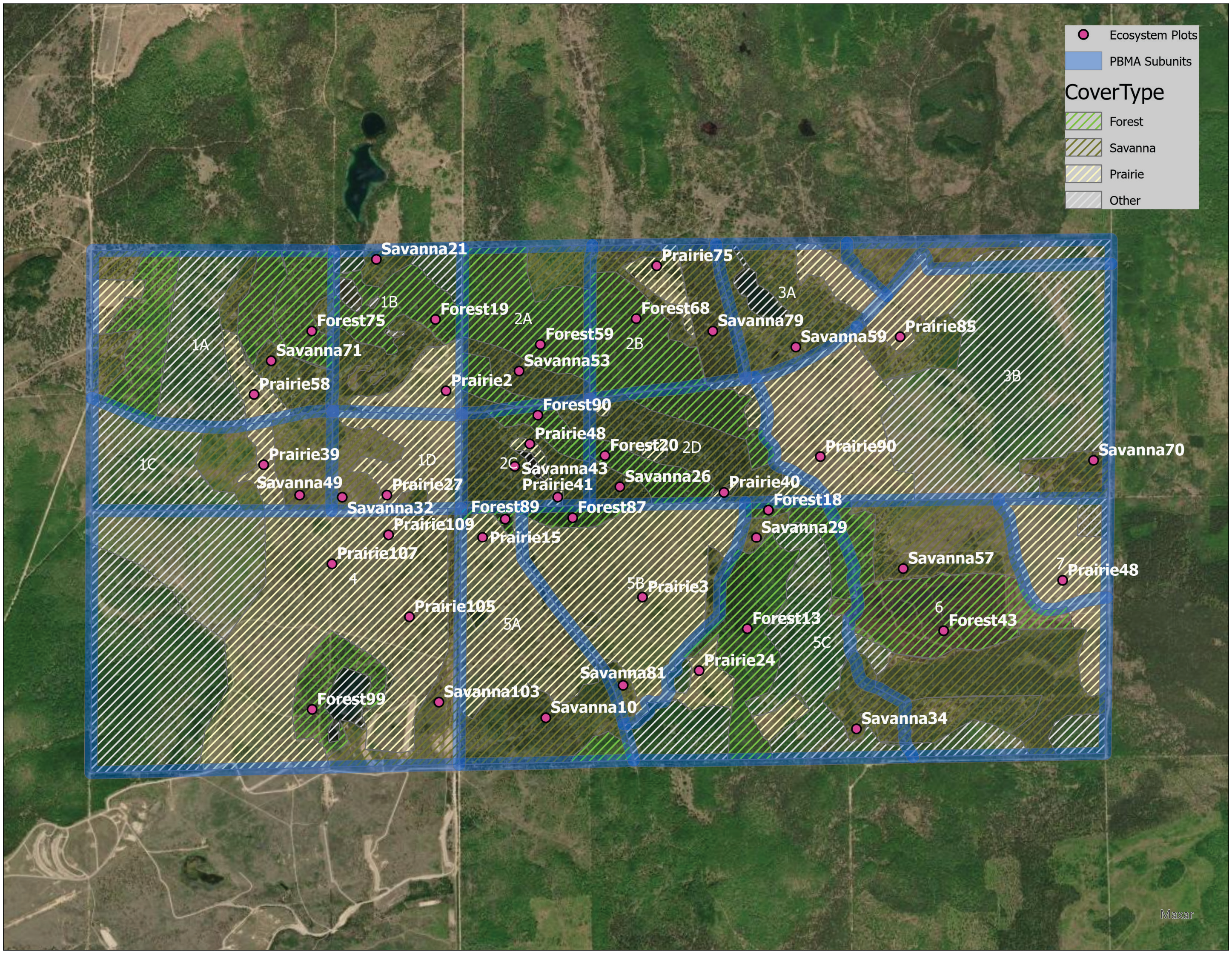

Figure 8. Ecosystem monitoring plots and cover type delineation of the PBMA.

are due to errors in cover type mapping prior to sampling that were corrected in th field. Blank datasheets are provided in Appendix B (Figures B2a-c).

We sampled 18, 20 X 20 m ecosystem plots in 2021, 15 plots in 2022, and 12 plots in 2023 for a total of 45 plots (*prairie*, n= 17; *savanna*, n= 16; *forest,* n=12). We navigated to each randomly selected point using the Avenza application on a Samsung Galaxy tablet. We randomly selected the initial axis of each plot by spinning a chaining pin, proceeding to lay the plot out in a counter-clockwise direction. Each plot corner was marked with a one-foot section of aluminum conduit marked with pink marking paint.

We sampled three strata in each plot: ground layer, subcanopy, and canopy (Figure C2).

Ground layer vegetation sampling was conducted within 10, 1x1 meter quadrats placed every 8 meters counter-clockwise around the perimeter of the plot, beginning at 0 meters (point of origin) and ending at 72 meters. Within each 1x1m quadrat, we estimated the percent cover of ground layer plant species (all herbaceous species, all woody species ≤ 1 m tall) to the nearest one percent. Vascular plants were identified to the species when possible, otherwise to the genus. For lichens and mosses, we recorded reindeer lichen (*Cladonia rangiferina* and *C. mitis*), British soldiers (*C. cristatella*), and hair-cap moss (*Polytrichum* spp.) separately, and lumped all other mosses (multiple genera, including *Atrichum*, *Thuidium*, and others) together under the morpho-group 'feather mosses'. Due to layering, the total percent may add up to more than 100 percent. We also separately estimated the percent cover of all ground cover in the following categories: vegetation, leaf litter, bare ground, rocks, and woody debris. Ground layer vegetation provides the fine fuels needed to carry low-intensity ground fires and patches of bare ground are needed for recruitment of both canopy species and ground layer forbs and graminoids, while other ground cover may impede those processes (Mitchell et al. 2006). Ground cover category estimates sum to 100 percent. In 2022 the ground layer vegetation was sampled erroneously using a 0.5 X 0.5 m quadrat. However, because measurements were percentage estimates and not overall cover measurements, we believe this did not significantly affect the results, and we included these data in our analysis. We also included year as a variable in all analyses to control for the potential effect of this difference (see Data Analysis, below).

We sampled the subcanopy layer (all woody stems ≤ 5 cm DBH, and > 1 m tall) in two 2x20m belt transects bisecting the plot between the 5- and 55-meter, and 15- and 45-meter marks. We counted the number of stems for each species, recording living and dead-standing stems separately. Finally, we sampled the canopy layer (all woody stems > 5 cm DBH) in the 20 x 20 plot. We recorded the DBH of each individual of each species, recording living and dead-standing stems (snags) separately. Snags were included within the canopy if they were self-supported (e.g., not prevented from falling to the ground by another tree) and at least as tall as breast height. Finally, a whole plot plant list was created with a meander survey throughout the plot, recording every unique species observed that was not recorded in 1x1m quadrats.

To further characterize changes due to management and plant community succession, we also sampled ground layer plant community composition in rough fescue permanent monitoring plots. We recorded the presence of each plant species in 1 x 1 m quadrats at 10 m intervals along each randomly generated 100 m transect at both FESALT01 and FESALT02 (Figure C1). Although we did not record abundance, we recorded which species was dominant in each quadrat.

Ecosystem monitoring plot showing point of origin (e.g., 0 meters) marked with pink paint.

Data Analysis

We analyzed for differences in plant community composition and ecosystem structure to provide a baseline for measuring management effects in the PBMA. These data describe underlying differences between cover types and subunits against which future management effects can be compared. All analysis was conducted in RStudio, version 9.0.375 (Posit Team 2024).

Floristic Quality Assessment

We used Floristic Quality Assessment (FQA) metrics to compare ecosystem quality among plots, subunits, and cover types using composition data from both rare plant and ecosystem monitoring plots (Reznicek et al. 2014, Freyman et al. 2016). The FQA utilizes plant species composition to derive the Floristic Quality Index (FQI). The FQI is a quantitative metric of ecosystem quality that can be used as a relatively objective comparison among natural community occurrences of the same type. Drawing upon expert consensus among botanists familiar with the flora of Michigan, each vascular plant species native to Michigan has been assigned an a priori coefficient of conservatism (C-value) that ranges from 0 to 10 on a scale of increasing conservatism or fidelity to pre-European colonization habitats (Reznicek et al. 2014). Plant species with a C-value of 7 to 10 are considered highly conservative with a strong fidelity to specific, high-quality ecosystems (Herman et al. 2001). A C-value of 4 to 6 indicates moderate conservatism and a C-value of 1 to 3 indicates low or no conservatism (e.g., ruderal species). Non-native species were given a C-value of 0 for these calculations.

We calculated FQI for each natural community occurrence as:

$$\mathbf{FQI} = \bar{C} \times \sqrt{n}$$

where $\bar{C}$ = *mean C-value* and n = *species richness*. Michigan sites with an FQI of 35 or greater possess sufficient conservatism and richness that they are considered floristically important from a statewide perspective (Herman et al. 2001). FQI scores greater than 50 indicate exceptional sites with extremely high conservation value (Herman et al. 2001). Mean C-values may represent a less biased indicator of relative conservation value and are provided with conservation metrics (Matthews et al. 2005, Slaughter et al. 2015). Tracking changes to the FQI or mean C-value of a site following biodiversity stewardship is a useful means of evaluating the success of management.

Rare Plant Monitoring

To test for differences in demographic parameters among years, we constructed repeated measures ANOVA models, using the *lmer* function in the *lme4* R package, with the number of rosettes, number of flowering culms, and the number of flowering heads as response variables in separate models. We included both survey year (2021-2023) and plot as fixed effects, and plant ID as a random factor. Because we were unable to relocate several plants, we conducted these analyses only on the subset of individuals that were observed in all three years.

Ecosystem Monitoring

We tested for differences in several diversity and ecosystem structure metrics among both cover types and subunits.

<u>Ecosystem Structure – Canopy and Groundcover Metrics</u>

We calculated plot-level metrics to assess differences in both vertical structure (canopy metrics) and ground cover structure. Canopy metrics included the basal area of living trees (m^2/ha and ft^2/ac), and the number of living and snag trees and living and snag shrub stems (per hectare and per acre). Basal area metrics were derived from tree DBH. Ground cover metrics included litter depth, as the mean of all litter depth measurements in each quadrat in each plot, and the mean percent cover among quadrats for leaf litter, woody debris, bare ground, and ground layer vegetation.

<u>Plant community - Diversity Metrics</u>

First, we calculated species richness, inverse Simpson diversity (1/D), and inverse Simpson evenness ($E_{1/D}$) at two scales. We calculated small-scale richness, 1/D, and $E_{1/D}$ per m^2 as the mean among 1 x 1 m^2 quadrats; and medium-scale or transect richness as the cumulative values from all the quadrat data combined, and medium-scale 1/D and $E_{1/D}$ using the mean plot-level abundance values. Inverse Simpson diversity is calculated as 1/D, where D= ∑(i=1 to S) * p_i^2, where S = species richness, p = x_i/ ∑x, and x_i = the abundance of the x^{th} species. We used inverse Simpson diversity because it has been shown to vary independently of species richness (Smith and Wilson 1996). Inverse Simpson evenness is calculated as (1/D)/S. Finally, we calculated large-scale or whole plot richness, reflecting all species recorded in quadrats or meander surveys in each 20 x 20 m plot. Using composition in whole plots, we calculated both mean C-value and FQI for each plot.

To test for differences between cover types and subunits, we constructed general linear models (two-factor ANOVAs) for each diversity metric, with cover type and subunit as fixed effects. When model results indicated at least a marginally significant difference ($p<0.10$) between cover types or subunits, we conducted a post-hoc test for differences among cover types with Tukey's Honest Significant Difference test. We also tested for the relationship between specific ecosystem structure metrics and diversity metrics independent of cover type designations, using regression models. First, we constructed individual regression models testing the relationship between canopy basal area and each diversity metric, and the individual regression models testing the relationship between living stem density and each diversity metric. We did not include basal area and stem density as predictors in the same multiple regression because they are highly correlated ($r = 0.91$). Then we constructed a multiple regression model for each diversity metric with ground cover structure metrics (leaf litter depth; cover of leaf litter, woody debris, bare ground, and ground layer vegetation) as predictors. Some ground cover metrics were correlated ($r \leq 0.50$; see Table D1), but variance inflation factors for variables in these models were all < 2.

Plant Community – Composition Metrics

We tested for differences in plant community composition using perMANOVA and Indicator Species Analysis with the R package *vegan*. First, we calculated pairwise Bray–Curtis compositional dissimilarities among all plots using quadrat abundance data with the *metaMDS* function, and Jaccard dissimilarities using whole plot composition (presence-absence). Then, we tested for differences in plant community composition between cover type and subunit with perMANOVA using the *adonis2* function. To assess between-group differences, we calculated Bonferroni-corrected p values with the pairwise.adonis function in the *pairwiseAdonis* package in R (Martinez Arbizu, 2019). To visualize how composition differed among cover types, we plotted both Bray-Curtis and Jaccard dissimilarities on a non-metric multi-dimensional scaling (NMDS) ordination plot and grouped data by cover type. We also fit a vector of the ground cover structure metrics to the NMDS ordination

Botanist Elizabeth Haber collecting data in 1 X 1 m quadrat.

plot to visualize how the relationship between ground cover metrics and composition was associated with cover type.

We also tested for the relationship between specific ecosystem structure metrics and composition metrics independent of cover type designations. We conducted individual perMANOVAs testing the relationship between Bray-Curtis and Jaccard dissimilarity and canopy basal area, living stem density, leaf litter depth, and each ground cover structure metric (cover of leaf litter, woody debris, bare ground, and ground layer vegetation). We did not include ground cover structure metrics in a single perMANOVA because there is no method for calculating type II sums of squares and the order each variable is introduced into the model affects estimation of coefficients for subsequent variables.

Finally, we conducted Indicator Species Analysis with the *indval* function to determine which ground layer species were characteristic of each cover type, again using both Bray-Curtis and Jaccard dissimilarity matrices (Dufrene and Legendre 1997). We also examined differences in C-value between species selected by indicator species analysis for each cover type.

We calculated the frequency of occurrence (e.g., out of 100) for each species observed in 1 X 1 m quadrats in rough fescue permanent monitoring plots (FESALT01 and FESALT02) and calculated the mean among both plots. We also tallied the number of quadrats for which each species was the dominant and calculated the mean among both plots.

Ecosystem monitoring plot in prairie covertype in Subunit 1D.

RESULTS

Rare Plant Surveys

We conducted rare plant surveys in subunits 2A, 2B, 2C, 2D, 5A, and 5B in 2021; subunits subunits 1A, 1B, 1C, and 1D and unit 4 in 2022; and subunits 3A, 3B, and 5C and units 6 and 7 in 2023. No pale agoseris was observed. One existing occurrence of Alleghany plum was redocumented, comprised of at least five individuals, along Stephan Bridge Rd on the margin of subunit 2A. We reduced the EO Rank from BC to C due to the apparent lack of population growth since 2004. An additional individual of Alleghany plum was observed 2.5 km to the southwest of the PBMA, within the 30 complex and just downhill from range control (44.71373, -84.63115).

Hill's thistle and rough fescue were observed in most subunits of the PBMA (Table 2, Figure 9). We documented 453 individuals of Hill's thistle across all subunits of the PBMA except 2A, with the highest abundance occurring in unit 2 with 131 individuals and unit 4 with 132 individuals (Table 2). In contrast, 11 or fewer individuals were documented in subunits 1C, 1D, 3A, and 5C, and units 6 and 7. We documented an estimated 26,323 individuals of rough fescue in all subunits of the PBMA except 1A, 1B, and 1C and unit 7, with the highest abundance occurring in Unit 4 with an estimated 21,283 individuals. Less than 500 individuals were estimated in subunits 1D, 2B, 3A, 3B, 5A, 5B, and 5C. The Hill's thistle populations were added to the existing EO (EOID 615), which resulted in an increase in the EO Rank from BC to AB (Table 3). The rough fescue populations were added to the existing EO (EOID 1888).

Table 2. Abundance of rare plant species observed in each Unit and Subunit of the PBMA. *Prunus umbellata documented in 2022 adjacent to but outside of Unit 4.

