Unionville Serpentine Barrens Restoration and Management Plan

Appendix F. 2016–2020 Update

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Summary of highest stewardship priorities for 2016–2020

Land and ecosystem stewardship priorities

The highest stewardship priorities for the next five years at the Unionville Barrens are to:

- hire expertise or train staff in order to ensure that a participant is always present and active during every major stewardship activity who knows all species of conservation concern on sight and the locations of every known stand of all highest-priority plant species of greatest conservation need, to help prevent accidental mortality in critically low populations;
- continue searching for new stands and monitoring known stands of the highest-priority plant species of greatest conservation need on a regular basis;
- temporarily mark stands of the highest-priority plant species of greatest conservation need at risk for accidental harm because they are in or near customary equipment travel lanes or in an area slated for tree removal or soil organic matter reduction, and make sure all equipment operators are familiar with those locations;
- continue applying prescribed fire to at least one burn unit at the Unionville Barrens every year;
- contract with a timber harvester to remove trees of non-serpentine barrens species from at least 25 acres of grassland restoration areas;
- eradicate autumn-olive from the most severely affected remnant (pre-2012) grasslands and grassland restoration areas;
- explore options and costs of sharpshooter deer culling by requesting proposals from multiple contractors specializing in deer management;
- georeference wetlands, including serpentine wetlands, marshes, spring seeps, and intermittent streams.

Sound science in every phase of stewardship

Science-based stewardship requires incorporating the scientific method—the best means ever devised for reducing uncertainty—into routine, everyday stewardship practices. It is vital to:

- continue cyclic monitoring of quantitative desired conditions metrics;
- conduct trials of new stewardship practices (e.g., growing-season prescribed fire) in accord with experimental design principles so that credible inferences can be made from the results, typically comparing outcomes in at least two units subjected to a trial practice, at least two units subjected to the practice with which it is being compared, and at least two units with no treatment, making sure all units are closely similar and interspersed on the landscape;
- have trends in quantitative metrics and differences among treatments analyzed by a qualified ecological biostatistician;
- conduct regular brainstorming sessions, preferably onsite, among the analyst, the science team, and the stewardship staff on whether and how stewardship practices need to be adjusted based on the analyses of trends and outcomes;
- update the stewardship plan accordingly, no less often than every five years.

Additional land protection essential for stewardship success

The sustainability of the Unionville Barrens and their constituent species, habitats, and communities crucially depends on protecting the remainder of the barrens and bringing those lands into the stewardship program. It is of the highest priority to protect as much as possible of the land underlain by serpentinite now owned by the Kramkowskis and Heckerts, along with a buffer at least 100 feet wide.

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Introduction

The Natural Lands Trust and its partners have made much progress in ecosystem restoration since the *Unionville Serpentine Barrens Restoration and Management Plan* (Latham and McGeehin 2012) was completed. The main achievement was the clearing of trees from 12.4 acres of land designated for grassland restoration, nearly tripling the acreage in grassland vegetation overlying serpentinite toward the goal of 50 or more acres of serpentine grassland in total. Other major successes include the start of autumn-olive eradication, the establishment of a prescribed fire program committed to burning one or more forest-grassland units each year, conducting a baseline survey of the biological resources of the site, and establishing a program for long-term monitoring of desired conditions metrics. At this writing, progress is being made toward the crucial goal of placing the remainder of the Unionville Barrens land under protective ownership by NLT.

Much was learned in the four-year-long startup of the long-term monitoring program. Monitoring for four consecutive years at the start speeded the process of refining the list of key metrics so monitoring could be carried out efficiently and be supportable in perpetuity. In addition, conducting baseline surveys over multiple years resulted in high confidence that most existing stands of endangered and threatened species have been located and their present status documented, and it gave a sound basis for ranking priorities and planning for each population's recovery and long-term security. Few of the selected metrics will need to be monitored yearly from now on; depending on the particular indicator, most cycles can be three, four or five years long.

Several desired conditions metrics (all are covered in detail later in this document) improved from 2012 to 2015. Total grassland area increased from 7 to 19 acres, still in the "poor" range but nearly tripled. Whole-site (between-patch or β) diversity in native serpentine grassland plant species composition increased from fair to excellent in the 12.4-acre grassland restoration area, mainly because grassland species were scarce when quadrats were first surveyed before tree removal. Metrics of the population status of several plant species of conservation concern were upgraded because additional stands were discovered; those species are Bicknell's sedge, Richardson's sedge and Bicknell's hoary rockrose (all endangered), shortleaf pine and lion's-foot (both threatened), and Elliot's beardgrass (rare, i.e., near-threatened) and dwarf chinkapin oak (key insect host plant). In addition, the population status of side-oats grama (threatened) was potentially made more secure by planting new stands in Units 1 and 2 using plugs raised at the Mt. Cuba Center from seed collected at Unit 6 (management units are mapped in Fig. F-1); later monitoring results will determine if they establish successfully and spread.

Several desired conditions metrics also improved in forest stands. There was a slight increase in canopy dominance by oaks, most likely due to the lateral growth of branches of adult trees. Cover of native trees of seedling and sapling size increased but only of the prolific root-sprouting species American beech and sassafras. Most small stems of these species did not arise from seeds; they can increase in the face of a deer population above ecological carrying capacity because they are fed by massive root systems and upper canopy photosynthesis and they are among the species least preferred by deer.

A few of the desired conditions metrics deteriorated from 2012 to 2015. They include some of the indicators of local (within-patch or α) and whole-site (between-patch or β) native serpentine grassland plant species diversity, which declined from the good to the fair range or from the excellent to the good range, mainly in remnant (extant before 2012) grasslands. This is tentatively hypothesized to be part of a transitory short-term fluctuation, possibly due to the weather patterns of the 2012–2015 period. Data from the next monitoring cycle will help to resolve this question. In forest samples, local native species diversity indicators worsened, likely because of the proliferation of Japanese stiltgrass, which may be continuing to spread or may have gained advantage from the relatively high and consistent rainfall of the period.

This stewardship plan update is framed within slightly revised boundaries of the barrens core management area (previously "study area" on Maps 4-8 in Latham and McGeehin 2012) and management units (Map 10 in Latham and McGeehin 2012) to reflect better understanding of the site and its constraints and opportunities (see new map in Fig. F-1 and acreage statistics of the units, categorized by vegetation type and present-day ownership, in Table F-1).

F.1 Selective tree removal

F.1.1 Expand tree removal area

In new tree removal areas (hatched in orange in Fig. F-2), flush-cut or uproot all trees except:

- serpentine barrens oaks—post oak (*Quercus stellata*), Bush's oak (*Q.* ×*bushii* or *Q. marilandica* × *velutina*), blackjack oak (*Q. marilandica*), dwarf chinkapin oak (*Q. prinoides*) and Faxon oak (*Q.* ×*faxonii* or *Q. alba* × *prinoides*);
- any other oak species of conservation concern in Pennsylvania, if found, such as southern red oak (*Q. falcata*);
- shortleaf pine (*Pinus echinata*); and
- certain groves of eastern red-cedar (*Juniperus virginiana*; see F.1.3, below).

It is essential that tree removal and all other work involving heavy machinery be preceded by the temporary marking with stakes and caution tape of all nearby stands of the highest-priority plant species of greatest conservation need. They are the species whose populations at the Unionville Barrens are dangerously low. Such stands need to be marked anywhere heavy machinery is likely to go, including access routes from roads and the tree removal areas themselves. Pre-2012 remnant grasslands, whether species of critically low population sizes are present or not, should be avoided whenever practical during the growing season. More details, including a list of the highest-priority plant species of greatest conservation need, are covered later, in Sections F.6 and F.7.

F.1.2 Restore connectivity of largest remnant grasslands

Connect Units 2 and 5 grasslands by removing the trees in a segment of the valley of Feldspar Run (Fig. F-2). This will join more than four-fifths of the total area of remnant and restored grasslands at the Unionville Barrens together into one contiguous unit. The rest will be divided among three small outliers in Units 3 and 4 and part of Unit 7 (Fig. F-3).

F.1.3 Remove eastern red-cedar in some areas, preserve it in others

Eastern red-cedar can invade serpentine grasslands and eventually displace them completely, but a few groves need to be saved to serve as habitat for specialist-feeding insects, in particular the juniper hairstreak (*Callophrys gryneus*), a near-threatened butterfly whose population at the Unionville Barrens is one of the largest in the region. It may thrive here and not elsewhere because the eastern red-cedar population at the barrens is more stable than typical transient, early-successional stands and may have been present continuously for