Subunit	*Cirsium hillii*	*Festuca altaica*	*Prunus umbellata*
1A	29	0	0
1B	48	0	0
1C	10	0	0
1D	11	32	0
1 total:	98	32	0
2A	0	131	5
2B	48	63	0
2C	56	1,160	0
2D	27	656	0
2 total:	131	2,010	5
3A	6	3	0
3B	24	264	0
3 total:	30	267	0
4	132	21,283	0*
5A	33	393	0
5B	24	144	0
5C	1	234	0
5 total:	58	771	0
6	3	969	0
7	1	0	0
Total:	453	25,332	5

Rare Plant Monitoring

We were unable to relocate 9 (14%) marked Hill's thistle individuals in 2022 and 30 (47%) in 2023, and 10 (26%) marked rough fescue individuals in both 2022 and 2023. In some cases, metal tags and stakes were no longer attached to the plant we marked. Some of the tags were likely removed from the area by small mammals or other animals, as suggested by teeth marks observed on some tags. For these individuals, we often were able to figure out

Table 3. Rare plant EOs in the PBMA following 2021-2023 surveys

EO ID	Scientific name	Common name	State status	G/S rank	First observed	Last observed	EO Rank
615	*Cirsium hillii*	Hill's thistle	SC	G3/S3	1992	2023	AB
1888	*Festuca altaica*	Rough fescue	SC	G5/S2S3	1992	2023	A
14571	*Prunus umbellata*	Alleghany plum	SC	G5/S3	2004	2022	C

Figure 9. Rare plant EOs documented in the PBMA. Single EO of Prunus umbellata along Stephan Bridge Rd. on boundary of subunits 1B and 2A.

which numbered tag was missing based on the location and surrounding tag numbers, but others remained unknown and no data was collected. We conducted statistical analyses on the subset of individuals that were observed in all years (Table 4) and provide summary figures and tables showing all marked individuals (Figures D1, D2).

We observed minor fluctuations in demographic parameters over time, but few differences were statistically significant (Table 4). On average, we recorded fewer Hill's thistle rosettes at all three plots in 2022 when compared to 2021. Subsequent increases in rosette number observed in 2023 did not make up for the losses in 2022. These shifts in rosette number did not appear to correspond to any pattern in other metrics of population viability (i.e., height of flowering culms or number of heads). There was a marginally significant difference in head number between plots ($p=0.08$) and yearXplot interaction in rosette number ($p=0.06$). Rosette number differed significantly among plots in 2022 ($p<0.01$), and among years in plot CIRHIL02 ($p=0.04$). The width of rough fescue plants was significantly reduced in in 2022, at least in plot FESALT02 ($p=0.03$). The number of flowering culms, in contrast, increased dramatically in 2022, although no flowering culms were observed in 2023 or in any year in FESALT02.

Ecosystem Monitoring

We collected data on ecosystem structure and the plant community primarily to facilitate tracking of ecological integrity in the PBMA over time, specifically in response to management. These data also increase understanding of the pine barrens ecosystem by describing the variation in several ecosystem parameters, which we present as initial results below.

Ecosystem structure - Canopy Metrics

Canopy basal area, live trees per hectare, and

Table 4. Rare plant monitoring results (mean values by year and ANOVA results). Values for Year, Plot, and YearxPlot interaction are p-values.

	Plot	2021	2022	2023	Year	Plot	YearXPlot	R^2
Cirsium hillii		*Number of rosettes*			0.36	**0.06**	**0.06**	0.10
	CIRHIL01	1.94	1.69	1.75				
	CIRHIL02	1.42	1.08	1.25				
	CIRHIL03	1.83	1.50	1.50				
		Culm height (cm)			0.14	0.74	0.74	0.02
	CIRHIL01	0.44	0.38	0.63				
	CIRHIL02	0.00	0.08	0.00				
	CIRHIL03	0.00	0.17	0.17				
		Number of heads			0.08	0.40	0.40	0.02
	CIRHIL01	0.69	0.69	0.94				
	CIRHIL02	0.00	0.08	0.00				
	CIRHIL03	0.00	0.17	0.17				
Festuca altaica		*Clump width at base (cm)*			**0.03**	0.16	0.16	0.52
	FESALT01	19.71	19.50	17.36				
	FESALT02	2.55	0.95	2.64				
		Number of culms			0.60	0.73	0.73	0.11
	FESALT01	6.00	41.14	0.00				
	FESALT02	0.00	0.00	0.00				

tree snags per hectare differed among cover types. The basal area and number of live trees per hectare was significantly lower in Prairie plots than in both Forest and Savanna plots (full model, $p<0.001$; Tukey's HSD, $p<0.001$ except $p<0.01$ for basal area of Prairie vs. Savanna) (Table 5, Figure D2). Basal area was also lower in Savanna plots than Forest plots, although the difference was only marginally significant (Tukey's HSD, $p=0.07$), while the number of live trees in Savanna was not statistically different than in Forest (Tukey's HSD, $p=0.90$). The number of tree snags was higher in Forest than in both Savanna and Prairie plots (full model, $p<0.001$; Tukey's HSD, $p<0.001$).

There was a statistically significant difference between subunits only for the number of live trees per hectare, largely driven by a high density of trees in subunit 1B (mean = 1,042 trees/ha), relative to the low tree density in subunits 1C, 4, and 6 (mean = 25, 75, and 325 trees/ha, respectively) (Tables 5, D2). Tree density was also sparse in subunits 1D and 7 with 325 and 25 live trees/ha, respectively. Live and dead shrub stem density was similar among cover types.

Ecosystem Structure – Groundcover Metrics

Among groundcover metrics, only percent woody debris differed among cover types ($p<0.05$), being about twice as high in Forest plots than in both Prairie and Savanna plots (Table 5, Figure D4). Mean percent cover of bare ground was lowest in Forest plots and highest in Prairie plots, although this difference was not statistically significant ($p=0.45$). Litter depth differed significantly between some subunits. Mean litter depth in subunit 1C (3.58 cm) was significantly higher than in several other subunits (1D, 2B, 2C, 2D, 3B, 5A, 5B, 5C, 6, 7; mean ranged from 0.40-1.73 cm) (Table D2). There were marginally significant ($p<0.10$) differences in percent litter cover, percent vegetation cover, and percent bare ground cover among subunits.

Plant community - Diversity Metrics

Diversity generally did not differ between cover types and subunits, especially for species richness and inverse Simpson diversity (Table 6). At the small scale (1 m^2), evenness was higher in Prairie plots, although this difference was only marginally significant ($p<0.10$). Evenness differed between some subunits at both the small (1 m^2; $p=0.05$) and medium (10 m^2; $p = 0.02$) (Tables 6,

Table 5. Mean values and ANOVA results for models predicting structure metrics. Values for Type and Subunit are p-values. All p-values <0.10 in **bold**.

Structure metric	Forest	Savanna	Prairie	Type	Subunit	R^2
Canopy basal area (m^2/hectare)	19.15	11.31	0.41	**<0.001**	0.13	0.48
Canopy basal area (ft^2/acre)	83.40	49.26	1.80			
Live trees/ha	720.83	675.00	108.82	**<0.001**	**0.02**	0.60
Live trees/acre	291.71	273.16	44.04			
Tree snags/ha	522.92	85.94	7.35	**<0.001**	0.75	0.40
Tree snags/acre	211.62	34.78	2.98			
Shrub stems/ha	70.83	403.13	211.76	0.42	**0.06**	0.27
Shrub stems/ac	28.67	163.14	85.70			
Shrub snags/ac	3.37	5.69	2.38	0.49	0.25	0.10
Shrub snags/ha	8.33	14.06	5.88			
Litter depth (cm)	1.56	1.73	1.69	0.92	**<0.01**	0.42
Litter cover (%)	22.69	28.51	26.41	0.26	**0.08**	0.24
Woody debris cover (%)	10.03	4.54	4.46	**0.01**	0.73	0.17
Vegetation cover (%)	60.48	59.98	56.54	0.96	**0.05**	0.26
Bare ground cover (%)	0.40	1.60	3.22	0.45	**0.09**	0.23

Table 6. Mean values and ANOVA results for models predicting diversity metrics. Values for Type and Subunit are p-values. SR = species richness; FQI = Floristic Quality Assessment. All p-values <0.10 in **bold**.

Diversity metric	Forest	Savanna	Prairie	Type	Subunit	R^2
SR/m^2	6.54	7.20	7.75	0.51	0.61	0.00
Inverse Simpson/m^2	3.36	3.73	4.47	0.18	0.30	0.21
Evenness/m^2	0.31	0.33	0.38	**0.08**	**0.05**	0.35
Cumulative SR	16.75	18.81	18.82	0.59	0.31	0.06
Inverse Simpson	3.80	4.72	5.20	0.31	0.29	0.14
Evenness	0.23	0.26	0.29	0.24	**0.02**	0.37
Whole Plot SR	22.83	26.88	26.00	0.37	0.72	0.00
Mean C-value	4.58	4.72	4.88	0.75	0.11	0.17
FQI	22.00	23.19	22.78	0.82	0.66	0.00

D3). Diversity was correlated with neither basal area nor stem density (Table D4). Several ground cover structure metrics predicted diversity (Table D5). Small- and medium-scale inverse Simpson diversity and small-scale evenness increased with percent litter cover; small-scale and large-scale species richness decreased and mean C-value increased with increasing woody debris cover (Figure 10); and small-scale and medium-scale richness increased and small-scale and medium-scale evenness decreased with increasing vegetation cover (Figure 11).

Diversity in pine barrens is composed of (*above*): showy forbs like hairy puccoon (*Lithospermum carolinense*) (*left*) and frostweed (*Crocanthemum canadense*) (*right*); and (*below*): ericaceous shrubs like bearberry (*Arctostaphylos uva-ursi*).

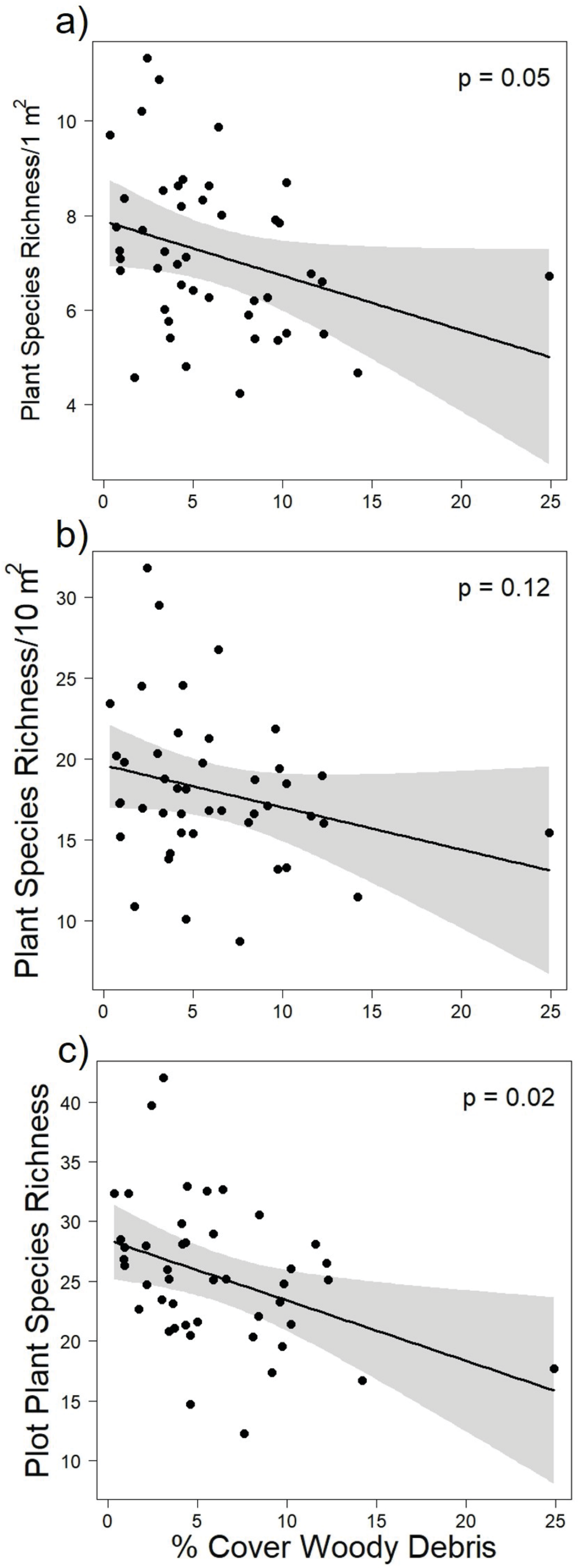

Figure 10. Relationship of % cover of woody debris with species richness at small (a), medium (b), and large(c) scales. Partial residual plots controlling for other ground cover metrics.

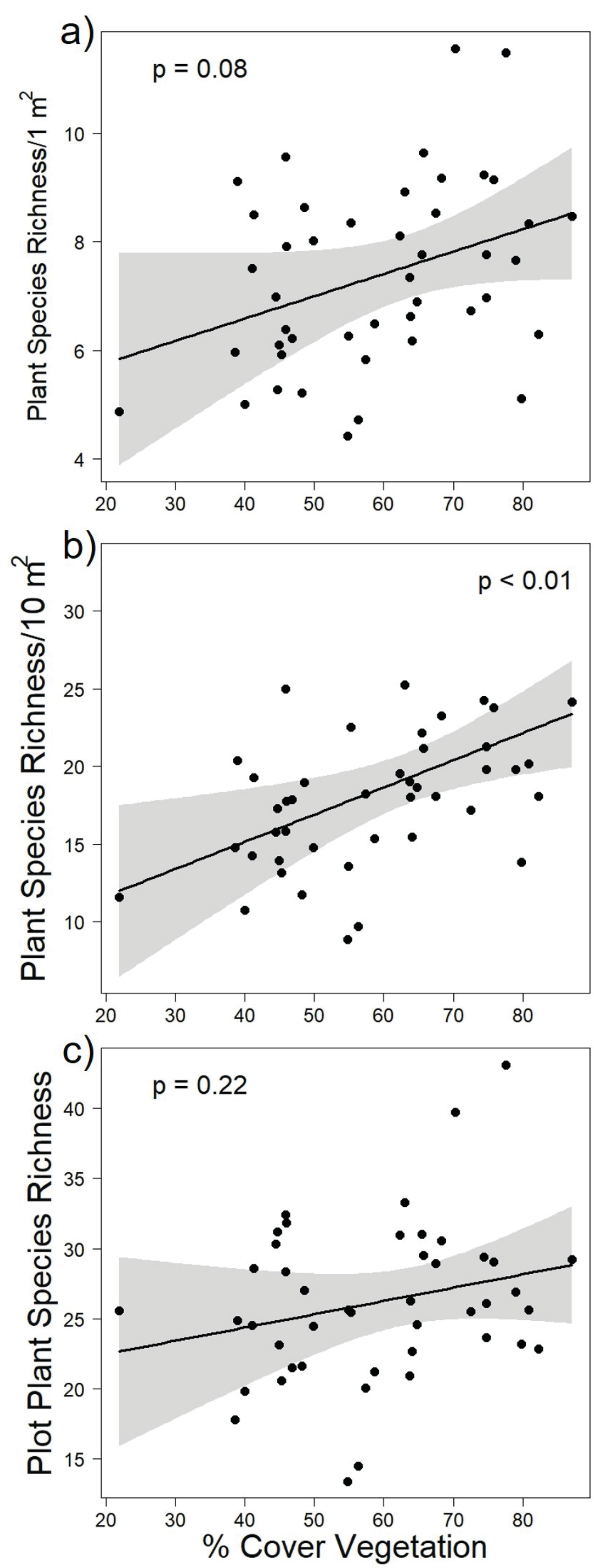

Figure 11. Relationship of % cover of vegetation with species richness at small (a), medium (b), and large(c) scales. Partial residual plots controlling for other ground cover metrics.

Plant community - Composition Metrics
A total of 102 plant taxa were recorded in ecosystem plots (including both quadrats and walkthrough surveys) in 2021-2023. Of these 101 taxa, 40 (40%) were recorded in all three cover types, 28 (28%) in two cover types, and 33 (33%) in a single cover type (Table 7). Species composition differed significantly between cover types for both quadrat data (perMANOVA, $p<0.01$) and whole plot data (perMANOVA, $p<0.01$) (Figure 10). Post-hoc Bonferroni tests indicated that composition in Prairie plots was significantly different from both Forest plots (quadrat and whole plots, $p<0.01$) and Savanna plots (quadrats, $p=0.03$; whole plots, $p<0.01$). Differences between composition in Forest and Savanna plot was significant for whole plots ($p=0.03$) and marginally significant for quadrat data ($p=0.06$).