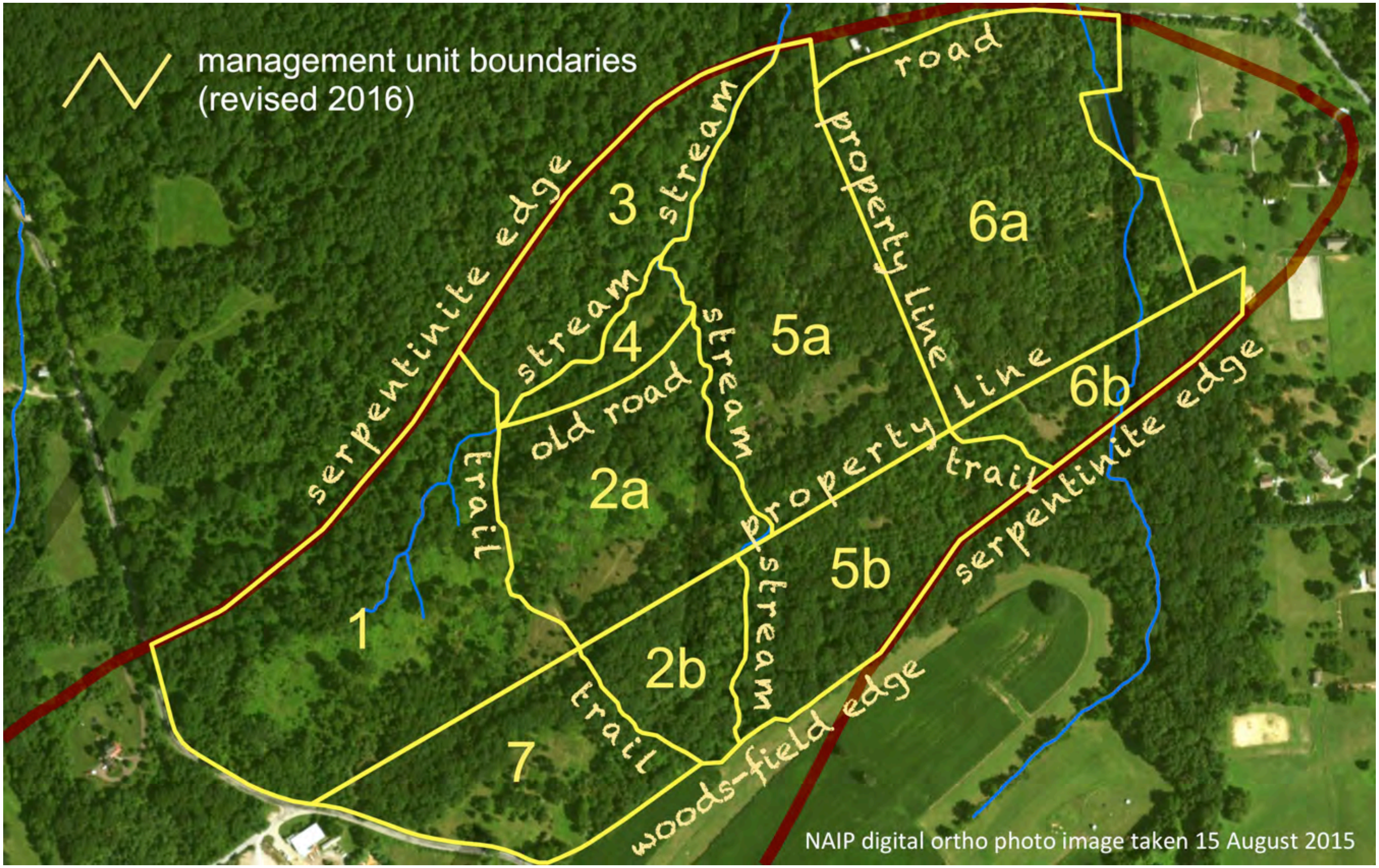


Figure F-1. **Revised Unionville Barrens management unit boundaries** with edges identified. Minor modifications were made to boundaries shown in Map 10 of the 2012 *Restoration and Management Plan* to better reflect site needs and constraints. Eventual protection of Units 2b, 5b, 6a, 6b and 7 and additional grassland restoration will lead to more changes in unit boundaries over time. See Table F-1 for descriptions of units.

Table F-1. **Revised Unionville Barrens management units and their component grassland and forest management areas.** Approximate sizes are in acres, broken down by 2015 ownership. Acreages are rough estimates, pending updating of GIS data using 2015 imagery and digitizing revised management unit boundaries.

management unit / 2015 ownership		2015 grassland	additional area targeted for grassland restoration 2016–2020	grassland management area total	forest management area	management unit total
Unit 1	NLT	**7.1**	**2.5**	**9.6**	**10.9**	**20.5**
Unit 2	**2a.** NLT	5.6	0.5	6.1	5.7	11.8
	2b. Heckert	0	0	0	4.9	4.9
	total	**5.6**	**0.5**	**6.1**	**10.6**	**16.7**
Unit 3	NLT	**0.2**	**2.7**	**2.9**	**7.0**	**9.9**
Unit 4	NLT	**0.4**	**0.1**	**0.5**	**1.7**	**2.2**
Unit 5	**5a.** NLT	2.0	6.4	8.4	9.0	17.4
	5b. Heckert	0.1	1.5	1.6	8.4	10.0
	total	**2.1**	**7.9**	**10.0**	**17.4**	**27.4**
Unit 6	**6a.** Kramkowski	1.4	15.8	17.2	6.5	23.7
	6b. Heckert	0.3	0	0.3	4.2	4.5
	total	**1.7**	**15.8**	**17.5**	**10.7**	**28.2**
Unit 7	Heckert	**0.2**	**5.2**	**5.4**	**4.1**	**9.5**
	grand total	17.3	34.7	52.0	62.4	114.4

hundreds or thousands of years. A network of preserved groves (approximate locations* and extent shown on Fig. F-3) will also serve as valuable habitat for nesting and migratory bird species that prefer or depend on conifers, such as overwintering northern saw-whet and long-eared owls and nesting warblers.

F.1.4 Revisit 2012 tree removal area

All mature oaks left behind in the 2012 tree removal area in Units 1 and 2 grassland restoration areas (hatched in green in Fig. F-2) should be removed except post oak, blackjack oak, dwarf chinkapin oak and hybrids involving any of those species. Their preservation during the 2012 tree removal was an experiment; there is now enough evidence to consider it complete. Shade cast by the scarlet oaks (*Quercus coccinea*), northern red oaks (*Q. rubra*) and black oaks (*Q. velutina*) that were left standing is almost certainly contributing to the ability of Japanese stiltgrass (*Microstegium vimineum*) to slow recolonization by the characteristic native serpentine barrens species in the tree removal area. Serpentine savanna trees are much shorter and have an open-grown branching form, with lower branches near ground level (where the deer population is low enough to allow low branches to remain intact). These characteristics are key to their function as egg-laying and larval feeding sites for serpentine barrens-

* One or more of the small patches in Unit 6 marked as red-cedar groves in Fig. F-3 may instead be stands of eastern white pine (*Pinus strobus*), which should be removed along with the surrounding hardwoods.

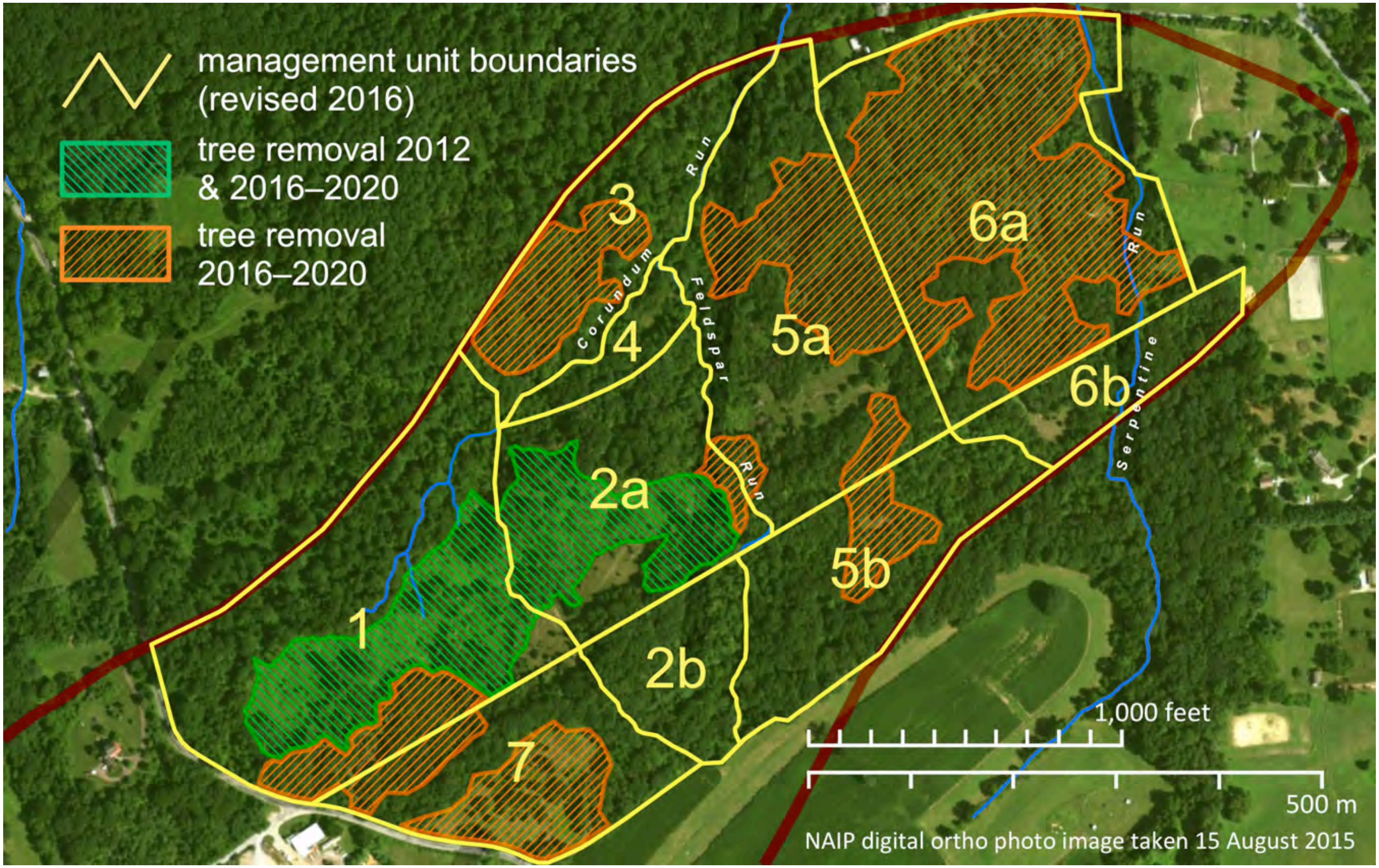


Figure F-2. **Unionville Barrens selective tree removal areas, 2016–2020**. All trees in hatched areas are to be removed except (1) serpentine barrens oaks (post oak, blackjack oak, dwarf chinkapin oak and hybrids involving any of those species); (2) any other oak species of conservation concern, if found, such as southern red oak; (3) shortleaf pine; and (4) certain groves of eastern red-cedar (see Fig. F-3).