Differences in composition among cover types may be due to both canopy and ground cover structure, although individual structure metrics generally explained little variation in composition. Both basal area and stem density predicted both Bray-Curtis (R^2 = 0.15 and 0.13, respectively) and Jaccard dissimilarities (R^2 = 0.09 and 0.08, respectively) (Table D4). The association of ground cover and composition differed by metric (Table D6). Bray-Curtis dissmiliarities were associated with litter cover ($R^2 = 0.07$), woody debris ($R^2 = 0.08$), and bare ground ($R^2 = 0.06$), while Jaccard dissimilarities were associated with litter depth ($R^2 = 0.03$), woody debris ($R^2 = 0.06$), vegetation cover ($R^2 = 0.03$), and bare ground ($R^2 = 0.04$).

Birdfoot violet (*Viola pedata*), observed in 13 prairie or savanna plots, but no forest plots.

Table 7. Plant species observed in ecosystem plots, showing number of plots of each cover type, total number of types, and plots of all types in which each species was observed. Species in **bold** are non-native.

Species	Common Name	Prairie	Savanna	Forest	Types	Plots
Acer rubrum	red maple	2	5	5	3	12
Achillea millefolium	yarrow	0	1	0	1	1
Agrostis scabra	ticklegrass	1	2	0	2	3
Amelanchier interior	serviceberry	0	3	3	2	6
Amelanchier spicata	shadbush serviceberry	15	15	10	3	40
Andropogon gerardii	big bluestem	15	13	9	3	37
Anemone quinquefolia	wood anemone	0	1	0	1	1
Antennaria howellii	small pussytoes	4	0	0	1	4
Antennaria parlinii	smooth pussytoes	2	3	0	2	5
Apocynum androsaemifolium	spreading dogbane	7	6	9	3	22
Arctostaphylos uva-ursi	bearberry	14	14	10	3	38
Aronia prunifolia	chokeberry	0	3	0	1	3
Avenella flexuosa	hair grass	15	15	11	3	41
Betula papyrifera	paper birch	0	1	0	1	1
Brachyelytrum aristosum	northern shorthusk	0	0	1	1	1
Bromus kalmii	prairie brome	4	0	0	1	4
Calystegia spithamaea	low bindweed	0	1	0	1	1
Campanula rotundifolia	harebell	9	2	2	3	13
Carex pensylvanica	sedge	17	16	12	3	45
Ceanothus herbaceus	new jersey tea	1	0	0	1	1
Cirsium hillii	hills thistle	2	1	0	2	3
Cladonia cristatella	British soldiers lichen	5	6	5	3	16
Cladonia rangiferina	Reindeer lichen	16	14	10	3	40
Comptonia peregrina	sweetfern	14	15	11	3	40
Conyza canadensis	horseweed	1	1	0	2	2
Crataegus sp.	hawthorn	4	2	2	3	8
Crocanthemum canadense	common frostweed	2	6	1	3	9
Various	crust lichen	1	0	0	1	1
Cypripedium acaule	pink lady-slipper	0	1	0	1	1
Danthonia spicata	poverty grass	17	15	8	3	40
Dichanthelium columbianum	panic grass	2	4	0	2	6
Dichanthelium depauperatum	panic grass	6	5	2	3	13
Dichanthelium sp	panic grass	5	3	0	2	8
Diphasiastrum tristachyum	ground-cedar	0	1	0	1	1
Elymus trachycaulus	slender wheatgrass	1	1	1	3	3
Epigaea repens	trailing-arbutus	1	5	8	3	14
Erigeron strigosus	daisy fleabane	1	1	0	2	2
Various	Feather moss	9	13	12	3	34
Festuca altaica	rough fescue	0	0	1	1	1
Fragaria virginiana	wild strawberry	5	6	0	2	11
Gaultheria procumbens	wintergreen	4	6	10	3	20
Gaylussacia baccata	huckleberry	0	1	1	2	2
Helianthus occidentalis	western sunflower	2	1	0	2	3
Hieracium aurantiacum	**orange hawkweed**	1	2	0	2	3
Hieracium caespitosum	**king devil**	9	0	1	2	10
Hieracium kalmii	kalms hawkweed	1	4	1	3	6

Table 7, continued

Species	Common Name	Prairie	Savanna	Forest	Types	Plots
Hieracium venosum	rattlesnake-weed	7	7	5	3	19
Hypericum perforatum	**common st. johns-wort**	6	3	0	2	9
Koeleria macrantha	june grass	6	0	0	1	6
Lactuca canadensis	tall lettuce	0	2	0	1	2
Lechea intermedia	intermediate pinweed	1	0	0	1	1
Leucobryum sp	pincushion moss	5	3	1	3	9
Liatris cylindracea	cylindrical blazing-star	3	1	0	2	4
Liatris scariosa	northern blazing-star	4	0	0	1	4
Various	liverwort	0	1	0	1	1
Maianthemum canadense	canada mayflower	0	6	7	2	13
Melampyrum lineare	cow-wheat	4	7	5	3	16
Monotropa uniflora	indian-pipe	0	0	1	1	1
Muhlenbergia sp.	marsh wild-timothy	0	0	1	1	1
Oryzopsis asperifolia	rough-leaved rice-grass	7	3	5	3	15
Packera paupercula	balsam ragwort	1	0	0	1	1
Pinus banksiana	jack pine	5	14	9	3	28
Pinus resinosa	red pine	0	2	0	1	2
Pinus strobus	white pine	0	1	0	1	1
Piptatheropsis pungens	rice-grass	2	5	4	3	11
Plantago major	**common plantain**	0	1	0	1	1
Poa pratensis	**kentucky bluegrass**	1	2	1	3	4
Polygala polygama	racemed milkwort	2	0	0	1	2
Polytrichum sp.	haircap moss	10	9	3	3	22
Populus balsamifera	balsam poplar	0	1	0	1	1
Populus grandidentata	big-tooth aspen	0	1	1	2	2
Populus tremuloides	quaking aspen	2	2	0	2	4
Potentilla simplex	old-field cinquefoil	1	1	0	2	2
Prunus pensylvanica	pin cherry	1	1	0	2	2
Prunus pumila	sand cherry	16	13	11	3	40
Prunus serotina	wild black cherry	8	11	9	3	28
Prunus virginiana	choke cherry	1	2	2	3	5
Pseudognaphalium obtusifolium	old-field balsam	0	0	1	1	1
Pteridium aquilinum	bracken fern	4	9	9	3	22
Quercus alba	white oak	1	8	8	3	17
Quercus ellipsoidalis	hills oak	11	15	12	3	38
Rosa carolina	pasture rose	2	1	0	2	3
Rubus flagellaris	northern dewberry	8	5	5	3	18
Salix humilis	prairie willow	5	4	0	2	9
Schizachne purpurascens	false melic	3	4	1	3	8
Schizachyrium scoparium	little bluestem	13	9	6	3	28
Sibbaldiopsis tridentata	three-toothed cinquefoil	1	0	0	1	1
Solidago hispida	hairy goldenrod	11	11	5	3	27
Solidago juncea	early goldenrod	2	2	0	2	4
Solidago nemoralis	old-field goldenrod	7	3	0	2	10
Solidago ptarmicoides	upland white goldenrod	7	2	0	2	9
Solidago simplex	gillmans goldenrod	0	1	0	1	1

Table 7, continued

Species	Common Name	Prairie	Savanna	Forest	Types	Plots
Solidago speciosa	showy goldenrod	1	0	0	1	1
Sorghastrum nutans	indian grass	5	0	1	2	6
Symphyotrichum laeve	smooth aster	11	9	0	2	20
Taraxacum officinale	**common dandelion**	0	2	0	1	2
***Tragopogon* sp.**	**common goats beard**	0	1	0	1	1
Vaccinium angustifolium	low sweet blueberry	17	16	12	3	45
Veronica officinalis	**common speedwell**	0	1	0	1	1
Viola adunca	sand violet	12	3	2	3	17
Viola pedata	birdfoot violet	8	5	0	2	13

Sand cherry (*Prunus pumila*), observed in 40 plots, including plots of all cover types.

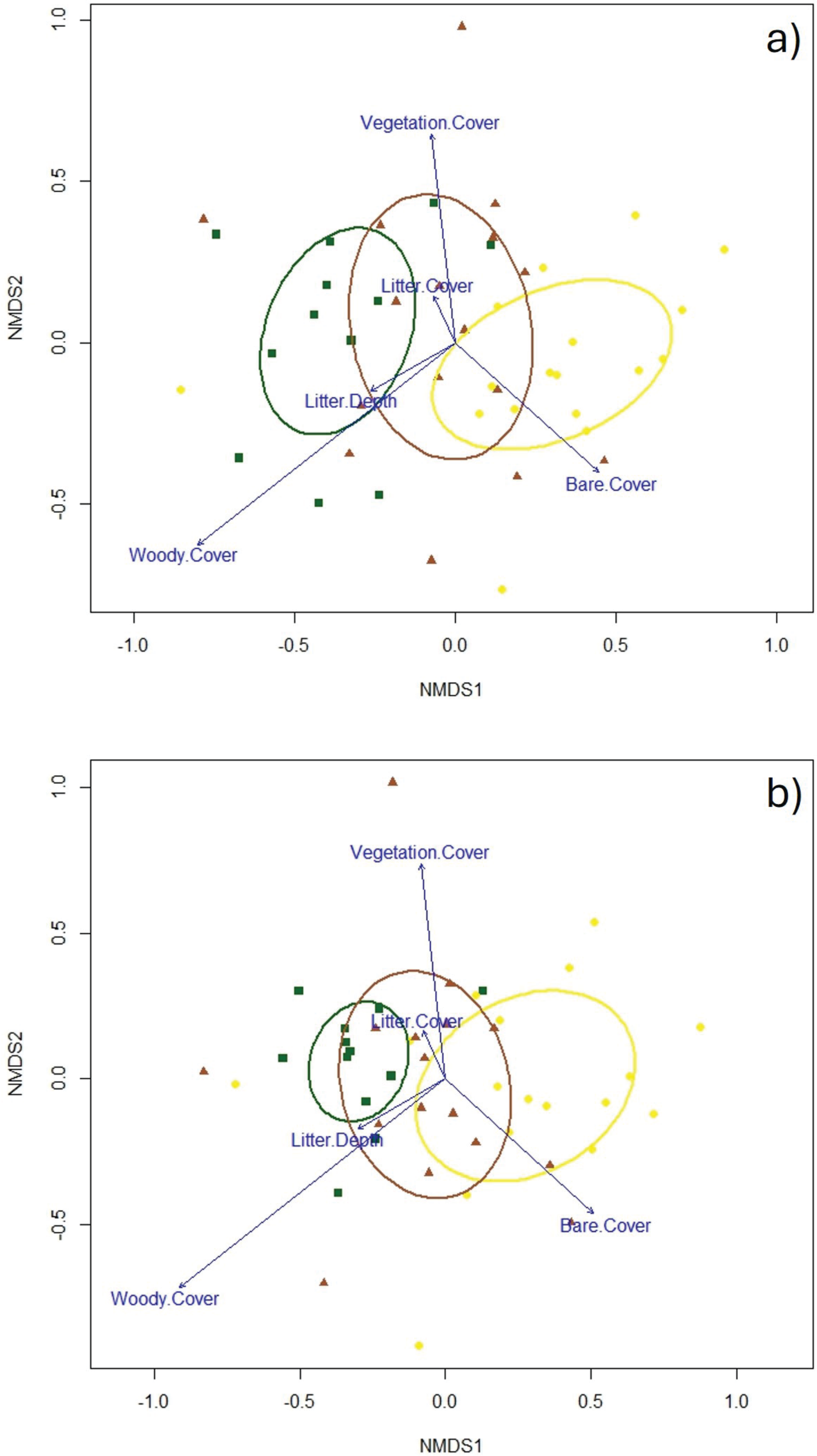

Figure 12. Plant community composition varies by cover type and ground cover structure metrics. NMDS plots for Bray-curtis (a) and Jaccard (b) dissimilarities. Data points closer together have more similar composition. Yellow dots = prairie plots, brown triangles = savanna plots, green squares = forest plots. Ellipses display 95% confidence interval of grouping factors by cover type. Blue arrows = vector of ground cover structure metrics fit to ordination.

Table 8. Indicator Species Analysis results. IV = indicator value. *p<0.05, **p<0.01. Species in **bold** = indicators for both quadrat (abundance-weighted) and whole plot (presence-absence) data. C = coefficient of conservatism.

Species Name	Common Name	Cluster	IV (plot)	IV (quad)	C
Apocynum androsaemifolium	**Spreading dogbane**	**Forest**	**0.366***	**0.288***	**3**
Epigaea repens	**Trailing arbutus**	**Forest**	**0.428****	**0.351***	**7**
Gaultheria procumbens	**Wintergreen**	**Forest**	**0.481****	**0.418***	**5**
Maianthemum canadense	Wild lily-of-the-valley	Forest	0.355*	NA	4
Pteridium aquilinum	**Bracken fern**	**Forest**	**0.363***	**0.383***	**0**
Quercus alba	White oak	Forest	0.362*	NA	5
Various	**Feather mosses**	**Forest**	**0.427***	**0.727****	**NA**
		Total species:	7	5	
				mean-C:	4.00
Antennaria howellii	Small pussytoes	Prairie	0.235*	NA	2
Bromus kalmii	Prairie brome	Prairie	0.235*	NA	8
Campanula rotundifolia	Harebell	Prairie	0.341*	NA	6
Carex pensylvanica	Pennsylvania sedge	Prairie	NA	0.495*	4
Danthonia spicata	**Poverty grass**	**Prairie**	**0.384****	**0.705****	**4**
Hieracium spp.	Adventive hawkweeds	Prairie	0.400**	NA	0
Koeleria macrantha	June grass	Prairie	0.353**	NA	9
Liatris scariosa	New England blazing star	Prairie	0.235*	NA	5
Prunus pumila	Sand cherry	Prairie	NA	0.574**	8
Schizachyrium scoparium	Little bluestem	Prairie	NA	0.429*	5
Solidago nemoralis	Gray goldenrod	Prairie	0.283	NA	2
Solidago ptarmicoides	Upland white goldenrod	Prairie	0.316*	NA	6
Symphyotrichum laeve	**Smooth blue aster**	**Prairie**	**0.346***	**0.410***	**5**
Viola adunca	Sand violet	Prairie	0.470**	NA	4
Viola pedata	Birdfoot violet	Prairie	NA	0.375*	8
		Total species:	11	6	
				mean-C:	5.07
Pinus banksiana	Jack pine	Savanna	0.399*	NA	5

According to indicator species analysis, several species characterized both Forest and Prairie plots, although results differed somewhat between quadrat and whole plot data (Table 8). Three of the seven species in the Forest cluster were woody species, while two were forbs, one was a fern, and one was feather mosses. The Prairie cluster included five graminoid and nine forb species but only one woody species (sand cherry [*Prunus pumila*]) Notably, six of the fifteen species in the Prairie cluster belong to the sunflower (Asteraceae) family and two are violets (Violaceae). A single species, jack pine, characterized the Savanna cluster. The mean C-value was slightly higher in the Prairie cluster (5.07) than the Forest cluster (4.00).

Species composition in the rare plant monitoring plots was similar to the ecosystem plots. Pennsylvania sedge (*Carex pensylvanica*) was the most frequent dominant (FESALT01: 65 of 100 plots; FESALT02: 22 of 100 plots), with sweet lowbush blueberry (*Vaccinium angustifolium*) also frequently dominant (FESALT01: 22 plots; FESALT02: 33 plots) (Table 9). Species richness was greater and more variable in FESALT02 (plot mean = 6.1, transect mean 5.1-7.5) than in FESALT01 (plot mean = 4.8, transect mean 3.8-5.6) (Table10).

Table 9. Dominant species in quadrats sampled during rare plant monitoring. Frequency of each species being classified as dominant in a quadrat.

Species name	Common name	FESALT01	FESALT02	mean
Carex pensylvanica	Pennsylvania sedge	65	22	43.5
Vaccinium angustifolium	Low sweet blueberry	22	33	27.5
Cladonia rangiferina	Reindeer lichen	0	19	9.5
Various taxa	Feather mosses	0	10	5
Avenella flexuosa	Tufted hair-grass	1	5	3
Oryzopsis asperifolia	Rough-leaved rice-grass	4	0	2
Pteridium aquilinum	Bracken fern	4	0	2
Andropogon gerardii	Big bluestem	1	2	1.5
Arctostaphylos uva-ursi	Bearberry	0	3	1.5
Comptonia peregrina	Sweet fern	1	2	1.5
Festuca altaica	Rough fescue	1	1	1
Epigaea repens	Trailing arbutus	0	1	0.5
Prunus pumila	Sand cherry	0	1	0.5
Schizachne purpurascens	False melic	1	0	0.5
Schizachyrium scoparium	Little bluestem	0	1	0.5
	Total quadrats:	100	100	

Low sweet blueberry (*Vaccinium angustifolium*) was observed in all 45 ecosystem monitoring plots and 55 (27.5%) of quadrats in rare plant monitoring plots.

Table 10. Frequency of occurrence for plant species observed in rare plant monitoring plots. SR = species richness. Species above line have > 10% frequency in at least one plot.

Species name	Common name	FESALT01	FESALT02	mean
Vaccinium angustifolium	Low sweet blueberry	90.0	98.0	94.0
Carex pensylvanica	Pennsylvania sedge	96.0	82.0	89.0
Prunus pumila	Sand cherry	42.0	68.0	55.0
Comptonia peregrina	Sweet fern	14.0	62.0	38.0
Cladonia rangiferina	Reindeer lichen	0.0	58.0	29.0
Pteridium aquilinum	Bracken fern	50.0	1.0	25.5
Andropogon gerardii	Big bluestem	10.0	38.0	24.0
Oryzopsis asperifolia	Rough-leaved rice-grass	41.0	4.0	22.5
Amelanchier spicata	Shadbush serviceberry	27.0	15.0	21.0
Avenella flexuosa	Tufted hair-grass	11.0	29.0	20.0
Various	Feather moss	0.0	36.0	18.0
Arctostaphylos uva-ursi	Bearberry	10.0	25.0	17.5
Schizachyrium scoparium	Little bluestem	5.0	15.0	10.0
Danthonia spicata	Poverty grass	11.0	9.0	10.0
Festuca altaica	Rough fescue	7.0	12.0	9.5
*Hypericum perforatum**	Common St. John's-wort	0.0	14.0	7.0
Dichanthelium depauperatum	Panic grass	13.0	1.0	7.0
Quercus ellipsoidalis	Hill's oak	10.0	3.0	6.5
Rubus flagellaris	Dewberry	10.0	3.0	6.5
Epigaea repens	Trailing arbutus	0.0	10.0	5.0
Symphyotrichum laeve	Smooth blue aster	2.0	7.0	4.5
Schizachne purpurascens	False melic	4.0	5.0	4.5
Apocynum androsaemifolium	Spreading dogbane	7.0	0.0	3.5
Pinus banksiana	Jack pine	0.0	6.0	3.0
Prunus serotina	Wild black cherry	1.0	5.0	3.0
Solidago nemoralis	Gray goldenrod	0.0	5.0	2.5
Piptatheropsis pungens	Rice-grass	1.0	4.0	2.5
Gaultheria procumbens	Wintergreen	5.0	0.0	2.5
Maianthemum canadense	Wild lily-of-the-valley	0.0	4.0	2.0
Solidago hispida	Hairy goldenrod	0.0	4.0	2.0
Polygala polygama	Racemed milkwort	2.0	2.0	2.0
*Hieracium caespitosum**	Yellow hawkweed	0.0	3.0	1.5
Fragaria virginiana	Wild strawberry	0.0	2.0	1.0
Hieracium venosum	Rattlesnake-weed	0.0	2.0	1.0
Koeleria macrantha	Junegrass	1.0	1.0	1.0
Campanula rotundifolia	Harebell	2.0	0.0	1.0
Cirsium hillii	Hill's thistle	2.0	0.0	1.0
Conyza canadensis	Horseweed	2.0	0.0	1.0
Crataegus sp	Hawthorne	2.0	0.0	1.0
Salix humilis	Prairie willow	2.0	0.0	1.0
*Lactuca saligna**	Willow-leaved lettuce	0.0	1.0	0.5
Melampyrum lineare	Cow-wheat	0.0	1.0	0.5
Antennaria howellii	Small pussytoes	1.0	0.0	0.5
Quercus alba	White oak	1.0	0.0	0.5
Viola adunca	Sand violet	1.0	0.0	0.5
Viola sagittata	Arrow-leaved violet	1.0	0.0	0.5
	Mean plot SR	4.8	6.1	
	Total SR (# native)	33 (33)	33** (30)	
	FQI	29.3	26.4	
	Mean-C	5.1	4.6	

 

Soils in pine barrens are droughty and often bare or dominated by non-vascular pioneers like British-soldier lichen (*Cladonia cristatella*) (*below*). Rosette-forming forbs thrive here, like (*upper left*) showy goldenrod (*Solidago speciosa* var. *jejunifolia*) and (*upper right*) hairy goldenrod (*S. hispida*).

DISCUSSION

We conducted focused rare plant surveys and vegetation monitoring that provides a baseline for tracking the effects of management in the PBMA. We collected data on ecosystem metrics that assess the ecological integrity of the pine barrens natural community, including rare plant species occurrence and viability, canopy and subcanopy structure and composition, ground layer plant community structure and composition, and overall plant species diversity and composition. Although these data will be a valuable reference in the future following management activities, they also facilitate detailed contemporary descriptions of how these ecosystem metrics vary across the PBMA. First, we explore how canopy structure varied among cover types and subunits, then explore how that translated into differences in the ground layer plant community (see Table 11 for a summary).

Canopy Structure Defines Pine Barrens

Describing canopy structure is vital for guiding management decisions in pine barrens. Aspects of canopy structure are related to stand age, fire risk, and the ability to support barrens-specific biodiversity (Mitchell et al. 2006, Comer 2010, Bried et al. 2015, Jolly et al. 2016). Tree cover increases in density with stand age, which in turn increases the risk of stand-replacing wildfires and reduces the diversity of ground layer savanna species by limiting light availability (Leach and Givnish 1999, Mitchell et al. 2006, Pavlovic et al. 2006). Habitat suitability for key animal species also decreases with increasing tree cover and stand age, including birds such as Kirtland's warbler and insects such as secretive locust (Rabe et al. 2000, Olson 2002).

The ecological influence of tree cover through light availability can be inferred by measuring canopy cover, and overall habitat suitability can be inferred through tree biomass estimates such as basal area and stem density. We assigned a priori cover types based on three categories loosely associated with canopy cover (Figure C3, Prairie, <10% cover; Figure C4, Savanna, 10-80% cover; Figure C5, Forest, >80% cover), but did not measure canopy cover in the field so differences between cover types may not explicitly be related to differences in canopy cover. We did measure basal area and stem density. Basal area (and to a lesser extent stem density) may be a suitable substitute for canopy cover estimates, or even a better estimate of overall tree cover for species that indicate successional stage of an ecosystem (Cade 1997). Canopy cover is frequently positively correlated with basal area in pine-dominated ecosystems, although the strength and form of the relationship is also influenced by environmental factors, stem density, or species-

Table 11. Summary of how structural and plant community metrics varied by cover type.

Ecosystem metric	Forest	Savanna	Prairie
Tree density and canopy cover	High, many snags	Intermediate, but few snags	Low overall
Shrub density	Low, but intermediate snags	High overall, including snags	Intermediate overall
Ground cover characteristics	High cover of woody debris, little bare ground	Generally intermediate values	Highest bare ground cover
Ground layer diversity	Increases very slightly from Forest to Savanna to Prairie		
Ground layer composition	Woody species, feather moss, weedy forbs	Jack pine, both "forest" and "savanna" species	Heliophytes, graminoids

specific traits, and may not be consistent across the full range of values (Cade 1997, Mitchell and Popovich 1997, Korhonen et al. 2007). For example, basal area best explained canopy cover in Scots pine (*Pinus sylvestris*) stands in Finland, although the relationship was slightly non-linear, and accounting for tree height, site fertility, and stand density improved the ability to predict canopy cover (Korhonen et al. 2007).

Canopy structure metrics varied among plots at the scale of the PBMA, often differing between cover types, but smaller-scale variation (i.e., within subunits) was minimal (Tables 5, D2). The canopy biomass was highest in Forest plots and lowest in Prairie plots, in terms of living stem density, snag density, and canopy basal area (Table 5, Figure D3). These differences confirm the *a priori* delineation of cover at the PBMA into Prairie (Figure C3) and Forest (Figure C5) types. Living stem density and basal area were also higher in Savanna plots than in Prairie plots (Table 5, Figure D3). The differences between Forest and Savanna plots were less evident. Savanna plots had similar living tree density to Forest plots, while the difference in basal area was marginally significant ($p<0.10$). Lower basal area but similar stem density in Savanna vs. Forest plots was likely because the canopy was composed of lower-diameter (and presumably younger) trees. This indicates that portions of the PBMA that retain Savanna structure are fire-suppressed, as more frequent low-intensity fires would have thinned the density of younger, smaller stems. Given that basal area is intermediate in Savanna plots, relative to Forest and Prairie plots, it is likely that canopy cover is also intermediate.

The spatial heterogeneity that defines the pine barrens natural community is best represented within the Frog Lake Barrens EO that is primarily structured by fire and not silviculture (Figure 4). However, heterogeneity is declining due to the absence of recent fire, having last burned in a wildfire in 1958. Canopy closure is high overall with closed-canopied patches common. There are few large (> 5 acres) openings within the EO and these are mostly limited to frost pockets. Outside of the EO, most Prairie plots occurred in large clearcut areas with few to no trees, that are not characteristic of remnant pine barrens (Comer 2010). Despite being labelled as a "prairie" cover type, these open areas are also not characteristic of remnant dry sand prairie either, which are structured by climatic (i.e., generally occurring in frost pockets) and edaphic variation more strongly than by silviculture, and frequently contain a few scattered Hill's and white oak or red, white, or jack pine trees (Cohen et al. 2015). These clearcut areas are contrasted with the portions of the PBMA dominated by a dense canopy of jack pine. One consequence of high stem density and presumably advanced age was a significantly higher density of snags in Forest plots, comparable to the number of living stems (Table 5). This is consistent with recent succession to closed-canopied conditions, indicating self-thinning as canopy trees succumb to increased light (and likely moisture and nutrient) competition associated with the transition from savanna to forest conditions (Ferguson and Archibald 2002).

The Plant Community Across Cover Types

Canopy structural variation was associated with differences in species composition but not diversity or floristic quality. Species that occurred in many or most plots such as low sweet blueberry, reindeer lichen, Pennsylvania sedge, and tufted hairgrass are adapted to a wide range of light environments (Table 7). Despite considerable overlap in ground layer species composition between Prairie, Savanna, and Forest plots, both perMANOVA and indicator species analysis indicate differences. Composition in Savanna plots differed somewhat from that of Forest plots, but this difference was only marginally significant (perMANOVA, $p=0.06$ for both quadrat data [Bray-Curtis dissimilarity] and whole plot data [Jaccard dissimilarity]; Figure 12). The difference in composition in Prairie plots vs. both Savanna and Forest plots was more pronounced (perMANOVA, $p<0.05$; Figure 12). Both canopy basal area and stem density predicted differences in plant community composition, indicating that compositional differences by cover type were at least in part due to differences in these canopy structure

Canopy heterogeneity defines pine barrens. The filtered light of a heterogenous canopy (above, subunit 2C) often supports a diverse community of species, which may not persist after a clearcut and a high-intensity fire (below, subunit 3B).

metrics (Table D4). The degree of compositional similarity among cover types may be attributed to differences or similarity in canopy cover and the associated light environment. According to indicator species analysis, heliophytic forbs (e.g., smooth blue aster [*Symphyotrichum laeve*]) and graminoid species (e.g., poverty grass [*Danthonia spicata*]) characterized Prairie plots (Table 8). The ground layer in Forest plots by comparison, was characterized by woody species, mosses, and bracken fern, generally species adapted to low light environments. Because of the intermediate light environment of Savanna plots, only jack pine was selected as an indicator species, likely because conditions support both species that prefer prairie and forest structure. Finally, differences in composition were also influenced by ground cover metrics (Table D6, Figure 12). In particular, composition in Forest plots was influenced by higher woody debris cover, whereas higher cover of bare ground influenced composition in Prairie plots.

Diversity did not differ between cover types (Table 10, Figure D5), nor was diversity predicted by canopy structure metrics that differed by cover type (e.g., basal area and stem density, Table D4), despite shifts in composition. Studies in Midwestern oak savannas in Indiana and Wisconsin have also demonstrated shifts in composition but not diversity across gradients of light availability and soil texture or nutrients (Leach and Givnish 1999, Pavlovic et al. 2006). These and other studies emphasize that high diversity in savannas is a result of supporting species adapted to the heterogeneity of canopy and edaphic conditions. This suggests that the PBMA supports a plant community composed of a diversity of species adapted to a wide range of canopy cover conditions. It is also possible that fire suppression in the Frog Lake Barrens is also suppressing fire-dependent plant species in that high-quality remnant, and diversity may be higher in some canopy cover conditions after the reintroduction of fire.

Ground cover predicted diversity more strongly than canopy conditions (Table D5). Small-scale and large-scale species richness (but not medium-scale) was highest where woody debris cover was low (Figure 10), while small-scale and medium-scale species richness (but not large-scale) increased with percent cover of vegetative cover (Figure 11). Higher diversity was also associated with greater litter cover, at least for inverse Simpson's diversity at small- and medium scales, and small-scale evenness (Table D5). Woody debris was more abundant and leaf litter was less abundant in the ground layer of Forest plots, suggesting a potential mechanism for diversity suppression with canopy closure. Much of the leaf litter in pine barrens derives from graminoid species such as Pennsylvania sedge, rather than tree leaves, and also represents fine fuels that carry ground fires. Diversity, evenness, and litter cover may be correlated because they are all associated with high-quality microhabitats that were historically structured by fire. It will be illuminating to see how these relationships shift with the reintroduction of fire to high-quality portions of the PBMA.

The Status of Rare Plant Species

We greatly expanded the mapped extent of both Hill's thistle and rough fescue at PBMA. Although both species are widespread in the Highplains region, fire suppression and habitat destruction through plantation establishment and other anthropogenic land uses reduce populations locally (Higman and Penskar 1996). Local population reductions and extirpations can lead to slow, landscape-level declines by reducing gene flow and dispersal between populations (Kuussaari et al. 2009, Carlsen et al. 2022).

Hill's thistle and rough fescue appear to be more abundant or at least more fecund in the PBMA in microhabitats with low canopy cover, and with recent fire. We observed the highest abundance of both species in Unit 4, an area inside the fence of the 30 complex firing range. This area has little tree cover and areas inside the fence have burned far more frequently than areas outside the fence over the past 80 or more years of military training (fire return interval near-annual vs. multi-decadal). We observed large populations in portions of the PBMA with intermediate to high canopy cover as well, in particular within the Frog Lake Barrens EO (e.g., subunits 2C and 2D).

Hill's thistle and rough fescue are clearly adapted to a fire-maintained landscape characterized by a heterogonous light environment, and do not require large treeless expanses to thrive.

There also appears to be ample habitat for Alleghany plum and pale agoseris throughout the PBMA. Despite several populations in the similar surrounding landscape, we did not observe new populations in the PBMA. Alleghany plum may be limited by fire suppression, lack of dispersal agents, or its distribution in the landscape may be random. Pale agoseris, on the other hand, is more likely to occur in large glacial drainages (Lincoln et al. 2023). The absence of such features at PBMA may explain the absence of pale agoseris.

The comprehensive mapping of Hill's thistle and rough fescue provides a coarse status assessment and baseline for tracking status over time but inferring population viability requires multiple years of demographic data. In rare plant monitoring plots, few demographic parameters for Hill's thistle and rough fescue varied between years and plots (Table 4). In part, this is due to the reduced replication that resulted from our inability to relocate marked individuals in 2022 and 2023. It is also difficult to determine whether the changes we observed were due to stochasticity in the populations or the data, or due to plot-to-plot or year-to-year environmental changes (e.g., precipitation). The responses to upcoming management may yield more dramatic responses.

Rough fescue (*Festuca altaica*) clump sprouting following a prescribed fire in subunit 5B.