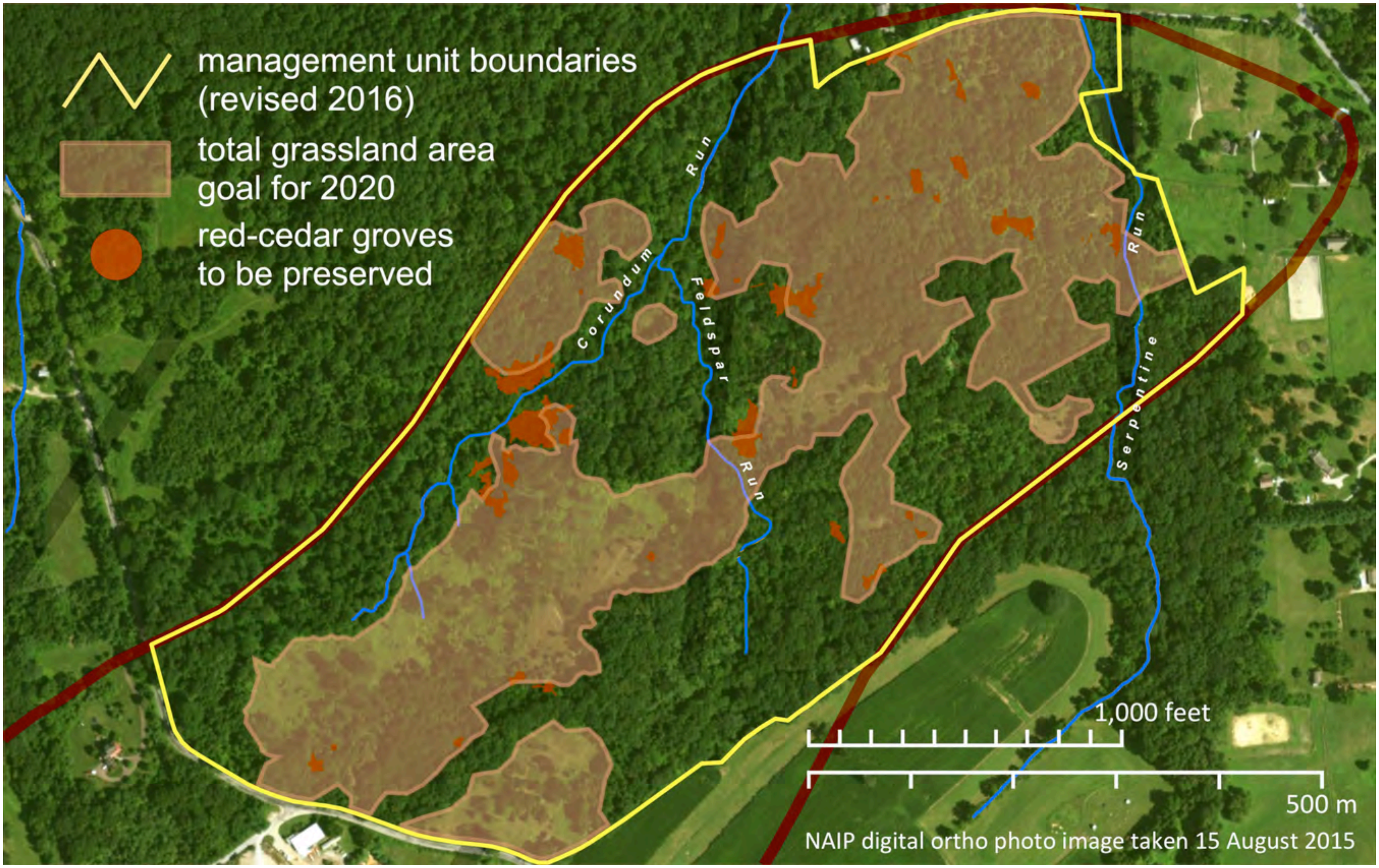


Figure F-3. **Unionville Barrens total grassland and eastern red-cedar area goal for 2020**, including open prairie, savanna (grassland with scattered post oak, blackjack oak, dwarf chinkapin oak and hybrids involving any of those species), and scattered eastern red-cedar groves to be preserved in grassland and forest.

specialist insect species that avoid laying eggs anywhere but on oak branches close to the ground.

F.1.5 Rescue shortleaf pine

During tree removal in Unit 3, take the utmost care to leave the Unionville Barrens' single shortleaf pine and an area within at least 30 feet of the tree undisturbed. It is in the middle of a grove of eastern red-cedars, part of which is slated for preservation (Fig. F-3). The firebreak just upslope and parallel to Corundum Run passes within a few feet of the tree. Any vehicular or equipment activity along the firebreak needs to be done with special caution so as not to injure its trunk or large near-surface roots.

F.2 Invasive species control

F.2.1 Autumn-olive

Autumn-olive (*Elaeagnus umbellata*) continues to be the top priority for eradication. Infestation in Units 1 and 6 is especially severe. The per-acre biomass of stems and branches is immense. It is essential to remove the brush and wood from the site, either as it is cut or by burning in piles and disposing of the ashes offsite. If the cut brush is burned, piles need to be located only in areas where no grassland plants are growing and never in intact remnant grasslands where species of greatest conservation need live. Ash residues from autumn-olive burning need to be hauled offsite because the species houses symbiotic bacteria in root nodules that convert inert atmospheric nitrogen to mineralized forms available to plants. Its nitrogen-rich leaf litter and ashes from burning its wood and leaves act as fertilizer, promoting invasive plant growth.

F.2.2 Black locust and ailanthus

Because of their ability to proliferate in grasslands at an exponential rate, all individuals of black locust (*Robinia pseudoacacia*) and tree-of-heaven or ailanthus (*Ailanthus altissima*) should be killed with herbicide at the earliest opportunity. These species are especially effective at killing native serpentine grassland plants by shading and by changing soil conditions. Ailanthus secretes allelopathic chemicals that deter establishment of other plants. Black locust, like autumn-olive, hosts nitrogen-fixing bacteria in root nodules. Its decaying leaf litter and substances given off by its roots make the soil more conducive to invasion by nonnatives and non-grassland species.

There are scattered individuals of both species throughout the site. Black locust reacts to cutting by prolific root-sprouting from its wide-ranging network of rhizomes. Painting herbicide on cut stumps or girdled trunks does not prevent suckering. The most effective and efficient way of eradicating them is to leave the trunks intact and employ a basal bark application of triclopyr (e.g., Garlon 4) mixed with a penetrant or in a ready-mixed formulation (e.g., Pathfinder II). This method has proven its reliability in many trials across the country but nevertheless black locust in particular is known for resprouting, sometimes years after it has apparently been eradicated. Follow-up monitoring and treatment are essential.

F.2.3 Chinese silvergrass

There are scattered clumps of Chinese silvergrass (*Miscanthus sinensis*) throughout the barrens, including several at the intersection of Cannery and Kelsall Roads. This invasive, nonnative, warm-season perennial grass forms very large clumps up to 6½ feet tall, spreads rapidly by airborne seeds, and is infamous for combusting explosively and lofting live embers during prescribed fires, creating severe risk of spot fires. If it were allowed to spread, prescribed fire would have to be postponed until eradication is complete. Much future trouble and expense can be avoided by nipping the infestation in the bud while it is still mild.

Its root systems are too robust and deep for plants to be eradicated by mechanical removal. According to one source[1], the most effective control method is:

1. In late winter or early spring before new growth starts, remove previous year's growth by cutting or burning the entire plant back to the ground. This ensures vigorous new growth and the lack of any dead leaves or culms improves conditions for chemical control.
2. When new growth is about 1 foot tall in mid-spring or early summer, spray all green tissue with glyphosate. Allow plant to die, and when completely brown, cut the dead foliage back to the ground. (If it is not feasible to remove the previous year's growth as indicated in step 1, wait until plants are 1–2 feet tall, usually in early to mid-summer, to proceed with spraying. Coverage is hampered if standing dead culms remain from the previous year.)
3. If necessary, spray regrowth again in late summer or early fall when growth is about 1 foot tall.
4. Monitor results the following year and repeat the process if necessary.

Chemical spraying of the cut surfaces after cutting plants back is not effective in controlling Chinese silvergrass. Actively growing green foliage needs to be present for good chemical control.

F.2.4 Japanese stiltgrass

The warm-season annual Japanese stiltgrass (*Microstegium vimineum*) has thoroughly invaded forest stands in the barrens area except where soils are highly acidic under oaks or alongside shrubs in the family Ericaceae—spotted wintergreen (*Chimaphila maculata*), trailing arbutus (*Epigaea repens*), teaberry (*Gaultheria procumbens*), black huckleberry (*Gaylussacia baccata*), mountain-laurel (*Kalmia latifolia*), pinxter-flower (*Rhododendron periclymenoides*), lowbush blueberry (*Vaccinium pallidum*), or deerberry (*V. stamineum*). It has also proliferated in the tree-removal area in Units 1 and 2, but monitoring has shown it to be steadily declining after an initial spike and it is expected to decline more rapidly after a combination of removal of the remaining canopy trees, prescribed fire, and the next prolonged drought.

Chemical control of stiltgrass is not appropriate at the Unionville Barrens because of the species' very large area of occupation and the danger of damage to non-target species, many of which are plant species of greatest conservation need (defined later and listed in Table F-2).

According to an experimental study[2] of nonchemical means of stiltgrass control, "Compared to untreated control plots, fall fire and mowing caused significant reductions in Japanese stiltgrass cover and biomass. Compared to controls, fall fires reduced Japanese stiltgrass cover by 79% and biomass by 90%, while mowing reduced cover by 70% and biomass by 95%. Spring fire significantly reduced Japanese stiltgrass cover but not its biomass ($P < 0.05$ for all variables)."[3]

If stiltgrass continues to sustain high cover in the grassland restoration area after the remaining tall trees are removed and after at least one growing season with a drought lasting long enough to cause high mortality of other invasives in the same area, then a trial of growing season fire should be tried. It is crucial to apply fire before the stiltgrass plants begin to ripen seed in fall. In planning for a late summer/early fall burning trial, an expert on serpentine barrens ecology and experimental design will need to be consulted to evaluate: (1) the level of stiltgrass abundance that should trigger a growing-season burn; (2) potentially extenuating circumstances involving plant species of greatest conservation need living within the burn units; and (3) how to set up the trials and monitoring in a way that will produce reliable, interpretable results.

F.3 Deer management

Tree seedlings of serpentine oak species are still not observed reaching sapling size anywhere in Unionville Barrens grasslands or forest stands, even though an organized yearly hunt has been conducted on the NLT-owned part of the barrens since 2010. Native shrubs are sparse or absent from most of the forest understory. In the grasslands, most of the characteristic serpentine shrub species are scarce or absent. Of one that is present, New Jersey tea (*Ceanothus americanus*), only two individuals are known. They have been seen flowering but deer nip off the branches before fruits can mature and produce seed. Many of the typical serpentine barrens low-growing shrubs, including running serviceberry (*Amelanchier stolonifera*), St. Andrew's-cross (*Hypericum stragulum*), and white meadowsweet (*Spiraea latifolia*), are absent. Pasture rose (*Rosa carolina*) is present in a few areas but may be protected from full eradication by its spines. Two serpentine barrens shrubs that are capable of growing tall enough to escape being killed by deer—dwarf chinkapin oak (*Quercus prinoides*) and winged sumac (*Rhus copallina*)—are present but quite scarce. All of the surviving dwarf chinkapin oaks—less than 10 are known, nearly all in Unit 5b—are tall adults with branches above deer-browsing height. The small stand in Unit 5a whose stems were accidently burned off has little chance of surviving by stump-sprouting unless it is protected by a well-maintained fence. Evidently no seedlings or stump sprouts survive their first winter, the season when deer-browsing pressure on native woody plants is most severe.

Comparing the 2015 plant species cover monitoring data from the six 5 × 5-m quadrats inside 3½-year-old deer exclosures with data from the adjacent unfenced quadrats shows a significant negative impact of deer on native herbaceous species as a group. The same result is shown for the subset of herbaceous natives that are characteristic serpentine grassland species, and for the two further-subdivided categories of characteristic serpentine forbs and graminoids (grasses, sedges and rushes). The graminoid result was not expected, since deer favor forbs during the growing season and graminoids usually constitute a minor part of their diet.

The next monitoring cycle is likely to show tree seedling and shrub recovery inside the exclosures but not outside. Deer-related differences in woody plant cover take longer to show up than in the herbaceous functional groups in part because of legacy effects. Prolonged exposure to deer populations in excess of ecological carrying capacity results in a shortage (or complete lack) of survivors of many native trees and shrubs. Without established root systems or nearby seed sources, measurable recovery does not occur inside fenced exclosures until chance events populate microsites suitable for germination and establishment with viable seeds. In the case of oaks, seedling establishment and survival to sapling stage requires not only nearby acorn sources of the right species but also an oak mast year followed by several years of growth exceeding the amount removed by browsing deer.

Lack of white-tailed deer population regulation by large predators is the principal cause of native tree and shrub regeneration failure in Pennsylvania and most of the East.[4] Not only do deer populations above ecological carrying capacity cause regeneration failure among native trees, loss of the native shrub layer, and impoverishment of species diversity among native herbaceous plants, but by selectively feeding on native species they indirectly increase the cover of nonnative invasive species. That in turn escalates the decline in native species cover and diversity through competition, and in some cases also through changes to soil conditions brought about by the nonnative plants and their associated soil microbes and nonnative invasive earthworms.

Many attempts have been made to restore native plant species diversity, tree regeneration, and the native shrub layer in areas where they have declined due to browsing pressure from record-high deer populations by relying on recreational hunters during regular hunting seasons. However, even where hunts are designed and controlled specifically to achieve biodiversity conservation objectives—for instance, by targeting only does—there is no quantitative evidence that full native plant species recovery has yet been brought about anywhere by recreational hunting alone.

Hunters operating within state regulations, which aim at the maximum sustained yield of deer hunting opportunity rather than ecological carrying capacity, are limited as a means of mimicking the extirpated large predators' roles in regulating deer populations. Short hunting seasons, limited hours, and the tendency to hunt not far from where the vehicle is parked contrasts with predation, which takes place year-round, any time of day or night, and anywhere prey may be found. Skill levels of hobbyist hunters are generally lower than those of large predators, with their scent-tracking abilities, sensitive hearing, and hunting skills honed by a lifetime of daily practice. Another crucial difference lies in predators' nonlethal effects on prey populations, termed by wildlife scientists the "ecology of fear"; in the presence of large predators deer have fewer offspring, partly because they spend less time feeding and more time hiding and possibly because chronically high cortisol (stress hormone) levels interfere with reproductive physiology. By contrast, on those few days each year when hunters are present deer have the option of simply moving to a neighboring property where hunters are not present.

Where the use of recreational hunting to achieve biodiversity conservation objectives has been associated with success, it is just one part of a larger toolkit that also includes periodically conducting a sharpshooter cull at baiting stations. In any case, providing recreational hunting opportunities is a prerequisite for receiving a permit from the Pennsylvania Game Commission to conduct deer culls. NLT is unsurpassed at organizing and managing yearly hunts on preserves and deploying skilled hunters who commit to a substantial level of hunting effort. But without either periodic sharpshooter culling over bait or a 12-foot-high gated deer fence around the entire site (as has been installed around 115 acres at the Tyler Arboretum, including a new fence to protect the Pink Hill serpentine barrens, and 100 acres at the Bowman's Hill Wildflower Preserve), desired conditions at the Unionville Barrens are unlikely ever to be achieved.

It is strongly recommended that NLT stewardship staff request proposals from deer depredation management professionals[5] and discuss with them what it will take in terms of culling effort, frequency, and cost to reduce and maintain the deer population at ecological carrying capacity at the Unionville Barrens. At the same time, costs and potential funding sources could be investigated for the alternative: enclosing the 114-acre Unionville Barrens management area in a state-of-the-art deer fence.

F.4 Prescription burning

F.4.1 Vary fire footprint and return interval in large grassland areas

The notion that there is an "ideal" fire return interval for a plant community is a fallacy if applied to the goal of biodiversity conservation. It may be true for forests devoted to production of timber products or for meadows dedicated to hay production but restoration of biodiversity requires a "shifting mosaic" of different disturbance histories, including variation among patches in both the frequency and severity of disturbance and different ages since the most recent disturbance. This is essential because the native plant and animal species all have different habitat needs, many of which are associated with different levels of natural disturbance severity and different stages of succession following disturbance.

In order to make sure that the return interval is varied among burn units it will be necessary to use new and different firebreaks from time to time in large, contiguous areas of grassland, to make sure that some areas are burned more often and some less often than the site-wide average. Some of the management unit boundaries will become obsolete in any case as the desired condition of site-wide grassland acreage is approached. The 45-50 acres of future serpentine grassland will need to have ever-changing firebreak patterns to achieve the objective of having different burn footprints with different areas of overlap among years. New, temporary firebreak segments can be mowed and raked as needed. The only constraint on firebreak location within a large, contiguous area of grassland is the need to keep firebreaks from crossing stands of plant species of greatest conservation, where the risk to individuals posed by soil compaction or possible uprooting by heavy machinery is a life-or-death concern.

F.4.2 Experiment with late summer/ early fall burning

Trials of late summer/early fall fire are recommended in parts of grassland *restoration* areas after tree removal if Japanese stiltgrass cover remains high through at least one moderate- to high-severity drought (see F.2.4, pp. 10-11). Growing-season fire should also be considered as an occasional alternative treatment for grassland *maintenance*. The fire regime over the last several thousand years would not have been restricted to early spring.

As noted above, prescribed fire for biodiversity conservation needs to vary from patch to patch across the landscape, as it would have done all during the evolutionary history of fire-maintained ecosystems, in order to accommodate the widely divergent habitat needs of all their component plant, animal and other species. Some spring-flowering forbs and cool-season (C_3) grasses, for instance, may benefit from, or even be dependent on, occasional growing-season fires or other disturbances to persist in a community dominated by warm-season (C_4) grasses. Of the 32 plants on the current list of plant species of greatest conservation need at the Unionville Barrens (Table F-2), 3 are warm-season grasses, 3 are cool-season grasses, 5 are sedges (which are also C_3/cool-season), 14 are forbs, and 7 are trees or shrubs.

Because no research has ever been published comparing the results of early spring fire and growing-season fire on the floras of temperate eastern North American serpentine barrens, trials done in an adaptive management context and the subsequent monitoring protocols warrant especially careful design and execution to make sure the results are reliable, interpretable, and generalizable to other sites. For instance, at least two replicates, preferably three, of each treatment are essential and the two treatments—early spring fire and growing-season fire—need to be interspersed on the landscape to ensure that the results can be attributed to treatment effects and not to uncontrolled factors associated with particular areas within the site.

F.5 Soil organic matter reduction

Research at the Nottingham Barrens demonstrated that the desired effects of severe fire during severe drought, which include soil organic matter reduction and mortality of greenbrier rhizomes and part of the soil seedbank, can be simulated in part by mechanical soil organic matter removal with offsite disposal. Outstandingly positive results at several other Northern Piedmont serpentine barrens make this the method of choice where repeated burning fails to produce desired conditions within a reasonable period in a localized area, or where fire-tolerant species such as common greenbrier form monospecific stands and respond to fire by vigorous regrowth. Cost and other constraints, such as difficult terrain for access by large machinery, make this a method only to be applied judiciously in limited areas.

It is essential that this method be applied only in patches where serpentine grassland plants are not present. The heavy machinery needs to stay away from stands of the highest-priority species of greatest conservation need, which are those whose populations at the Unionville Barrens are dangerously low. The method is appropriate in areas of near-total cover by autumn-olive or common greenbrier with few or no grassland species in the understory and no plant species of greatest conservation need.

The method employs a front-end loader or a backhoe for lifting the uppermost layer of soil and a dump truck to haul it away (Fig. F-4). Care needs to be taken to remove only the top few inches of the soil layer—the O and A horizons, which are

Figure F-4 (above and right). Soil organic matter reduction in a dense stand of common greenbrier at a serpentine barren, using a backhoe and dump truck.

generally black or dark brown in color. The B horizon, which is either light green, orange or light brown in serpentine soils, should be left intact as much as is feasible.

One high-priority site for this treatment is a quarter-acre stand of common greenbrier near the center of Unit 2a, adjacent to the large remnant (extant in2010) grassland in that unit along its northwest side. All nearby stands of the highest-priority species of greatest conservation need (first tier in Table F-2) need to be marked temporarily with stakes and caution tape during the soil organic matter reduction process to prevent accidental mortality in the highest-priority plant species of greatest conservation need (first tier in Table F-2), which have declined to critically low populations at the Unionville Barrens. Such stands need to be marked both around the excavation area perimeter and along the entire length of all access routes to be used by the heavy machinery across the grasslands from the road.

A disposal site needs to be identified for the removed soil organic matter. The material will consist of soil, roots and seeds, as well as stems of greenbrier or autumn-olive if they are not mowed, burned or cut beforehand. At other serpentine barrens where this procedure has been used, the material has been taken offsite and used immediately as clean fill or stockpiled and the organic component allowed to decompose.

F.6 Propagation and population augmentation

F.6.1 Population augmentation background

Population augmentation of species of conservation concern is one of three methods under the general heading of *translocation* (the others are species reintroduction and species introduction). Population augmentation is the placement of individuals into an environment where the species is currently known to occur. The goal of augmentation is to increase the population size and genetic diversity of a species with the intent of preventing probable local extirpation. It is used when the population of a plant species of greatest conservation need at a potential augmentation site is in decline due to habitat shrinkage or other causes, is in danger of extirpation, and is considered unlikely to recover without help.

The first step in augmentation is to gather seed from the target species only from within the augmentation site, raise plants in a greenhouse or nursery, and plant them in new locations at the site where habitat conditions are species-appropriate and likely to support establishment, taking care not to disturb individuals of any other species of conservation concern. Considerations in choosing planting sites include the species' habitat requirements and the likelihood of surrounding vegetation competitively interfering with the establishment and spread of the planted individuals.