Current Management Recommendations

Over the past quarter century, canopy structure in the PBMA has shifted away from the heterogeneity that characterizes the pine barrens natural community, and around which plant and animal species structure thriving populations (Kost et al. 2000, Comer 2010). Restoring that heterogeneity will require the application of frequent, low-intensity fire likely in combination with other management approaches. Kost et al. (2000) provided detailed management recommendations for the PBMA intended to restore and maintain that heterogeneity. Here we expand upon and update those recommendations. Researchers and land managers have continued to gather insights and understanding of pine barrens management. The knowledge of the fire history of the northern lower peninsula of Michigan, and how fire structures pine barrens, has continued to accumulate (Zimmerman 1956, Simard and Blank 1982, Cleland et al. 2004, Jolly et al. 2016, Stambaugh et al. 2024). The variation in the structure and diversity of pine barrens in Michigan is also better understood, as 24 of the 37 pine barrens in the Michigan Natural Heritage Database were documented since 2000, with 17 documented since 2020 (MNFI 2024).

The heterogeneity that defines the pine barrens natural community reflects the response of trees and shrubs to frequent fires of varying intensities over decades, against a backdrop of environmental variation (e.g., aspect, slope, soil productivity; Tucker et al. 2016, Hanberry 2017). In the PBMA, as elsewhere in the Highplains region, silviculture has replaced low-intensity fire as the primary determinant of structure. Canopy thinning is typically intensive (e.g., clearcuts or shelterwood cuts) due to concerns over canopy fires in dense jack pine stands. High-intensity (and high-severity) prescribed fires conducted in April and May and intended to reduce fuels and prevent wildfire often follow intensive thinning, resulting in widespread canopy mortality and dominance by the low-growing graminoid Pennsylvania (e.g., subunits 1C, 1D, 3A, 5A, and 5B). Conversely, fire suppression is applied in areas where canopy jack pine has been retained (e.g., Frog Lake Barrens EO), resulting in succession to the homogenized structure of closed-canopied dry northern forest dominated by jack pine. Traditionally, land managers have relied on silvicultural approaches to approximate barrens structure. Restoring the degree of canopy openness (as opposed to heterogeneity) that defines pine barrens (e.g., 30 +/- 10%; Kost et al. 2000) can be achieved through silviculture. However, relying on silviculture alone to replicate a pattern of heterogeneity generated by the interplay of fires of varying intensity and multiple environmental gradients has limitations. For example, silviculture alone does not yield the continuously distributed fine fuels (grasses and sedges, and pine needles) that carry low-intensity ground fires, especially when techniques like scarification are used to expose continuous bare soil to reduce competition with tree seedlings (Mitchell et al. 2006). Instead, traditional silvicultural approaches encourage the accumulation of ladder fuels in the form of dense midstory jack pine and Hill's oak that increase the probability of crown fires.

Establishing a fire regime focused primarily on low-intensity fires can restore and maintain heterogeneity in pine barrens and at the same time reduce wildfire risk from crown fires. Low-intensity fires, timed to coincide with high needle moisture in late summer through the dormant season, have several key effects (Jolly et al. 2016). High needle moisture limits flame length and consumes herbaceous and low shrub fuels through ground fires instead of resulting in stand-replacing crown fires. Instead of causing tree mortality, low-intensity fires "prime" canopy trees for future fires by stimulating resin production that seals the bark against subsequent injury (Hauser 2008). Low-intensity fires also reduce ladder fuels, stimulate growth of fine herbaceous fuels that will support subsequent ground fires, and therefore reduce the risk of wildfire by reducing the chance of crown fires (Wu et al. 2023). Low-intensity fires also burn hot enough to mirror the benefits of high-severity fires, such as seed germination, recruitment, and growth in ground layer plant species, and serotiny in jack pine cones required for recruitment (Gauthier et al. 1996, Mitchell et al. 2006).

The restoration and maintenance of heterogenous pine barrens structure will require frequent prescribed fire. The aim of the initial stage of managing pine barrens is to restore representative heterogenous canopy structure, while the long-term aim is to maintain that structure and the associated biodiversity. To reduce the density of coarse fuels and the chance of stand-replacing crown fires, in the short term we recommend thinning to a canopy density of 60 +/- 10%, combined with mastication of ladder fuels as needed. Over the long-term, replacing mechanical interventions with the use of low-intensity fire as a management tool will yield the best outcomes for biodiversity. We suggest a fire return interval of 5 to 20 years, the second fire occuring no less than five years after the first. Prescriptions should target low needle moisture conditions that support low intensity and severity fires, to avoid crown fires and significant canopy mortality, and reduce wildfire risk. These conditions are generally present during the late growing season (September through November) and throughout the dormant season (November through early March) (Jolly et al. 2016). The goal of fire is not always to reduce jack pine sapling density, as suggested by Kost et al. (2000). It will be beneficial to remove saplings in densely stocked portions to increase light availability and reduce ladder fuels, but restoration of heterogenous structure and maintaining multiple age classes will require stimulating sapling recruitment in thinly stocked portions.

Kost et al. (2000) also suggested planting of red and white pine (*Pinus resinosa* and *P. strobus*), and treatment of invasive species. Red and white pine were historically co-dominant or sub-dominant in the PBMA (Figure 3; Kost et al. 2000), and planting pines would enhance vertical structure. However, avoid planting red and white pine within the Frog Lake Barrens EO to retain its value as a reference area, but consider experimental plantings in portions of the PBMA that mostly or fully lack canopy structure. Invasive species such as spotted knapweed (*Centaurea stoebe*) occur very rarely and are concentrated along disturbed road edges and largely absent from interior portions of the PBMA. The spread of invasive species such as spotted knapweed and leafy spurge (*Euphorbia virgata*) is mostly limited to road and trail edges. However, occasional treatment along roads may be necessary to prevent spread into the interior portions of the PBMA. Encroachment from native deciduous tree species such as Hill's oak and wild black cherry (*Prunus serotina*) due to fire suppression is a threat. Aspen clones occupy several 50-150 hectare (~100-400 acre) patches. Low-intensity fire may limit the density of these species. After one or two fires, however, we recommend evaluating the need to manage these species with mechanical and chemical treatments.

Ecosystem plot in Unit 6 following prescribed burn that resulted in 100% canopy mortality.

Future Work

Surveys and monitoring over 2021-2023 have provided a rich baseline against which to gauge the effects of future management in the PBMA. Going forward, periodic monitoring of rare plant populations and ecosystem metrics will provide evidence of management efficacy. Here, we suggest a rough timeline for future surveys and monitoring.

We conducted rare plant population monitoring through meander surveys focused on likely habitat for pine barrens species, as well as finer-scale demographic monitoring of select individuals. Periodic mapping of rare plant populations in the PBMA every 5-10 years will provide a coarse metric of the stability of populations and indicate whether Hill's thistle and rough fescue are expanding into new areas. More frequent mapping and surveys will be beneficial in select areas, such as 1-2 years following a major management initiative that modifies ecosystem structure. Expanding surveys to include insect diversity, including rare insects such as dusted skipper, cobweb skipper, and secretive locust, will also be valuable (Table 1). Surveys that are conducted both prior to and following management will provide helpful indicators of management efficacy.

Finer-scale demographic monitoring of marked rare plant individuals can provide specific evidence linking the response of population parameters to changes in the environment, including those due to management. Unfortunately, because we were unable to locate a significant number of marked individuals in some populations in 2022 and 2023, the value of conducting follow-up sampling of marked individuals is reduced. Future efforts to conduct demographic monitoring should include greater replication and take better steps to ensure relocation of marked individuals.

We also collected data on aspects of ecosystem structure and plant community composition in 45 plots across the PBMA. Resampling these plots can provide useful information about shifts to these ecosystem metrics to indicate the effectiveness of management interventions in reaching management goals, and potentially indicate the appropriate timing or approach for future management. For example, mechanical intervention or prescribed fire may be desired following an increase in canopy basal area or live stem density beyond 10 m^2/hectare or 50 trees/hectare, respectively (Bried et al. 2015). Following management, resampling can determine whether densities below similar thresholds have been achieved. Further work is needed to determine ideal thresholds for

Leonard's skipper (*Hesperia leonardus*) nectaring on northern blazing star (*Liatris scariosa*).

Atlantis fritillary (*Speyera atlantis*) nectaring on hairy goldenrod (*Solidago hispida*).

indicating wildfire risk, regeneration potential, and ecological integrity associated with different basal areas and stocking rates (Bried et al. 2015, Danielson et al. 2024). Repeated sampling of ecosystem plots should occur with a frequency of 5-10 years, or in select areas following major management interventions.

Expanded surveys of pine barrens natural communities within Camp Grayling and adjacent State Forest compartments can place the PBMA in a broader regional context. Better documentation of the occurrence and variation in ecosystem attributes of pine barrens in the broader PBMA landscape can improve understanding of the regional importance of the PBMA, as well as how to better manage this natural community. Documenting more examples of pine barrens will facilitate several areas of inquiry that can benefit management in the PBMA. The PBMA landscape historically supported a fire- and grazer-driven shifting mosaic of forests, prairies, and savannas (Comer et al. 1995, Fuhlendorf and Engle 2004). Examining the ecological gradients within and around multiple examples of pine barrens can support a better understanding of how to reinstate this shifting mosaic in the PBMA and elsewhere at Camp Grayling. Similarly, pre-colonization (General Land Office 1890, Comer et al. 1995) and post-colonization conditions (% cover of habitat types, attributes such as red/white pine density, fire frequency, etc.) of multiple remnant pine barrens natural communities can place management in a historical context.

Conservation planning within PBMA and Camp Grayling in general can integrate management across natural communities and North and South Camp. Existing plans and tools are outdated and in need of revision, include the North Camp Grayling Pine Barrens Management Plan (Kost et al. 2000) and the Mapping Plant Alliances of the Pine Barrens Management Opportunity Area (Cohen et al. 2005). There is a wealth of data and insights reported in the current document and a refined understanding about plant community dynamics, fire ecology, and general ecological relationships is available in the primary and gray literature, and from natural areas managers. Revising the PBMA management plan will be strengthened by this combined understanding, setting the PBMA on a better course for supporting biodiversity. Similarly, the National Vegetation Classification (NVC) that is the basis for plant alliance mapping has been significantly refined since 2005. While the MNFI natural community classification is useful for focusing conservation on the highest-quality examples of ecosystems, the NVC is a comprehensive land cover classification. Remapping alliances for the PBMA (or Camp Grayling as a whole) will provide a unifying tool for putting all portions of the PBMA (or Camp Grayling landscape) in the same context. Finally, the results of the current report can be a springboard for additional conservation planning exercises, including: a Camp-wide conservation prioritization of natural communities, species, and habitat complexes; a proposed prescribed fire plan for Camp Grayling; and characterizing restoration potential following training-associated disturbances.

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Sunset over subunit 5B.

APPENDIX A - EO Ranking Criteria

Table A1. Global element rank definitions

Global Rank		DEFINITION
G1	Critically Imperiled	At very high risk of extinction or elimination due to extreme rarity (often 5 or fewer occurrences), very restricted range, very few populations or occurrences, very steep declines, very severe threats, or other factors.
G2	Imperiled	At high risk of extinction or elimination due to restricted range, few populations or occurrences (often 20 or fewer), steep declines, severe threats, or other factors.
G3	Vulnerable	At moderate risk of extinction or elimination due to a fairly restricted range, relatively few populations or occurrences (often 80 or fewer), recent and widespread declines, threats, or other factors.
G4	Apparently Secure	At fairly low risk of extinction or elimination due to an extensive range and/or many populations or occurrences, but with possible cause for some concern as a result of local recent declines, threats, or other factors.
G5	Secure	At very low risk or extinction or elimination due to a very extensive range, abundant populations or occurrences, and little to no concern from declines or threats.
GH	Possibly Extinct (species) or Eliminated (communities)	Known from only historical occurrences but still some hope of rediscovery. Examples of evidence include (1) that a species has not been documented in approximately 20-40 years despite some searching and/or some evidence of significant habitat loss or degradation; (2) that a species or ecosystem has been searched for unsuccessfully, but not thoroughly enough to presume that it is extinct or eliminated throughout its range.
GX	Presumed Extinct (species) or Eliminated (natural communities)	Not located despite intensive searches and virtually no likelihood of rediscovery (species); Eliminated throughout its range, due to loss of key dominant and characteristic taxa and/or elimination of the sites and ecological processes on which the type depends (natural communities).
GU	Unrankable	Currently unrankable due to lack of information or due to substantially conflicting information about status or trends.
G?	Inexact	Incomplete data

Table A2. Sub-national element rank definitions

Subnational (State) Rank		DEFINITION
S1	Critically Imperiled	At very high risk of extirpation in the state because of extreme rarity (often 5 or fewer occurrences) or other factors making it especially vulnerable to extirpation, including: very restricted range, very few populations or occurrences, very steep declines, or severe threats.
S2	Imperiled	At high risk of extirpation in the state due to restricted range, few populations or occurrences (often 20 or fewer), steep declines, severe threats, or other factors.
S3	Vulnerable	At moderate risk of extirpation in the state due to a fairly restricted range, relatively few populations or occurrences (often 80 or fewer), recent and widespread declines, threats, or other factors.
S4	Apparently Secure	At a fairly low risk of extirpation in the state due to an extensive range and/or many populations or occurrences, but with possible cause for some concern as a result of local recent declines, threats, or other factors.
S5	Secure	At very low or no risk of extirpation in the state due to a very extensive range, abundant populations or occurrences, with little to no concern from declines or threats.
SH	Possibly Extirpated	Known from only historical records but still some hope of rediscovery. There is evidence that the species or ecosystem may no longer be present in the jurisdiction, but not enough to state this with certainty. Examples of such evidence include (1) that a species has not been documented in approximately 20-40 years despite some searching and/or some evidence of significant habitat loss or degradation; (2) that a species or natural community has been searched for unsuccessfully, but not thoroughly enough to presume that it is no longer present in the jurisdiction.
SX	Presumed Extirpated	Species or ecosystem is believed to be extirpated from the state. Not located despite intensive searches of historical sites and other appropriate habitat, and virtually no likelihood that it will be rediscovered. [equivalent to “Regionally Extinct” in IUCN Red List terminology]
SNR	Unranked	National or subnational conservation status not yet assessed.
S?	Inexact	Incomplete data

Table A3. Element occurrence rank definitions

EO Rank	DEFINITION
A Excellent Viability	Occurrence exhibits optimal or at least exceptionally favorable characteristics with respect to population size and/or quality and quantity of occupied habitat; and, if current conditions prevail, the occurrence is very likely to persist for the foreseeable future (i.e., at least 20-30 years) in its current condition or better. These occurrences have characteristics (e.g., size, condition, landscape context) that make them relatively invulnerable to extirpation or sustained population declines, even if they have declined somewhat relative to historical levels. For species associated with habitat patches or ephemeral or particularly dynamic habitats, occurrences warranting an A rank generally consist of metapopulations rather than single demes (unless exceptionally large and robust). Occurrences of this rank typically include at least 1,000 mature individuals but may be smaller (100s) or might require larger populations (10,000s), depending on the species and its demographic characteristics. However, occurrences can be ranked A even if population size is not known. For example, for occurrences lacking information on population size, an A rank may be appropriate under the following circumstances: the population is clearly very large but it is not known how large; the area of occupied habitat is exceptionally large; or the occurrence has excellent condition and landscape context and a long history of occurrence persistence. Occurrences with excellent estimated viability are ranked A even if one or more other occurrences have a much larger population size and/or much greater quantity of occupied habitat. In most cases, occurrences ranked A will occupy natural habitats. However, "natural" is an ambiguous concept, and occurrences in "unnatural" conditions (e.g., somewhat modified by human actions) may still be assigned a rank of A if they otherwise meet the criteria.
B Good Viability	Occurrence exhibits favorable characteristics with respect to population size and/or quality and quantity of occupied habitat; and, if current conditions prevail, the occurrence is likely to persist for the foreseeable future (i.e., at least 20-30 years) in its current condition or better. B-ranked occurrences have good estimated viability and, if protected, contribute importantly to maintaining or improving the conservation status of threatened or declining species. For species associated with habitat patches or ephemeral or particularly dynamic habitats, a high-quality occurrence may warrant a B rank if it consists of a single deme rather than a metapopulation (unless the single deme is exceptionally large and robust, in which case an A rank may be appropriate).
C Fair Viability	Occurrence characteristics (size, condition, and landscape context) are non-optimal such that occurrence persistence is uncertain under current conditions, or the occurrence does not meet A or B criteria but may persist for the foreseeable future with appropriate protection or management, or the occurrence is likely to persist but not necessarily maintain current or historical levels of population size or genetic variability. This rank may be applied to relatively low-quality occurrences with respect to size, condition, and/or landscape context if they still appear to have reasonable prospects for persistence for the foreseeable future (at least 20-30 years). Examples include very small non-degraded relict occurrences as well as some remnant occurrences of former landscape-level species such as many extant occurrences of tall-grass prairie insects. These occurrences represent the lower bound of occurrences worthy of protection.