In some cases a population targeted for augmentation is so small and depleted of genetic diversity that it is necessary to import seed from one or more nearby, ecologically similar sites that host larger populations of the species, if there is to be any hope of success. Small populations can suffer from inbreeding depression, in which deleterious versions of genes accumulate and their expression eventually debilitates such a high proportion of individuals that the entire population can die out. Even where inbreeding depression is not an issue genetic impoverishment also reduces small populations' evolutionary potential to deal with new conditions, such as climate change and newly introduced predators and pathogens. Introducing new "blood" from nearby populations can rescue a small population from these potentially lethal effects.

F.6.2 Species reintroduction

Species reintroduction is the placement of individuals into an environment where the species is currently absent but was known to occur historically. At least eight endangered, threatened or near-threatened plant species have died out since they were documented at the Unionville Barrens a century or more ago: colic-root (*Aletris farinosa*), stiff tick-trefoil (*Desmodium obtusum*), forked rush (*Juncus dichotomus*), downy lobelia (*Lobelia puberula*) and whip nut-rush (*Scleria triglomerata*)—all endangered; white heath aster (*Symphyotrichum ericoides* ssp. *ericoides*)—threatened; slender three-awn (*Aristida longespica* var. *longespica*) and slender crabgrass (*Digitaria filiformis*)—special indigenous populations meriting special conservation effort. The sequence of events leading to their loss was most likely triggered by habitat shrinkage.

Species reintroduction is something to be considered in the 2021–2025 Unionville Barrens stewardship plan update.

F.6.3 Species introduction

Species introduction is the placement of individuals into an environment where the species is currently absent and not known to have occurred historically. It is generally reserved for species in danger of regional extirpation or global extinction. Candidates for eventual introduction at the Unionville Barrens might include critically endangered species such as the federally listed sandplain gerardia (*Agalinis acuta*), one population of which occurs at the Soldiers Delight serpentine barrens in Maryland, and the globally endangered Reed's ptychostomum (*Ptychostomum reedii*), a moss whose known global distribution is limited to three serpentine barrens in Maryland and Pennsylvania. Other possibilities for introduction are state-endangered species whose historical occurrence has been greatly curtailed due to habitat loss—in this case, attrition of serpentine barrens; examples include thyme-leaf pinweed (*Lechea minor*), bulbous woodrush (*Luzula bulbosa*), prairie dropseed (*Sporobolus heterolepis*) and pink fuzzy-bean (*Strophostyles umbellata*). Species introduction should be attempted only with the greatest caution and after a team of qualified scientists weighs all relevant evidence about the ecological ramifications, including potential risks to donor populations and recipient sites. This is a new and little-tested practice in the ecological restoration toolkit. With fast-growing urgency to develop methods of biodiversity conservation to deal with the threats raised by climate change and continued habitat loss, the uncertainties about methods and risks of species introduction will need to be resolved through the adaptive management process. Formal scientific research is too slow and expensive to keep up with the need. This fact places a momentous responsibility on the agencies and organizations such as NLT who have stewardship of imperiled species and their habitats.

F.6.4 Population augmentation plan

At the Unionville Barrens for the 2016–2020 period translocation should be limited to population augmentation. The next and all later plan updates should also consider trials of species reintroduction or introduction for a small group of carefully selected plants.

The Pennsylvania Department of Conservation and Natural Resources (DCNR) is refining its translocation policy and rules for plant species of conservation concern. A draft[6] includes these provisions, which NLT and partner organizations engaged in this activity are required by state policy to follow:

> *Plants or propagules from wild populations of any species tracked by the Pennsylvania Natural Heritage Program (classified as*

endangered, threatened, rare, a "special population" or tentatively believed to be declining or imperiled and under study) should be collected only with permission and advice from the Pennsylvania Department of Conservation and Natural Resources (DCNR), Bureau of Forestry, Wild Plant Program. Before collecting material of a state-listed plant species, the applicant must obtain a Wild Plant Management Permit.

Protocols should be developed for long-term monitoring, and if necessary, management of the translocated plants. Costs for the management and monitoring programs should be determined and a funding source identified. Donor populations should also receive an ecological check-up to ensure that the translocation had no negative effects. Results from the monitoring should be made available to a relevant conservation agency (e.g., DCNR if the translocation involves a state-listed species) so that they can inform future translocation proposals.

A detailed plan should be presented to qualified biologists for additional recommendations and approval. Translocation proposals involving state-listed species should be presented to the Pennsylvania Natural Heritage Program and Pennsylvania Department of Conservation and Natural Resources, Bureau of Forestry, Wild Plant Program.

Partner propagators such as the Mt. Cuba Center (Hockessin, Delaware), North Creek Nurseries, Inc. (Landenberg, Chester County), Octoraro Native Plant Nursery (Kirkwood, Lancaster County), or others might be recruited in exchange for keeping part of the plants raised from the collected seed for their own use. Seed-collecting and planting are ideal tasks for Force of Nature volunteers, so long as they are supervised throughout both activities by someone who knows all of the plant species of greatest conservation need (PSGCN) on sight (Table F-2) and the locations of every known stand of all of the highest-priority PSGCN (Table F-2, first tier). This is essential in order to avoid inadvertently killing any individuals of species with critically low population numbers and to minimize competitive interference between naturally occurring and planted individuals of PSGCN.

Numbers of seeds collected of species targeted for augmentation should be based on how many plants NLT's partners are willing to propagate of each species and estimated seed viability rates. There is no way to be sure of viability rates ahead of time—they depend on many factors that vary from place to place, from year to year, and from species to species—but professional propagators may be able to make educated guesses for at least some of the species based on their experience with near relatives or the propagation literature. Theoretically the minimum number of seeds needed from a given species is the number a propagator is willing to raise divided by the expected percent viability times 100. So for example if a propagator were willing to raise 80 dwarf chinkapin oaks (40 for in-house use and 40 for planting back into the barrens) and their estimated viability rate were 65%, then the minimum number of seeds to collect would be 80 divided by 65 times 100, which equals 123.

Because of uncertainty in any prediction of viability rates, target quantities for seed collection may be set somewhat higher than calculated estimates. Partners should be urged to keep records of actual viability rates of each species they propagate, so that future seed collection can be based on more accurate calculation of target quantities.

Candidate species for population augmentation are best prioritized based on estimated numbers of individuals present (see Table F-2). For the first few years of population augmentation trials, only the highest-priority PSGCN (Table F-2, first tier) should be subjects of augmentation, and those with the fewest numbers of individuals living in the barrens should be given highest priority.

For now, planting needs to be strictly limited to grassland restoration areas, avoiding any remnant grasslands that

Table F-2. **Plant species of greatest conservation need at the Unionville Barrens**. They are divided into three groups with different levels of priority: 1—*highest-priority plant species of greatest conservation need* are those at greatest risk of extirpation from the site; 2—*other plant species of greatest conservation need* are those at lower risk of extirpation but that nevertheless are at risk of adverse effects of low numbers and isolation from other populations; 3—*plant species of potential conservation need* are those for which there is still a relatively high level of uncertainty about their correct identification at the Unionville Barrens and further investigation is needed to confirm whether they are present.

plant taxon	common name	PABS status	estimated total abundance	stands georef-erenced to date	location & other comments	seed-collecting season for 1st-tier species
1ST TIER—HIGHEST-PRIORITY PLANT SPECIES OF GREATEST CONSERVATION NEED AT UNIONVILLE BARRENS						
Andropogon gyrans	Elliott's beardstem	PR	10-100	2	3 stands known so far. Additional stand to be georeferenced.	October
Aristolochia serpentaria	Virginia snakeroot		10-50	0	Food plant for rare insects. Scattered in Unit 5 forest & woodland.	late May
Baptisia tinctoria	horsefly weed		50-100	1	Food plant for rare insects. 1 small stand known so far, in Unit 5 grassland.	August
Bouteloua curtipendula	side-oats grama	PT	> 5,000	3	Additional stands were planted in Units 1 & 2a from seed collected in Unit 6a. To be georeferenced	September
Carex bicknellii	Bicknell's sedge	PE	< 20	1	2 stands known so far in Units 1 & 4 grassland. Additional stand to be georeferenced.	May–June
Carex richardsonii	Richardson's sedge	PE	10-100	1	2 stands known so far in grassland. Additional stand to be georeferenced.	May–June
Carex striatula	lined sedge	SP	?	0	1 stand known so far, in marsh in Unit 1. To be georeferenced.	May–June
Ceanothus americanus	New Jersey tea	SP	< 10	1	2 stands known so far close together in woodland on border of Units 2a & 4. Additional stand to be georeferenced.	summer
Dichanthelium oligosanthes	Heller's rosette grass	PT	100-1,000	0	Occurs in several patches in grassland.	spring & again in fall

Table continues on next page.

plant taxon	common name	PABS status	estimated total abundance	stands georef-erenced to date	location & other comments	seed-collecting season for 1st-tier species
Dichanthelium villosissimum	long-haired panic-grass	PE	?	0	Occurs or occurred in grassland. Not seen in recent years.	spring & again in fall
Helianthemum bicknellii	Bicknell's hoary rockrose	PE	10-100	2	3 stands known so far, in grassland. Additional stand to be georeferenced.	late June–early July
Phemeranthus teretifolius	round-leaf fameflower	PT	50-1,000	0	Occurs in several patches in gravel-forb community.	July
Pinus echinata	shortleaf pine	PT	1	0	1 individual known, in Unit 3 forest. To be georeferenced.	November–January
Prenanthes serpentaria	lion's-foot	PT	< 10	0	1 location known so far, in Unit 7 forest. To be georeferenced.	September–early October
Quercus prinoides	dwarf chinkapin oak		< 10	0	Mainly in Unit 5 in forest & in Unit 6b around grassland edge. Each individual to be georeferenced.	late August–early September
2ND TIER—OTHER PLANT SPECIES OF GREATEST CONSERVATION NEED AT UNIONVILLE BARRENS						
Ageratina aromatica	small-leaf white-snakeroot	PR	> 10,000		In many patches in grassland & along forest edges.	
Aristida purpurascens	arrow-feather three-awn	PT	> 5,000		Scattered throughout grassland.	
Asclepias verticillata	whorled milkweed	PT	500-5,000		Scattered throughout grassland.	
Cerastium velutinum var. *velutinum*	barrens chickweed	SP	> 10,000		Scattered throughout grassland.	
Deschampsia cespitosa	tufted hairgrass	PT	1,000-5,000		At seeps & other wet spots.	
Fimbristylis annua	annual fimbry	PT	1,000-5,000		In several patches in grassland & gravel-forb community. Seen aboveground only in some years.	

Table continues on next page.

plant taxon	common name	PABS status	estimated total abundance	stands georef-erenced to date	location & other comments	seed-collecting season for 1st-tier species
Minuartia michauxii	rock sandwort	SP	> 10,000		In several patches in grassland & gravel-forb community.	
Packera anonyma	Small's ragwort	SP	> 10,000		Scattered throughout grassland.	
Phlox subulata var. *subulata*	moss phlox		500-5,000		Foodplant for rare insects. Scattered throughout grassland.	
Quercus ×bushii (Q. marilandica × velutina)	Bush's oak		500–1,000		Identification needs to be confirmed (see *Q. marilandica*, below). Common in & around edges of most grasslands.	
Quercus ×faxonii (Q. alba × prinoides)	Faxon oak		< 10		Identification needs to be confirmed. 2 or 3 individuals known, in forest.	
Quercus stellata	post oak		500–1,000		Scattered in & around edges of most grasslands.	
Scleria pauciflora	few-flowered nut-rush	PT	5,000-10,000		Scattered throughout grassland.	
Symphyotrichum depauperatum	serpentine aster	PT	> 10,000		Scattered throughout grassland.	
Tipularia discolor	crippled cranefly	PR	10-100	4	Scattered sparsely throughout forest. More stands to be georeferenced.	
3RD TIER—PLANT SPECIES OF POTENTIAL CONSERVATION NEED AT UNIONVILLE BARRENS						
Quercus marilandica	blackjack oak		?		What is called *Quercus ×bushii* in this document has been identified by others as *Q. marilandica.* Identification to be confirmed.	
Sisyrinchium montanum var. *crebrum*	blue-eyed-grass	WATCH	?		Identification to be confirmed. Location unknown, but somewhere in Units 1, 2 or 5 grassland.	

were extant in 2010. Care should be taken to avoid planting closer than 10 feet from any individual of a plant species of greatest conservation need (Table F-2). Future translocation plantings of certain species may need to take place in mature remnant grasslands, but those decisions will be made only after due consideration by a team of qualified scientists based on all available evidence about individual species' needs and the risks to intact remnant grassland communities.

Planted seedlings of the two woody highest-priority PSGCN—shortleaf pine and dwarf chinkapin oak—will need to be protected by temporary shelters until they grow tall enough to escape deer browsing. Because shortleaf pine is likely to grow to heights of 30 to 50 feet or more in serpentine soils, it should be planted only along the northern edges of tree-removal areas to avoid shading other serpentine grassland species, most of which are shade-intolerant. Shortleaf pine lives at one other serpentine barren, Burks Mountain (Georgia), but it is uncertain what ecological role it might play if it were to be propagated into tree-removal areas at the Unionville Barrens. Pitch pine (*Pinus rigida*) is a member of the serpentine savanna, serpentine woodland, and serpentine forest communities at three barrens—Nottingham Barrens and Goat Hill in Pennsylvania and Buck Creek Barrens in North Carolina. It is highly fire tolerant and has a sparse canopy that allows enough light to penetrate that serpentine grassland plants often have continuous cover beneath it. Virginia pine (*P. virginiana*) is the most common pine on serpentine barrens, but it is not fire tolerant, its foliage casts dense shade, and it has been seen to destroy serpentine grasslands much as autumn-olive has done in parts of the Unionville Barrens. Because shortleaf pine is similar to pitch pine, including having many of the same fire tolerance traits[7], it is expected to be a "good citizen" in serpentine savannas and woodlands. If successful, restoration of a viable population of this Pennsylvania-threatened tree species at the northern limit of its range will enhance the uniqueness of the Unionville Barrens.

F.7 Vigilance toward plant species of greatest conservation need

It is vital to have a participant present and active during every major stewardship activity in the barrens, including prescribed burning, who knows all of the plant species of greatest conservation need (PSGCN) on sight (Table F-2) and the locations of every known stand of all of the highest-priority PSGCN (Table F-2, first tier). The Unionville Barrens populations of the 15 highest-priority PSGCN are patients in critical condition in need of intensive care. The possibility of accidentally killing a single individual of any of these populations is a matter of serious concern. The small numbers pose a grave risk to their continued existence. Population shrinkage, at the Unionville Barrens due to habitat loss as the grassland area drastically decreased during the twentieth century, results in a genetic bottleneck. Loss of genetic diversity erodes a population's evolutionary potential to survive new onslaughts like climate change and newly introduced predators and pathogens. It also often leads to inbreeding depression, which by itself can lead to extirpation. At least eight endangered, threatened or near-threatened plant species already have died out since they were documented at the Unionville Barrens in the early twentieth century (listed in section F.6 above, under species reintroduction). When a population reaches critically low numbers, each individual's importance to the survival of all becomes very high.

One of the key responsibilities of a worker who knows all of the PSGCN on sight is to continue the task of georeferencing locations of all individuals and stands of highest-priority PSGCN. However, recording GPS coordinates is not enough to assure these plants' safety. It is also vital to put in place procedures and safeguards to avoid soil disturbance and damage to aboveground plant parts by trampling or heavy equipment during stewardship activities conducted in the growing season. Such safeguards could include rerouting customary vehicular travel lanes; for instance, a newly discovered stand of the endangered Bicknell's sedge lies in the middle of such a travel lane in Unit 1. Disturbances that do not involve heavy soil disturbance or compaction, including fire, are harmless and in fact necessary for the persistence of most of the PSGCN. Soil disturbance in itself is generally beneficial to the serpentine grassland community, providing microhabitats for some species and enhancing native species diversity, but the risk it poses to the populations in critically low numbers makes it urgent to divert soil disturbance away from the small remaining stands of those species.

All available knowledgeable individuals should be recruited to search regularly for additional occurrences of the PSGCN (Table F-2), including members of the Philadelphia Botanical Club, botanically knowledgeable people affiliated with NLT, consultants and NLT staff. All newly discovered stands of PSGCN whose populations are critically low need to be georeferenced and stewardship staff need to have thorough familiarity with their locations so soil disturbance can be avoided at those sites.

Table F-3. **Butterfly and moth (Lepidoptera) species of conservation concern documented as present in the Unionville Barrens** in 13 survey days from 11 May to 26 October 2012 by Sam Smith.[8] Those listed in the *Pennsylvania Wildlife Action Plan, 2015-2025*[9] as species of greatest conservation need are marked by asterisks. The others are tracked and under study by the Pennsylvania Natural Heritage Program as species likely to be of conservation concern in Pennsylvania.[8]

common name	species	larval food plants present at Unionville Barrens
BUTTERFLIES		
pipevine swallowtail	*Battus philenor*	Virginia snakeroot (*Aristolochia virginiana*)
juniper hairstreak*	*Callophrys gryneus*	eastern red-cedar (*Juniperus virginiana*)
cobweb skipper*	*Hesperia metea*	sorghum tribe grasses (*Andropogon, Schizachyrium, Sorghastrum*)
MOTHS		
funerary dagger	*Acronicta funeralis*	several trees and shrubs (*Malus, Ulmus, Acer*)
dot-lined white	*Artace cribrarius*	oaks (*Quercus*), cherries (*Prunus*)
straight-lined mallow moth*	*Bagisara rectifascia*	mallow family (Malvaceae)—None known to be present in barrens; moth captured in survey was most likely transient.
graceful underwing	*Catocala gracilis*	lowbush blueberry (*Vaccinium pallidum*)
Packard's lichen moth	*Cithene packardii*	lichens
regal moth	*Citheronia regalis*	pignut hickory (*Carya glabra*)
ash sphinx moth*	*Manduca jasminearum*	white ash (*Fraxinus americana*)
Newman's brocade	*Meropleon ambifusca*	sedges? (Cyperaceae)

*Designated as species of greatest conservation need in *Pennsylvania Wildlife Action Plan, 2015-2025*[9]

The same knowledgeable individuals should be recruited to search for occurrences of additional plant species of conservation concern, including those that are known to have occurred at the Unionville Barrens in years past (listed in Section F.6.2, above). Any such species will be present as critically low populations or they would have been found by now. As such they will need to be georeferenced and treated with caution during stewardship activities.

One of those "lost" species, lion's-foot (*Prenanthes serpentaria*) was relocated at the site in 2014 by William Ryan, the first time it has been documented at the Unionville Barrens since 1908. In 2015 about 10 plants were present in a stand in the forest in Unit 7, which is not yet under NLT stewardship. They were not seen to flower, probably because they are in dense shade. Removing one or two overtopping trees (in winter to minimize soil disturbance) or simply girdling them may allow the lion's-foot plants to flower and fruit, at which time seeds could be collected and plugs established in a greenhouse to be planted in multiple locations in oak forest stands across the site, greatly increasing the population's likelihood of persistence.

Another key responsibility of a worker who knows all of the PSGCN is to conduct regular counts of all individuals of each highest-priority PSGCN. This is a crucial part of each 3 to 5-year ecological monitoring cycle but because the highest-priority PSGCN are critically imperiled at the site, they need to be monitored at least once in every growing season, and preferably multiple times, so any emerging problems can be addressed quickly enough for managers to have a fighting chance of success in averting a crisis.

F.8 Ecological monitoring

F.8.1 Cyclic monitoring of quantitative desired conditions metrics

Evidence-based stewardship involves continuing to monitor all indicators at the recommended frequencies (Table F-8), analyzing the data, and developing stewardship plan updates at no less than five-year intervals based on the results. As soon as is feasible, baseline data needs to be collected on indicators for which monitoring has not yet been started. The highest priorities are to:

- georeference wetlands, including serpentine wetlands, marshes, spring seeps, and intermittent streams;
- establish permanent quadrats in at least three of the largest serpentine wetlands dominated by tufted hairgrass (*Deschampsia cespitosa*) in order to track wetland desired conditions indicators (Table F-8, items 14-16 and populations of all PSGCN, including tufted hairgrass);
- begin quantitative monitoring of selected grassland arthropod species of highest conservation need.

Arthropods, which include insects, arachnids (spiders, daddy-long-legs, mites, ticks), myriopods (centipedes, millipedes) and crustaceans (crayfish, scuds, pillbugs, water-fleas), are by far the most species-diverse group of non-bacterial organisms on Earth and, it is safe to assume, in the Unionville Barrens. They are also key links in the food web on which all other wildlife depend. The arthropod fauna at the Unionville Barrens is still poorly known. The only survey to date was restricted to butterflies and moths[9], but those are considered bellwether arthropods—good indicators of ecological quality and integrity and rapid responders to environmental change. Despite a general scarcity of knowledge of the conservation needs of arthropod species relative to our understanding of the status of most vertebrate and vascular plant species, the

Pennsylvania Wildlife Action Plan, 2015–2025[10] lists 334 arthropod species of greatest conservation need in the state (compared with 214 vertebrate species and 114 mollusk species).