Table A3, continued. Element occurrence rank definitions

EO Rank	DEFINITION
D Poor Viability	If current conditions prevail, occurrence has a high risk of extirpation (because of small population size or area of occupancy, deteriorated habitat, poor conditions for reproduction, ongoing inappropriate management that is unlikely to change, or other factors). Questionably viable occurrences that could be restored to at least fair viability should not be ranked D if restoration is deemed feasible and plausible; in most such cases CD should be used. Very small occurrences that may be vulnerable to deleterious stochastic events may be ranked as follows: If the stochastic event is highly theoretical or of very low probability in the appropriate time frame (e.g., 20-30 years), then a C or CD rank may be appropriate. If a minority of other similar occurrences have disappeared as a result of, say, disease or inbreeding, then perhaps CD is best. If most of these small occurrences have been extirpated or are disappearing due to such events, then D is probably appropriate. The D rank also applies if the population is so small that there will inevitably be a year (or generation) in the near future in which by chance all adults will be the same gender.
E Verified Extant	Occurrence recently has been verified as still existing, but sufficient information on the factors used to estimate viability of the occurrence has not yet been obtained. Use of the E rank should be reserved for those situations in which the occurrence is thought to be extant, but an A, B, C, D, or combination rank cannot be assigned.
F Failed to Find	Occurrence has not been found despite a search by an experienced observer at a time and under conditions appropriate for the Element at a location where it was previously reported, but the occurrence still might be confirmed to exist at that location with additional field survey efforts. For occurrences with vague locational information, the search must include areas of appropriate habitat within the range of locational uncertainty.
H Historical	Recent field information verifying the continued existence of the occurrence is lacking. Examples of this rank include occurrences based only on historical collection data, or occurrences that previously were ranked A, B, C, D, or E but that are now, without field survey work, considered to be possibly extirpated due to general habitat loss or degradation of the environment in the area. H may be applied to recently verified occurrences if two or more competent subsequent efforts that should have found the species did not, or if there has been a known major disturbance since the last observation such that continued existence of the occurrence is in doubt (for example, an isolated Lepidoptera occurrence that was sprayed with Dimilin®).
X Extirpated	Adequate surveys by one or more experienced observers at times and under conditions appropriate for the species at the occurrence location, or other persuasive evidence, indicate that the species no longer exists there or that the habitat or environment of the occurrence has been destroyed to such an extent that it can no longer support the species.

Grayling Pine Barrens Monitoring - Marked Plants

site	tag	rosette.num	rosette.wd	leaf.long	culm.num	culm.ht.1	culm.ht.2	culm.ht.3	head.wd.1	head.wd.2	head.wd.3	head.wd.4	head.wd.5
CIRHIL01	21												
CIRHIL01	22												
CIRHIL01	23												
CIRHIL01	24												
CIRHIL01	25												
CIRHIL01	26												
CIRHIL01	27												
CIRHIL01	28												
CIRHIL01	29												
CIRHIL01	30												
CIRHIL01	31												
CIRHIL01	32												
CIRHIL01	33												
CIRHIL01	34												
CIRHIL01	35												
CIRHIL01	36												
CIRHIL01	37												
CIRHIL01	38												
CIRHIL01	39												
CIRHIL01	40												
CIRHIL01	41												
CIRHIL01	42												
CIRHIL01	43												
CIRHIL01	44												
CIRHIL02	21												
CIRHIL02	22												
CIRHIL02	23												
CIRHIL02	24												
CIRHIL02	25												
CIRHIL02	26												

Date:______________ Name(s):_______________________________________

Figure B1a. Marked plant datasheet for Hill's thistle.

Grayling Pine Barrens Monitoring - Marked Plants

site	tag	transect	baseline	position	width	density	culm.num	2022 note	2023 note
FESALT01	21	t01	55m	36.3					
FESALT01	22	t02	64m	16.4					
FESALT01	23	t02	64m	21.9					
FESALT01	24	t02	64m	24.5					
FESALT01	25	t02	64m	41.8					
FESALT01	26	t03	71m	13.8					
FESALT01	27	t03	71m	19.6					
FESALT01	28	t03	71m	20.3					
FESALT01	29	t03	71m	22					
FESALT01	30	t03	71m	28.7					
FESALT01	31	t04	84m	95.5					
FESALT01	32	t05	90m	95.9					
FESALT01	33	t06	100m	68.1					
FESALT01	34	t06	100m	89.3					
FESALT01	35	t07	122m	10.1					
FESALT01	36	t08	155m	6.3					
FESALT01	37	t08	155m	9.7					
FESALT01	38	t08	155m	19.1					
FESALT01	39	t09	162m	4.8					
FESALT01	40	t09	162m	20.5					
FESALT02	21	t01	2m	28.2					
FESALT02	22	t01	2m	29.2					
FESALT02	23	t01	2m	30.3					
FESALT02	24	t01	2m	31.3					
FESALT02	25	t01	2m	32.9					
FESALT02	26	t01	2m	34.4					
FESALT02	27	t01	2m	35.3					
FESALT02	28	t01	2m	36.9					
FESALT02	29	t01	2m	36.5					
FESALT02	30	t01	2m	37.4					
FESALT02	31	t03	59m	42					
FESALT02	32	t03	59m	43.8					
FESALT02	33	t03	59m	50.7					
FESALT02	34	t05	114m	18.9					
FESALT02	35	t05	114m	46.4					
FESALT02	36	t05	114m	55.3					
FESALT02	37	t05	114m	67.9					
FESALT02	38	t05	114m	74					
FESALT02	40	t05	114m	82.7					

Date:_________________ Name(s):____

Figure B1b. Marked plant datasheet for rough fescue.

Sub-Unit:______________________ PBMA__1 X 1 m plots Sampling Point:__________________:

	0m	8m	16m	24m	32m	40m	48m	56m	64m	72m
Litter Depth:										
Corner 1										
Corner 2										
Corner 3										
Corner 4										
Light reading:										
Notes: Declination -										
Groundcover (add to 100)	**0m**	**8m**	**16m**	**24m**	**32m**	**40m**	**48m**	**56m**	**64m**	**72m**
Woody debris										
Litter										
Rocks										
Bare ground										
Moss/lichen										
Tree base										
Vegetation										

Date:_________ Pg __ of __ Recorder/Observer:_______

Figure B2a. Ecosystem plot datasheet - quadrat data.

Sub-unit:_______________________ PBMA__Walkthrough Species Sampling Point:_________________

Species	Species	Species	Species
Notes:			

Date:__________ Pg __ of __ Recorder/Observer:___________

Figure B2b. Ecosystem plot datasheet - walkthrough species list.

Sub-Unit:__________________ PBMA__Structural Data Sampling Point:____________

Tree Species: >5cm DBH, in 20x50m plot (rooted at least half in plot)			
Species	**DBH (cm)**	**Species**	**DBH (cm)**
Shrub Species: <5cm DBH, in 2mx20m @ 5m and 15m			
Species	**# stems**	**Species**	**# stems**
Notes (CWD, stumps, disturbances, firescars, insects and other animals, etc.)			

Date:____________________ Pg __ of __ Recorder/Observer:___________

Figure B2c. Ecosystem plot datasheet - canopy structure.

APPENDIX C - Sampling Plot Diagrams

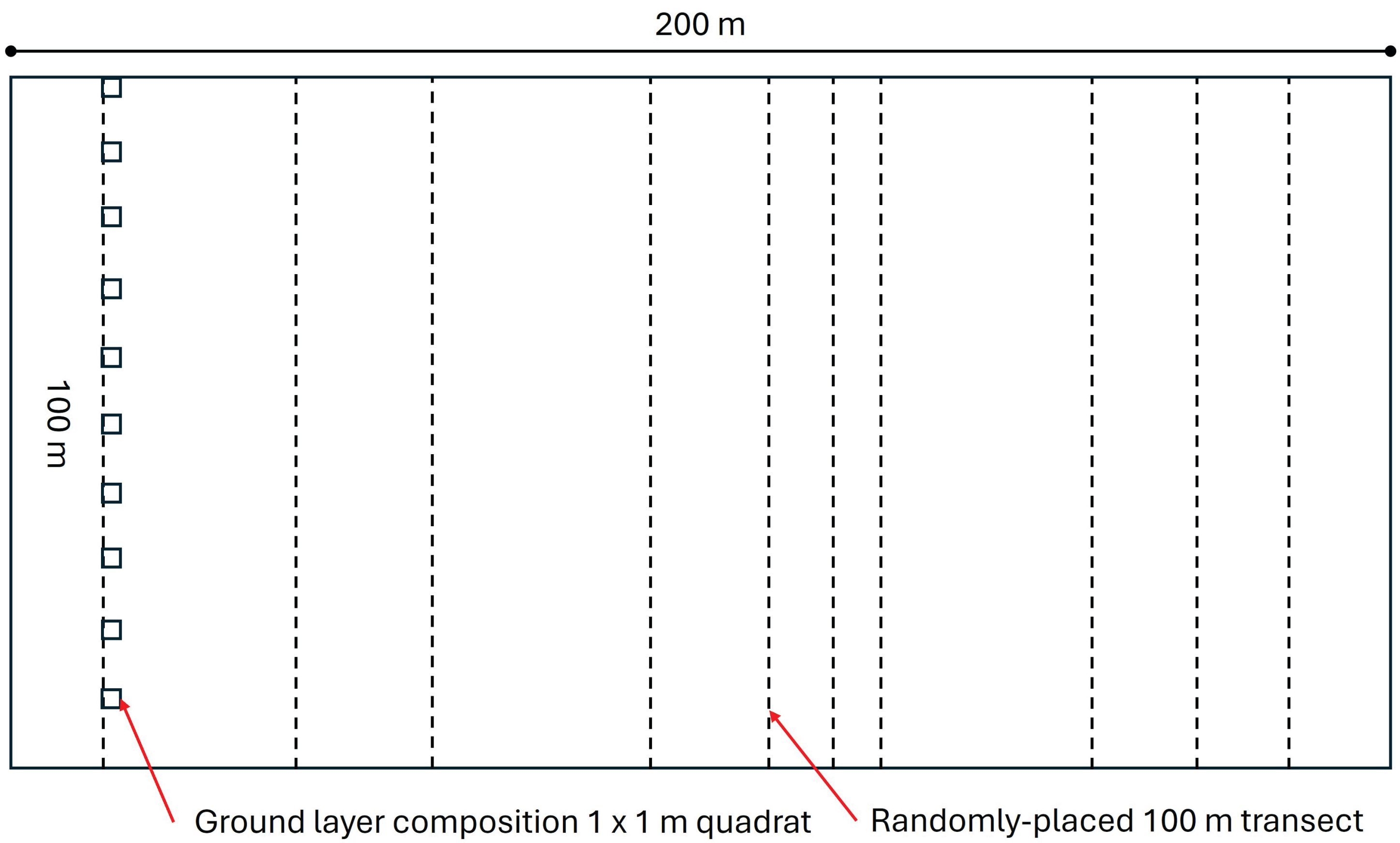


Figure C1. Rare plant monitoring plot layout.

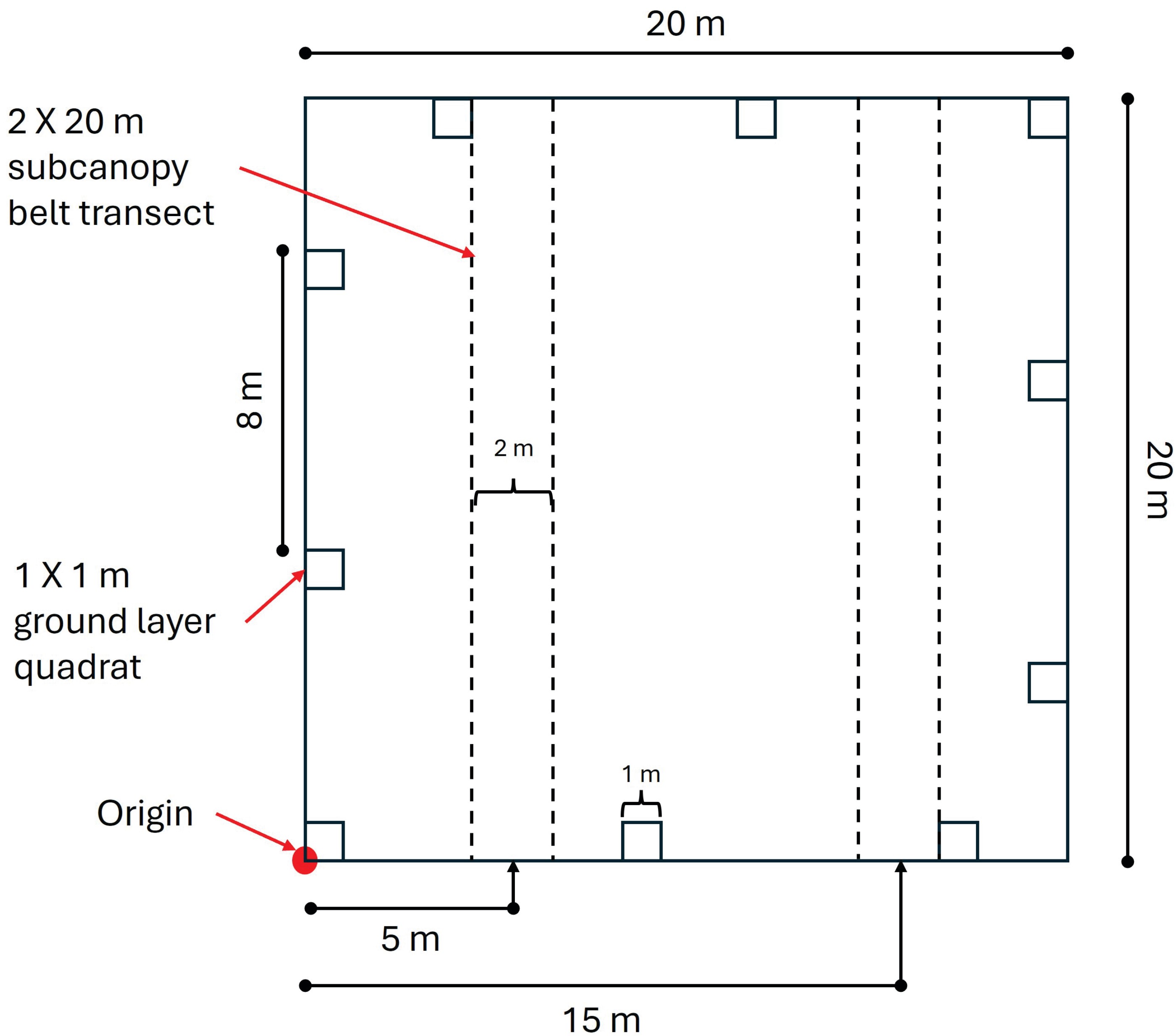


Figure C2. Ecosystem plot layout.




Prairie-02 (1B) | **Prairie-03 (5B)** | **Prairie-15 (5A)** | **Prairie-24 (5C)**

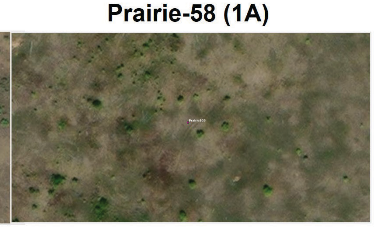



Prairie-27 (1D) | **Prairie-39 (1C)** | **Prairie-40 (2D)** | **Prairie-41 (2C)**




Prairie-48 (2C) | **Prairie-48 (7)** | **Prairie-58 (1A)** | **Prairie-75 (2B)**






Prairie-85 (3B) | **Prairie-90 (3B)** | **Prairie-105 (4)** | **Prairie-107 (4)**

Prairie-109 (4)

Figure C3. Aerial view of “prairie” ecosystem plots. Subunit in parentheses.