Sam Smith's 2012 butterfly and moth survey showed the tremendous diversity of just that one subset of arthropods at the barrens. His finds included several species known to be of greatest conservation need in the state (Table F-3). However, he documented presence, not population status. Information on population trends of these endangered, threatened and near-threatened species is vital for keeping track of whether and to what degree stewardship activities are succeeding in restoring and maintaining ecosystem integrity and native biodiversity.

Periodic quantitative monitoring of selected Lepidoptera (butterfly and moth) species of greatest conservation need should be undertaken by partnering with entomologists at regional universities, museums and state agencies. Experts in the methods of insect population tracking can develop and carry out practical monitoring plans for these animals.

F.8.2 Summary of results from baseline surveys and first monitoring cycle

This section summarizes the massive data set collected in 2012 through 2015 to launch the Unionville Barrens adaptive management long-term monitoring program. More-detailed analyses of some of the data will follow later in 2016 after William Ryan and Abby Fullem have completed their wildlife ecology Ph.D. dissertation at the University of Delaware and soil science senior thesis at Haverford College, respectively, and those products have been developed into publications by them and their academic advisors.

Annual monitoring for four years has laid a strong foundation for the monitoring program going forward. Future monitoring will be conducted one year out of every three to five years, depending on the indicator, and will build on the infrastructure and efficient protocols developed over the first four years of data collection.

Here the focus is mainly on those results that are directly pertinent to the desired conditions metrics and target values (Table F-8). They are divided into three categories:

- remote sensing metrics;
- plant species cover metrics;
- breeding bird metrics.

F.8.2.1 Remote sensing metrics

Computation of outcomes indicators that are based on aerial imagery is still incomplete. It will be done by analyzing 2015 NAIP multispectral aerial imagery from the U.S. Department of Agriculture's National Agriculture Imagery Program (NAIP) and 2015 lidar data from the U.S. Geological Survey. Using the same methods, the 2010 baseline analysis that was done for the original plan (Map 4 in Latham and McGeehin 2012) using 2010 NAIP imagery and 2008 lidar data will be repeated and the 2010 and 2015 results compared. It is necessary to repeat the previous analysis at each monitoring interval because image analysis technology and software change rapidly and the beginning and end conditions for a given monitoring interval both need to be analyzed in exactly the same way for a valid assessment of the change between them.

Grassland connectivity, the inverse of fragmentation, is one of the most important metrics for evaluating the outcomes of treatments and tracking the progress of restoration and management activities at the Unionville Barrens. Connectivity analysis divides the grassland (including serpentine Indian-grass – little bluestem grassland, serpentine gravel-forb community, and serpentine seep) into four landscape categories:

- *core* or *prairie* (> 10 m from any trees)
- *perforated* or *savanna* (grassland with scattered trees > 10 m from forest edge)

- *edge* (≤ 10 m from forest)
- *patch* (isolated fragments ≤ 20 m wide)

The initial, baseline connectivity analysis of serpentine grassland (Figure F-5 and Table F-4) showed 4.2 acres in remnant grassland in 2010, with just over one-tenth of an acre in combined prairie and savanna. The goal for 2020 is to increase total grassland to at least 45 acres, including at least 31 acres in prairie and savanna (45 acres total with 31 acres of interior gives a connectivity index of 0.75, the low end of the "excellent" range; see Table F-8, item 3b).

F.8.2.2 Plant species cover metrics

The main objective of species cover monitoring is to compare the effects of various combinations of treatments on selected indicators, which consist of key functional groups of species as well as single species of special importance. Major treatments from 2012 to 2015 were a large-scale canopy removal by a contractor, several smaller-scale canopy removal workdays in forest and savanna, and two prescription fires.

The results reported here (Figures F-6 to F-20) are comparisons of four-year trends in the responses of key plant groups to specific combinations of treatments (see Table F-5 for acreages of treatment combinations by management unit). In all comparisons, the unit of replication is the management unit; in cases where there were multiple sampling quadrats within a management unit × treatment combination, they are treated statistically as subsamples.

One of the most important indicators for tracking management success and progress is percent cover of **native characteristic serpentine barrens herbaceous species**. The decline of this metric in in the Units 1 and 2 tree-removal area from 2014 to 2015 (Figure F-6) is unlikely to be a cause for alarm because it also occurred in most other grassland plots and was most pronounced in those with no treatment. Such fluctuations are to be expected with changes in weather and other uncontrolled variables. This is a demonstration of the crucial importance of monitoring adaptive management outcomes by collecting data on the same indicators in experimental controls (untreated units) and in treatment units (whenever feasible, control and treatment units should be replicated, and treatments inter-

Table F-4. **Statistics on baseline (2010) connectivity analysis of serpentine grassland**. Grassland extent was mapped from 2010 NAIP imagery and 2008 lidar data and classified using Landscape Fragmentation Tool version 2.0 (Center for Land Use Education and Research 2015).

grassland category	2010 acres	2010 m^2
core (**prairie**: > 10 m from any trees)	0.05	202
perforated (**savanna**: grassland with scattered trees > 10 m from forest edge)	0.07	283
grassland interior (sum of above)	0.12	485
edge (within 10 m of forest)	1.07	4,330
patch (isolated fragment with 0 interior)	3.01	12,200
grassland total (interior + edge + patch)	4.20	17,000
ratio of prairie to savanna	0.71	0.71
ratio of grassland interior to total	0.03	0.03
grassland connectivity index (GCI)*		0.04

* This grassland connectivity index (GCI) varies from 0 (entirely fragmented) to 1 (highest level of connectivity possible for the given total grassland area). It is based on a definition of "edge" as the grassland area within 10 m of forest.

$$GCI = \frac{G_{interior}}{G_{total} - 20\sqrt{G_{total}\pi} - 100\pi}$$

where $G_{interior}$ is the grassland interior area in m^2 and G_{total} is the grassland area total (interior + edge + patch) in m^2 (1 acre ≈ 4,047 m^2).

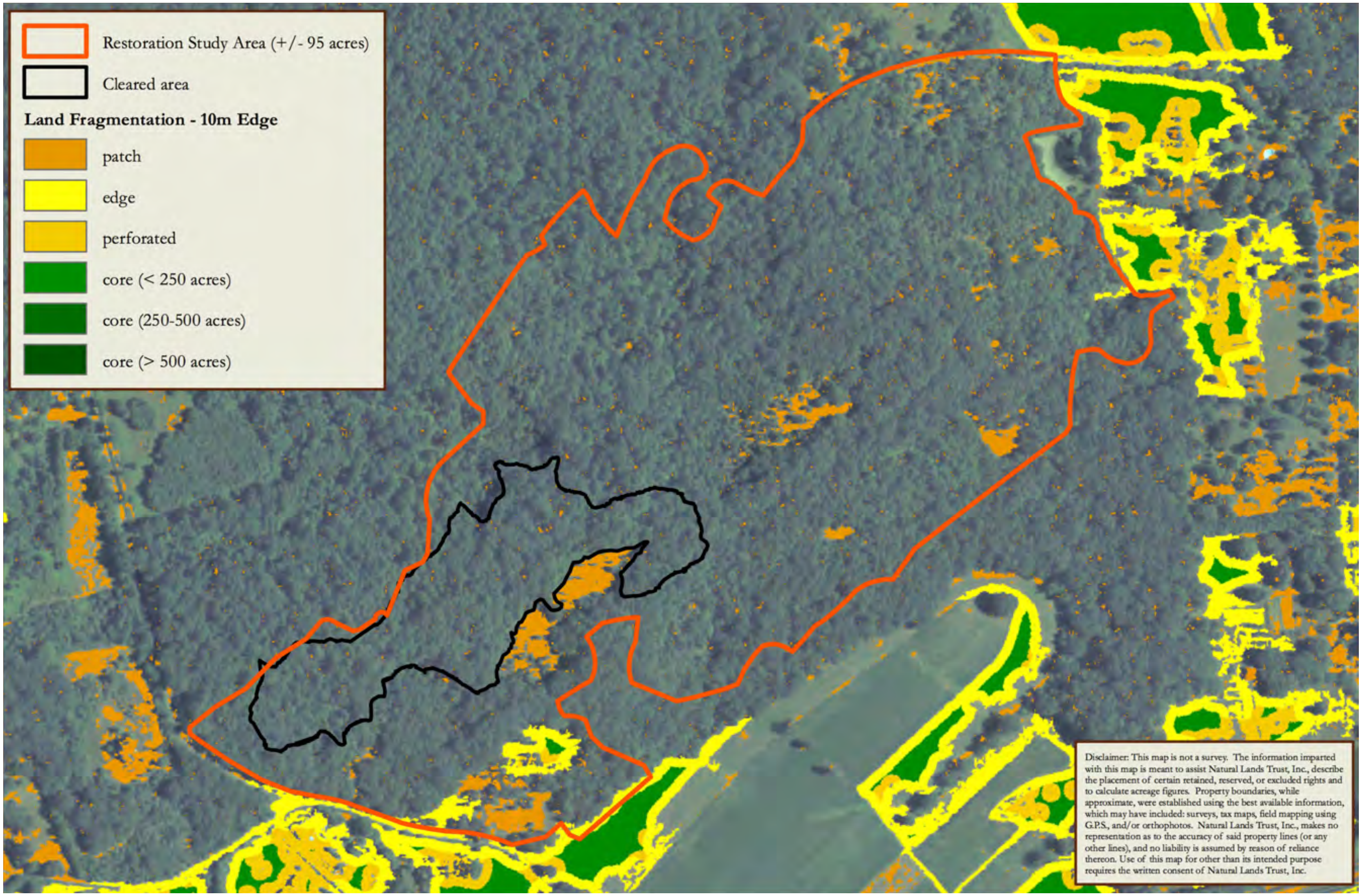


Figure F-5. **Baseline (2010) connectivity analysis of serpentine grassland**, using a 10-m “edge” buffer inside the edges of the “core” areas. “Patch” areas are all-edge. “Perforated” areas are savannas—grassland with scattered trees. “Core” areas are open prairie with no trees, consisting of grassland at least 10 m from the nearest tree. See Table F-4 for the acreage within each category.