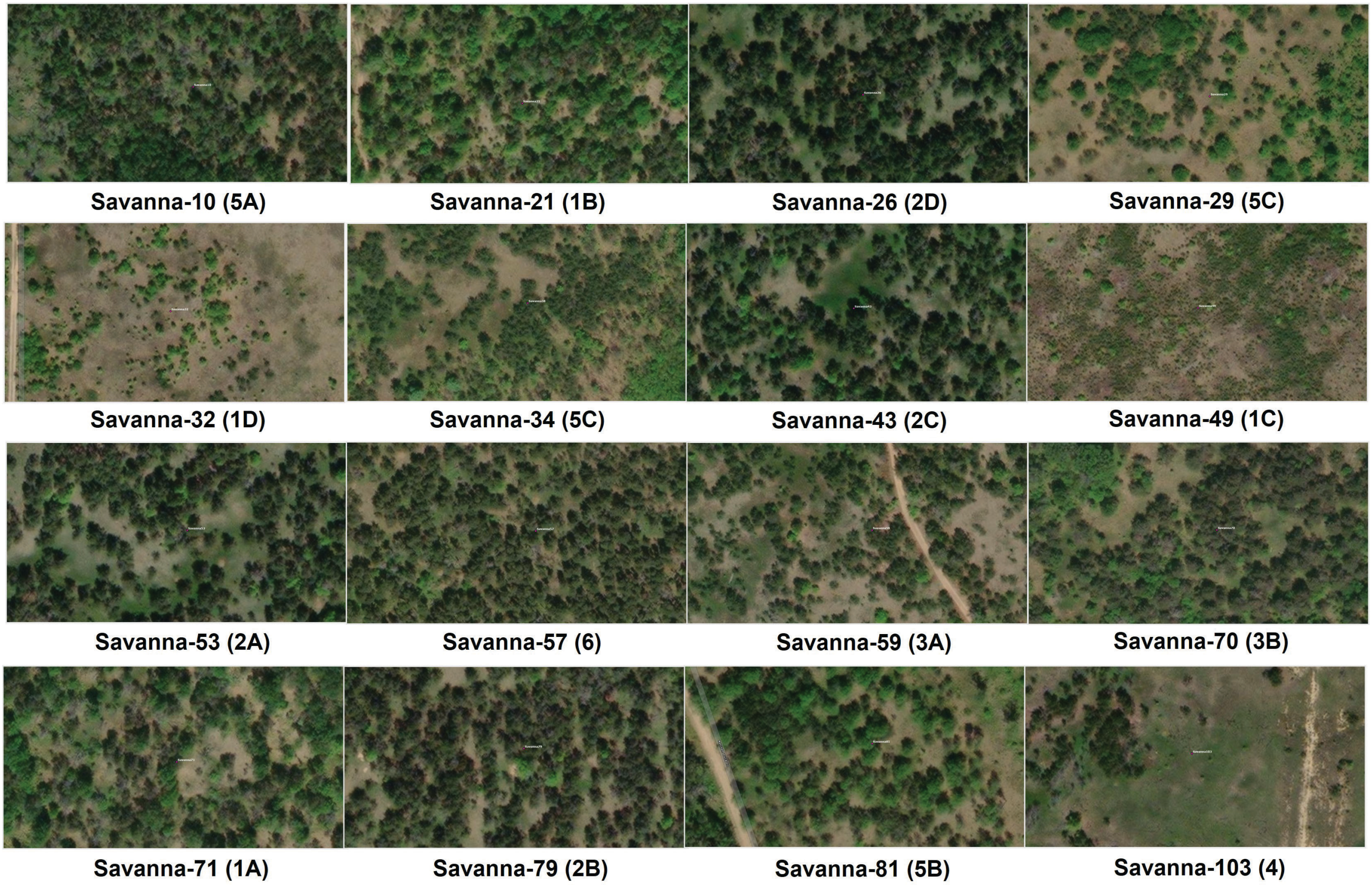


Figure C4. Aerial view of “savanna” ecosystem plots. Subunit in parentheses.

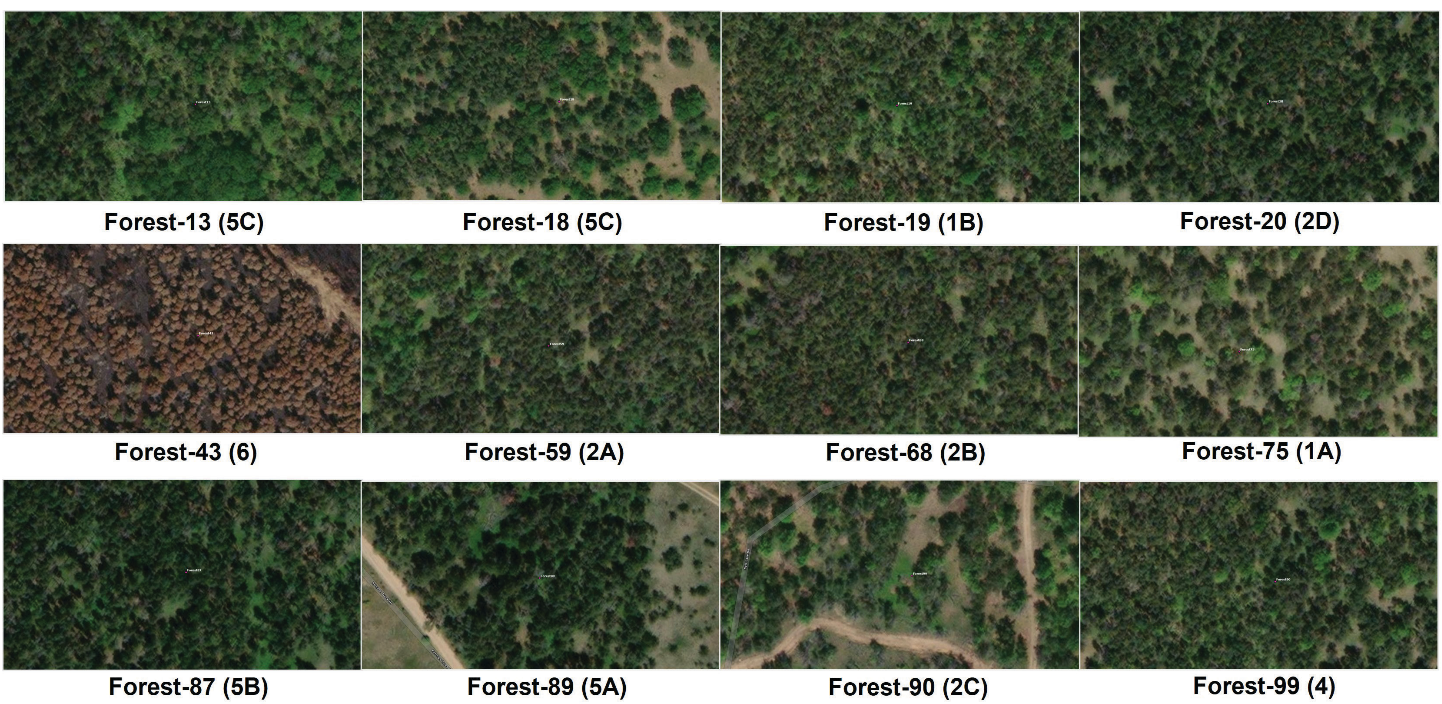


Figure C5. Aerial view of “forest” ecosystem plots. Subunit in parentheses.

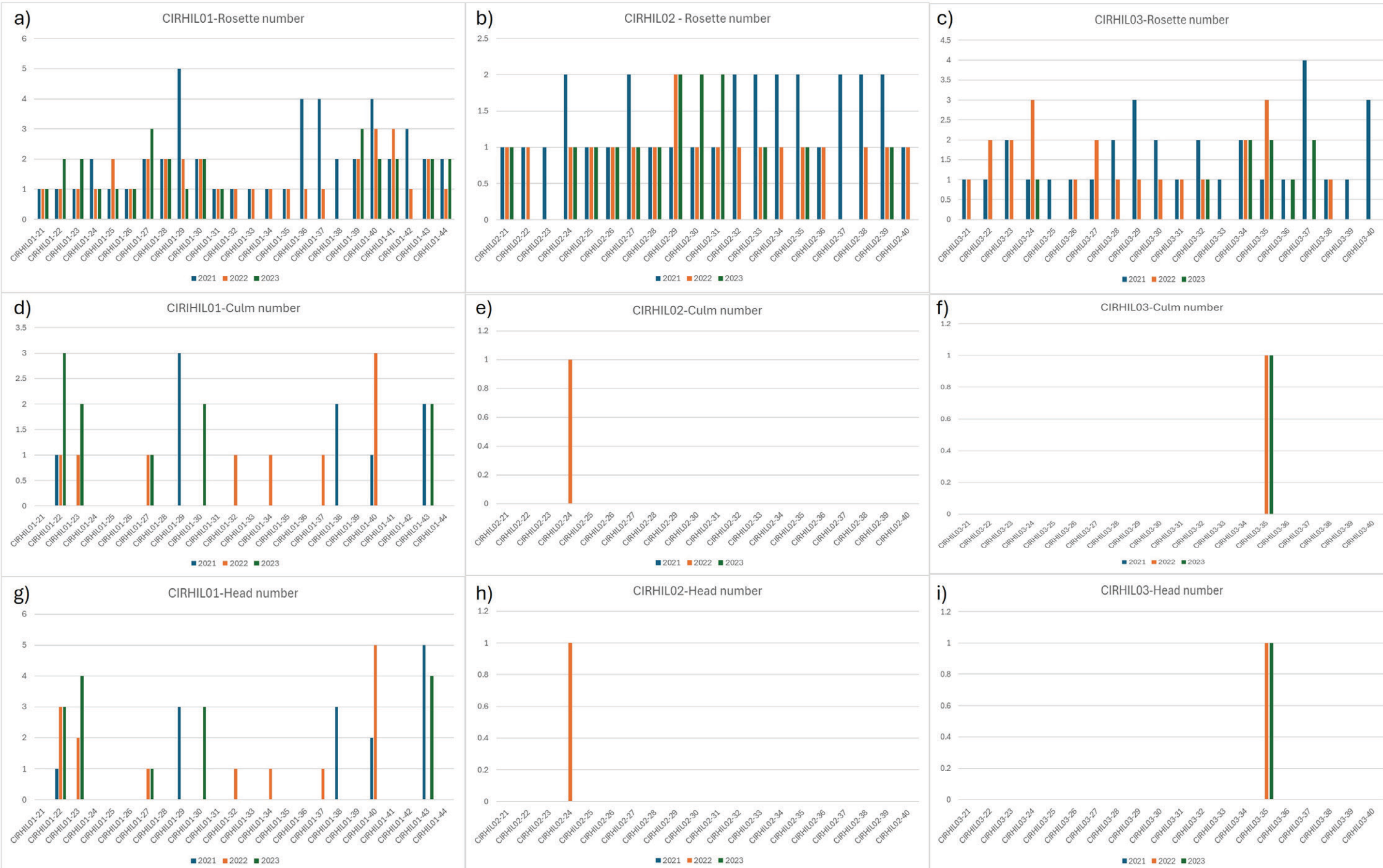


Figure D1. Results of marked plants monitoring - Hill's thistle.

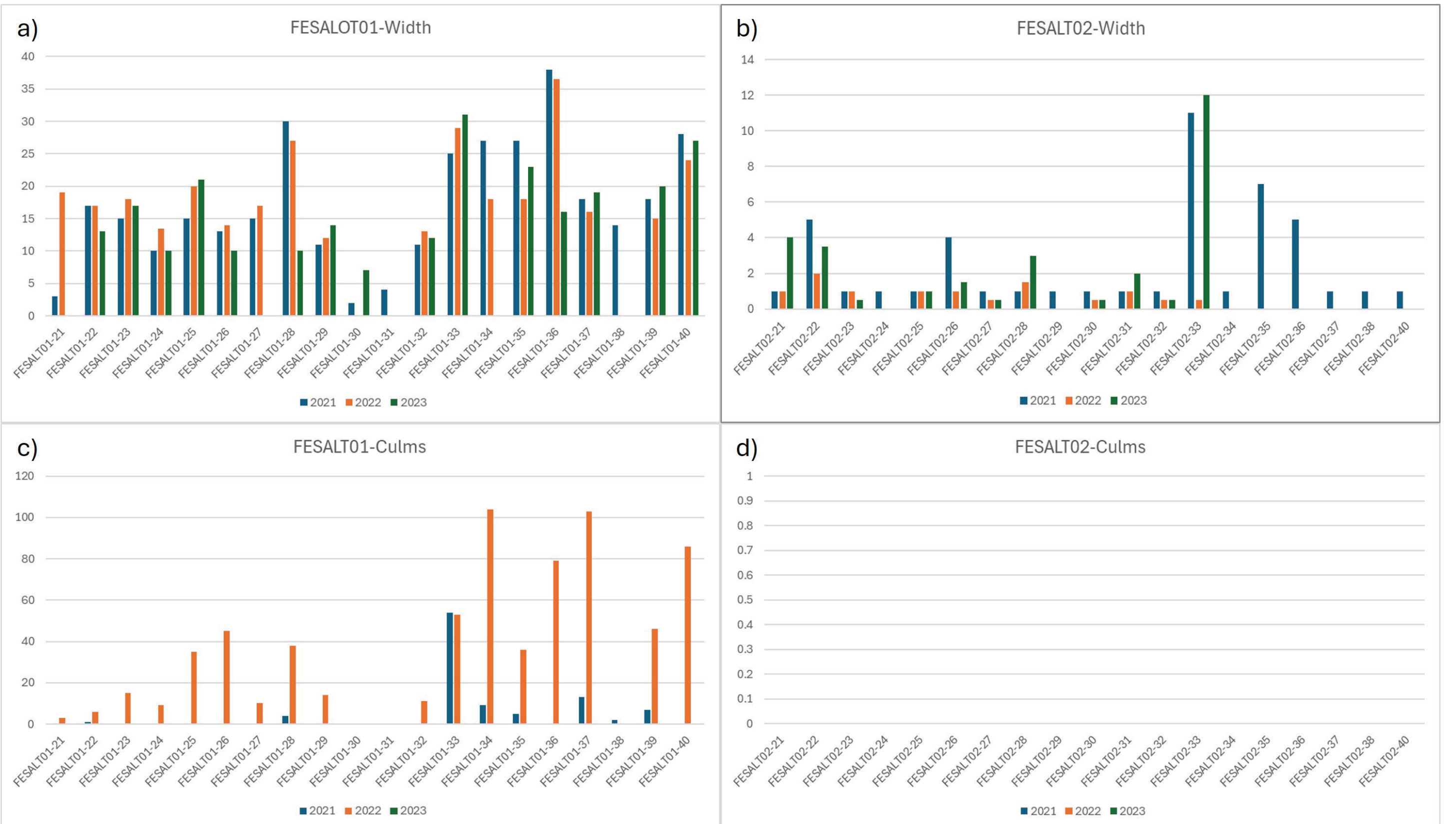


Figure D2. Results of marked plants monitoring - rough fescue.

Table D1. Correlation between all ground cover structure metrics. Pearson correlation coefficients, all **bold** values $p < 0.10$.

	Litter depth	Litter cover	Woody debris cover	Vegetation cover	Bare ground cover
Litter depth	1				
Litter cover	0.21	1			
Woody debris cover	0.01	0.01	1		
Vegetation cover	-0.17	**-0.50**	**-0.27**	1	
Bare ground cover	**-0.32**	0.01	0.08	**-0.28**	1

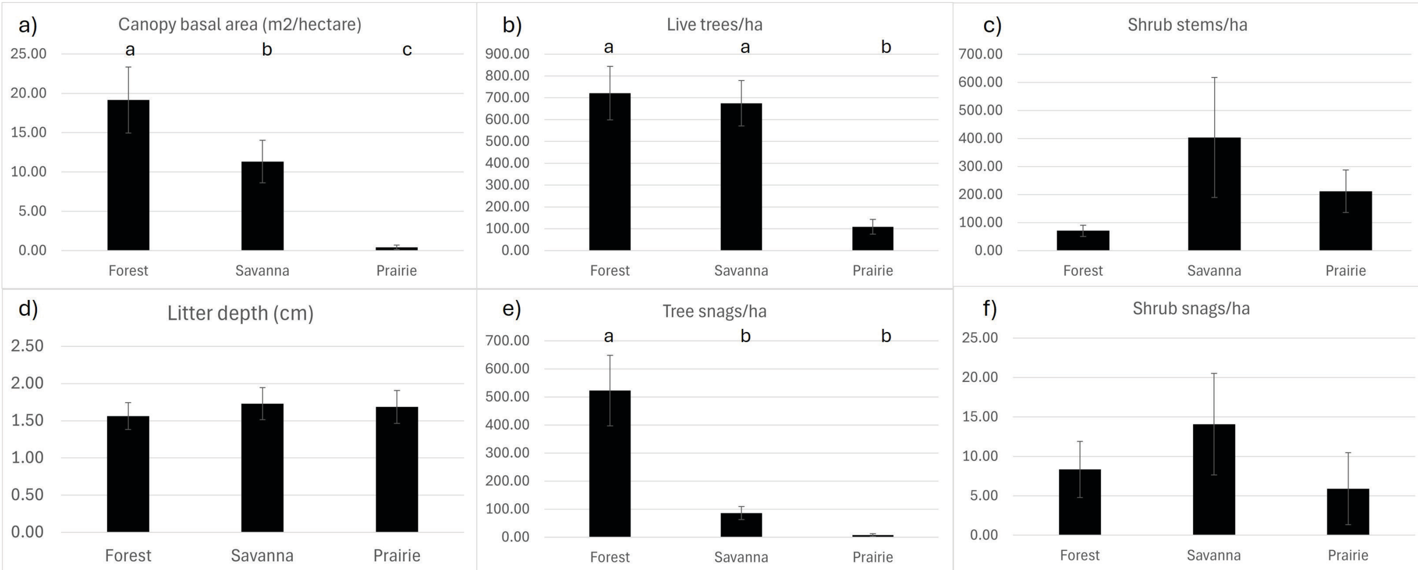


Figure D3. Mean and standard error for canopy structure metrics and litter depth among cover types. Cover types with different letters above bars are significantly different (p<0.05) according Tukey's post-hoc test.

Table D2. Mean values of structure metrics by subunit.

	Subunit															
	1A	1B	1C	1D	2A	2B	2C	2D	3A	3B	4	5A	5B	5C	6	7
Canopy basal area (m^2/hectare)	5.8	27.2	0	1.1	10.3	17.2	9.2	7.9	9.0	2.5	0.5	6.3	13.2	19.3	5.1	5.1
Live trees/ha	500	1041.7	25	325	512.5	683.3	400	466.7	700	183.3	75	383.3	558.3	955	325	325
Tree snags/ha	58.3	166.7	0	0	312.5	266.7	437.5	183.3	0	33.3	110.0	208.3	116.7	130	550	550
Shrub stems/ha	133.3	233.3	1987.5	175	137.5	225	81.3	83.3	100	500	65.0	175	41.7	225	125	125
Shrub snags/ha	16.7	16.7	12.5	0	37.5	8.3	0	0	0	0	0	0	0	35	12.5	12.5
Litter depth (cm)	2.38	1.85	3.58	1.24	1.49	1.31	1.33	1.46	1.54	1.41	2.50	1.26	0.83	1.73	1.29	1.29
Litter cover (%)	23.57	26.50	36.10	15.45	19.80	19.83	20.14	18.72	19.80	38.41	24.80	32.00	21.17	33.64	30.95	30.95
Woody debris cover (%)	5.67	6.60	4.80	2.25	7.83	5.73	4.79	4.88	3.40	5.18	6.14	9.02	6.35	5.18	14.60	14.60
Vegetation cover (%)	49.17	39.27	45.95	46.55	69.80	72.95	74.53	72.85	74.70	55.29	54.20	58.38	61.48	60.32	53.55	53.55
Bare ground cover (%)	0.83	0.67	0.50	1.00	0.00	0.83	0.19	3.08	1.20	0.78	1.22	0.43	10.40	0.64	0.65	0.65

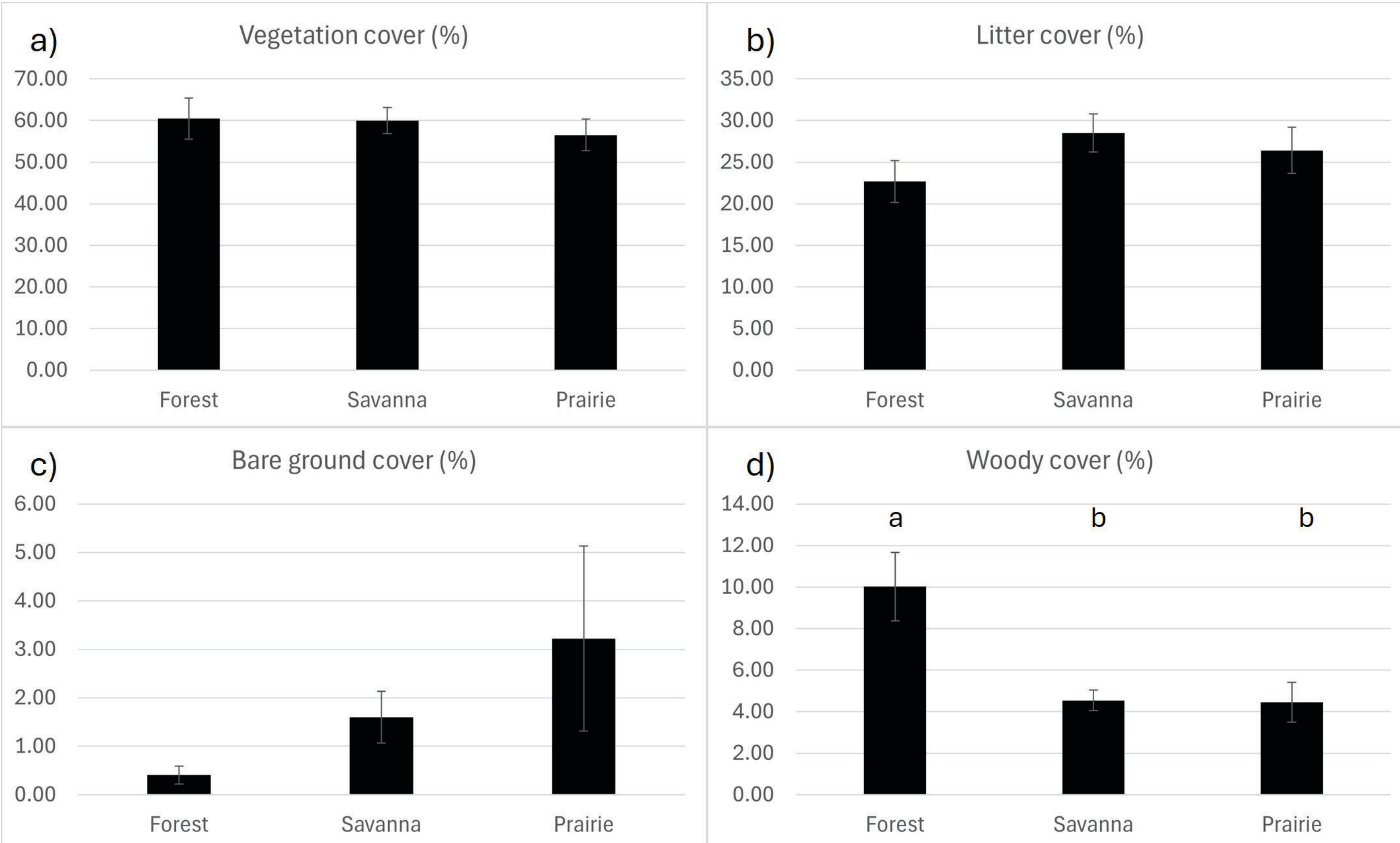


Figure D4. Mean and standard error for ground cover structure metrics among cover types. Cover types with different letters above bars are significantly different ($p<0.05$) according Tukey's post-hoc test.

Table D3. Mean values of diversity metrics by subunit.

	Subunit															
	1A	1B	1C	1D	2A	2B	2C	2D	3A	3B	4	5A	5B	5C	6	7
SR/m^2	6.4	5.9	6.9	5.8	7.4	8.0	8.9	8.0	7.8	8.8	7.2	7.0	6.5	6.1	6.6	6.6
Inverse Simpson/m^2	2.8	3.3	3.2	3.5	3.2	3.6	3.6	3.1	3.0	5.1	3.8	3.4	3.1	3.2	3.6	3.6
Evenness/m^2	0.33	0.41	0.36	0.44	0.36	0.37	0.33	0.31	0.32	0.49	0.41	0.38	0.38	0.39	0.41	0.41
Cumulative SR	16.3	12.7	17.0	12.5	19.5	21.3	24.0	21.0	21.0	22.7	17.0	19.0	15.7	16.2	15.5	15.5
Inverse Simpson	3.9	5.0	3.5	4.3	3.9	4.5	4.9	3.8	2.6	7.8	4.6	4.2	4.3	4.6	4.1	4.1
Evenness	0.27	0.38	0.20	0.34	0.20	0.21	0.20	0.18	0.12	0.36	0.27	0.22	0.28	0.29	0.26	0.26
Whole Plot SR	21.3	24.3	30.5	22.5	25.5	28.0	30.8	26.3	26.0	30.3	23.2	27.3	22.3	22.6	20.0	20.0
Mean C-value	4.4	4.5	4.5	4.5	4.3	4.8	4.6	4.6	5.3	4.1	4.9	4.0	4.6	4.4	5.4	5.4
FQI	19.9	22.0	24.9	21.5	21.5	25.1	25.7	23.5	27.2	22.1	23.5	20.7	21.0	20.8	23.8	23.8

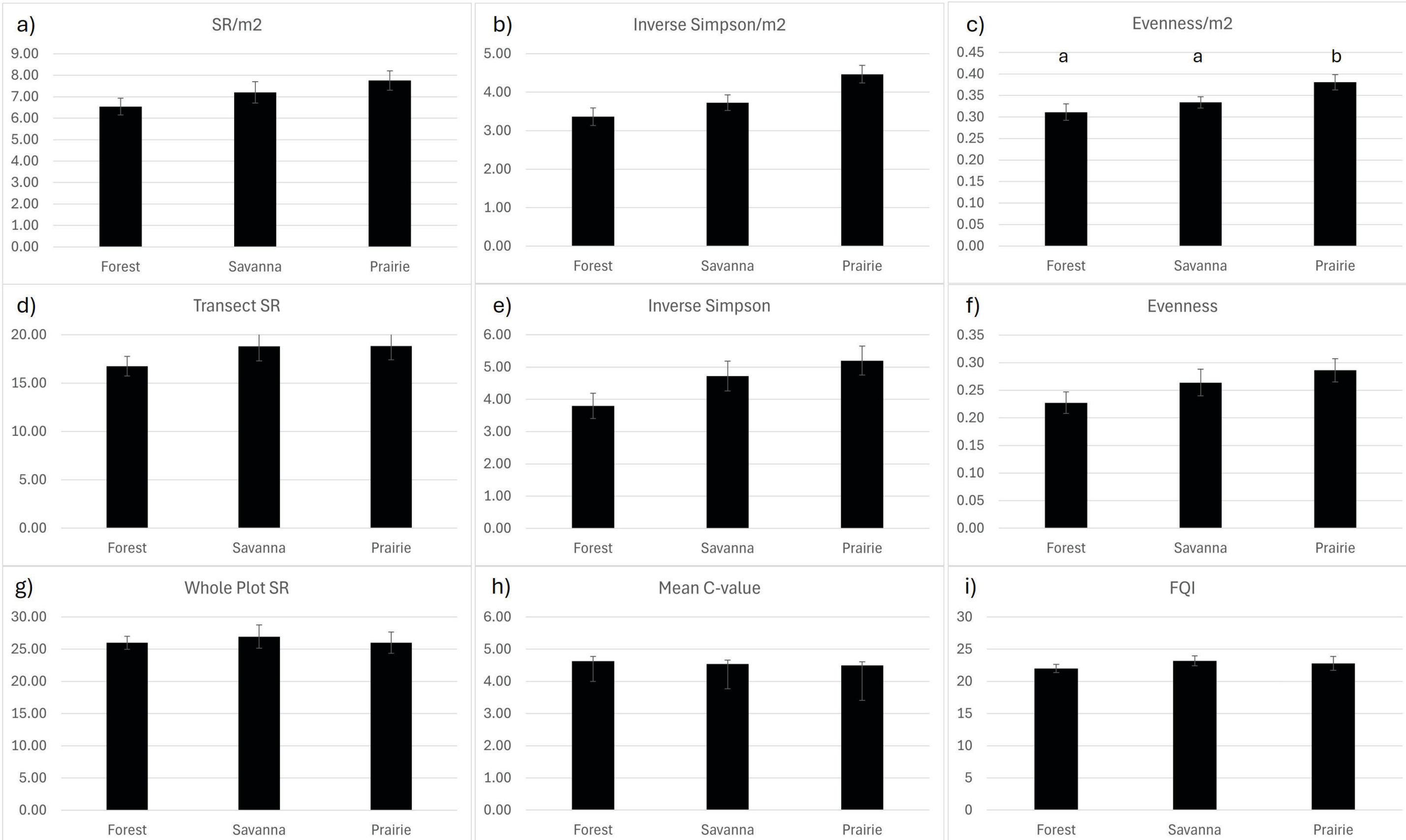


Figure D5. Mean and standard error for diversity metrics among cover types. SR = species richness; FQI = Floristic Quality Assessment. Cover types with different letters above bars are significantly different (p<0.05) according Tukey's post-hoc test.

Table D4. Relationship of diversity and composition with canopy structure. Values under basal area and stem density are p-values. SR = species richness; FQI = Floristic Quality Assessment. All p-values <0.10 in **bold.**

Diversity metric	Basal area	R^2	Stem density	R^2
SR/m^2	0.31	0.00	0.21	0.01
Inverse Simpson/m^2	0.27	0.01	**0.08**	**0.05**
Evenness/m^2	0.44	0.00	0.17	0.02
Cumulative SR	0.69	0.00	0.75	0.00
Inverse Simpson	0.84	0.00	0.63	0.00
Evenness	0.85	0.00	0.87	0.00
Whole Plot SR	0.67	0.00	0.77	0.00
Mean C-value	0.59	0.00	0.85	0.00
FQI	0.86	0.00	0.83	0.00
Bray-Curtis Dissimilarity	**<0.01**	**0.15**	**<0.01**	**0.13**
Jaccard Dissimilarity	**<0.01**	**0.09**	**<0.01**	**0.08**

Table D5. Relationship of diversity with ground cover metrics. Values under basal area and stem density are p-values. SR = species richness; FQI = Floristic Quality Assessment. All p-values <0.10 in **bold.**

Diversity metric	Litter Depth	Litter	Woody	Vegetation	Bare	R^2
SR/m^2	-0.11	0.11	**-0.29**	**0.34**	0.05	0.14
Inverse Simpson/m^2	-0.20	**0.35**	-0.25	-0.02	0.07	0.11
Evenness/m^2	-0.19	**0.38**	-0.07	**-0.38**	0.07	0.36
Cumulative SR	-0.09	0.23	-0.22	**0.49**	0.003	0.21
Inverse Simpson	-0.14	**0.33**	**-0.32**	0.02	0.04	0.11
Evenness	-0.09	0.08	-0.19	**-0.50**	0.02	0.19
Whole Plot SR	-0.06	0.20	**-0.37**	0.22	-0.10	0.16
Mean C-value	0.21	-0.08	**0.28**	-0.11	-0.11	0.00
FQI	0.07	0.12	-0.16	0.24	-0.06	0.00

Table D6. Relationship of composition with ground cover structure. Values under basal area and stem density are p-values. All p-values <0.10 in **bold.**

	Depth (cm)		Percent Cover							
Dissimilarity	**Litter**	**R^2**	**Litter**	**R^2**	**Woody**	**R^2**	**Vegetation**	**R^2**	**Bare**	**R^2**
Bray-Curtis	0.19	0.03	**<0.01**	**0.07**	**<0.01**	**0.08**	0.12	0.04	**0.01**	**0.06**
Jaccard	**0.04**	**0.03**	0.7	0.02	**<0.01**	**0.06**	**0.09**	**0.03**	**0.05**	**0.04**