Table F-5. **Grassland restoration treatment combinations in 2012–2015** by management unit and sampling intensity.

treatment combination	number of treatment replicates (management unit I.D. numbers in parentheses)	quadrats = number of subsamples across all replicates	treatment combination symbol in Figures F-6–F-20
forest with canopy removed 2012	2 (1,2)	4	**F CR12**
forest with canopy removed 2015, burned 2015	1 (4)	1	**F CR15B15**
all grasslands (includes all of those listed below)	5 (1–5)	7	**ALL G**
grassland with no treatment 2012–2015	2 (1,2)	2	**NT**
grassland burned 2015	1 (2)	2	**B15**
savanna with canopy removed 2014, burned 2015	1 (5)	2	**CR14B15**
savanna with canopy removed 2015, burned 2015	1 (4)	1	**CR15B15**

spersed on the landscape). That is the only way to separate the effects of management treatments from the effects of a myriad of other factors that are beyond managers' ability to control, including weather and soil differences. Note also that over all plots there was an even more consistent trend from 2012 to 2013 of increasing native characteristic serpentine barrens herbaceous species cover, which pre-dated all treatments except for the 2012 canopy removal in parts of Units 1 and 2.

Native characteristic serpentine barrens woody species include both desired savanna species (as long as they cover less than 25% of the savanna area) and desired serpentine woodland species that are not welcome in the savanna. At the Unionville Barrens the savanna group consists of New Jersey tea (*Ceanothus americanus*), black huckleberry (*Gaylussacia baccata*), Bush's oak (*Quercus ×bushii* or *Q. marilandica × velutina*), possibly blackjack oak (*Q. marilandica*), dwarf chinkapin oak (*Q. prinoides*), post oak (*Q. stellata*), shining sumac (*Rhus copallina*), pasture rose (*Rosa carolina*) and deerberry (*Vaccinium stamineum*). The

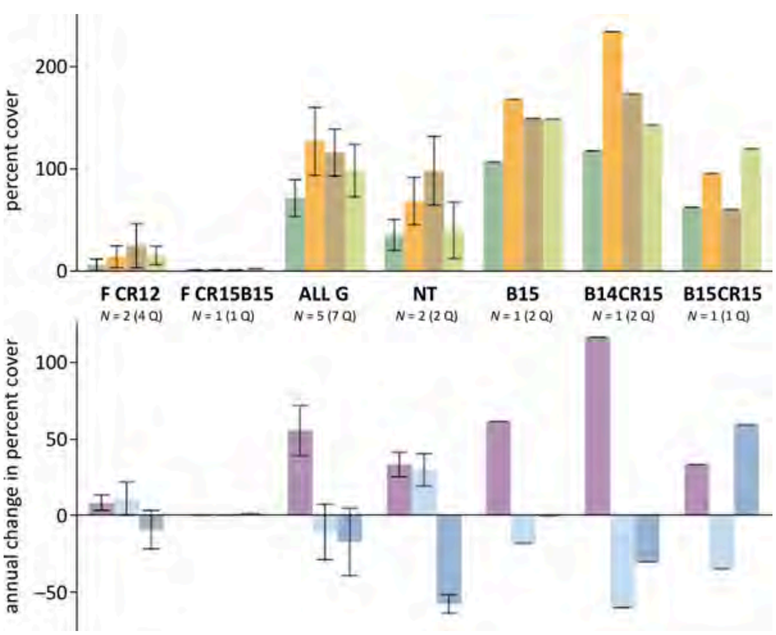


Figure F-6. **Trends in native characteristic serpentine barrens herbaceous species percent cover** by treatment combination (see Table 1 for meaning of symbols). Bars in the upper graph show percent cover in 2012, 2013, 2014 and 2015. Cover of multi-species groups can exceed 100% because of overlap of leaves among different species. Bars in the lower graph show annual percent change in cover 2012–2013, 2013–2014 and 2014–2015. Error bars for replicated data are ± 1 standard error.

woodland group includes all of those plus eastern red-cedar (*Juniperus virginiana*), shortleaf pine (*Pinus echinata*), bigtooth aspen (*Populus grandidentata*), catbrier (*Smilax glauca*) and common greenbrier (*S. rotundifolia*).

The only substantial trend in this functional group's cover is a steady increase from 2012 to 2015 in the 2012 tree removal area of Units 1 and 2 (Figure F-7). This trend is due mainly to a year-by-year increase in greenbrier cover, and secondarily to a similarly steady increase in the cover of pasture rose.

Desired conditions in serpentine grasslands include a balanced mix of forbs and graminoids consisting mainly of native characteristic serpentine barrens species. If one group begins to edge the other out over time, then adjustments to the management regime are called for.

At the Unionville Barrens the **native characteristic serpentine barrens forb species** consist of small-leaf white snakeroot (*Ageratina aromatica*), common ragweed (*Ambrosia artemisiifolia*), plantain-leaf pussytoe (*Antennaria plantaginifolia*), lyre-leaf rockcress (*Arabis lyrata*), whorled milkweed (*Asclepias verticillata*), green milkweed (*A. viridiflora*), ebony spleenwort (*Asplenium platyneuron*), barrens chickweed (*Cerastium velutinum* var. *velutinum*), swamp thistle (*Cirsium muticum*), Maryland tick-clover (*Desmodium marilandicum*), Bicknell's hoary rockrose (*Helianthemum bicknellii*), bluets (*Houstonia caerulea*), spotted St. John's-wort (*Hypericum punctatum*), slender bush-clover (*Lespedeza virginica*), spiked lobelia (*Lobelia spicata* var. *spicata*), rock sandwort (*Minuartia michauxii*), sundrops (*Oenothera fruticosa*), royal fern (*Osmunda regalis*), Small's ragwort (*Packera anonyma*), round-leaf fameflower (*Phemeranthus teretifolius*), moss phlox (*Phlox subulata* ssp. *subulata*), whorled milkwort (*Polygala verticillata*), slender knotweed (*Polygonum tenue*), dwarf cinquefoil (*Potentilla canadensis*), narrow-leaf mountain-mint (*Pycnanthemum tenuifolium*), rose-pink (*Sabatia angularis*), early saxifrage (*Saxifraga virginiensis*), few-flowered nutrush (*Scleria pauciflora*), needletip blue-eyed-grass (*Sisyrinchium mucronatum*), carrion-flower (*Smilax herbacea*), gray goldenrod (*Solidago nemoralis*), wrinkle-leaf goldenrod (*S. rugosa*), serpentine aster (*Symphyotrichum depauperatum*), calico aster (*S. lateriflorum*), heath aster (*S. pilosum*) and arrow-leaf violet (*Viola sagittata*).

The **native characteristic serpentine**

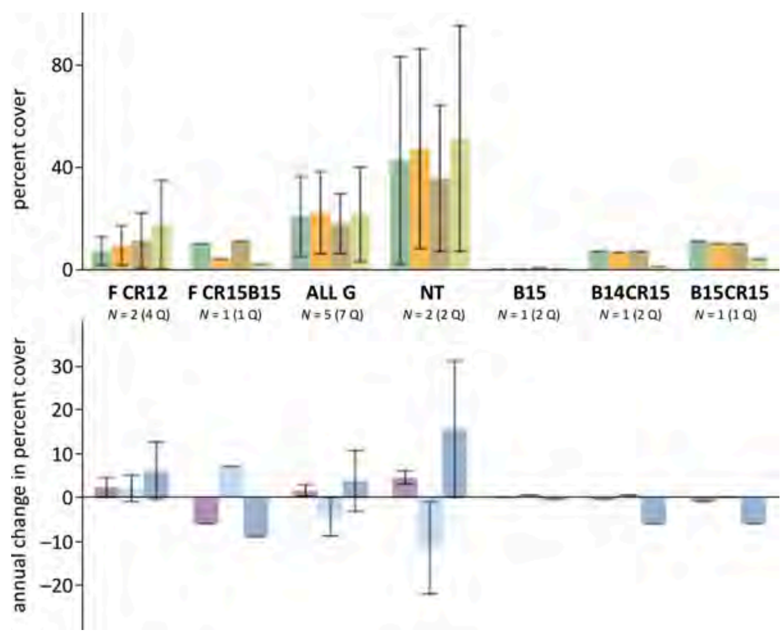


Figure F-7. **Trends in native characteristic serpentine barrens woody species percent cover** by treatment combination (see Table 1 for meaning of symbols). See the Figure 3 caption for meaning of bars and error bars in the two graphs.

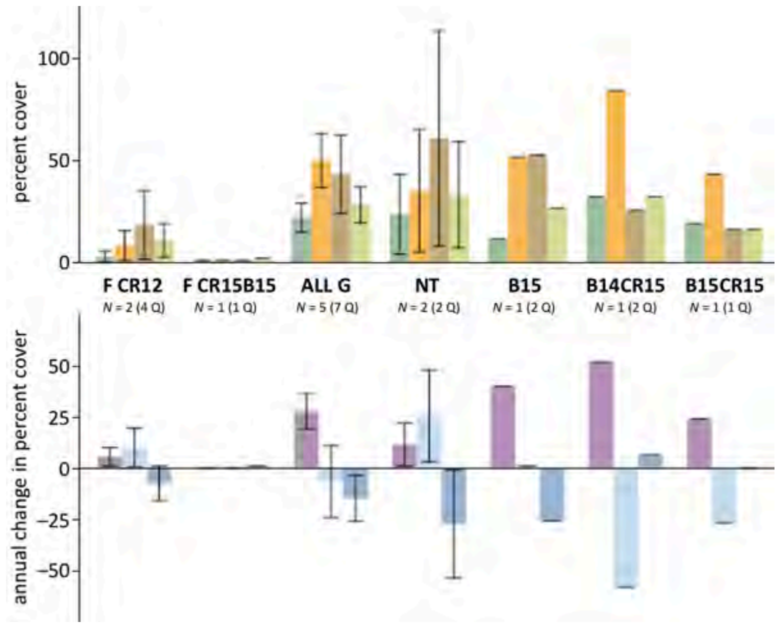


Figure F-8. **Trends in native characteristic serpentine barrens forb species percent cover** by treatment combination (see Table 1 for meaning of symbols). See the Figure 3 caption for meaning of bars and error bars in the two graphs.

barrens graminoid species at the Unionville Barrens fall into three groups: sedges—Bicknell's sedge (*Carex bicknellii*), blue sedge (*C. glaucodea*), fuzzy-wuzzy sedge (*C. hirsutella*), Richardson's sedge (*C. richardsonii*), slender spikerush (*Eleocharis tenuis*) and annual fimbry (*Fimbristylis annua*); rushes—lopsided rush (*Juncus secundus*), path rush (*J. tenuis* var. *tenuis*) and common woodrush (*Luzula multiflora*); and grasses—upland bentgrass (*Agrostis perennans*), big bluestem (*Andropogon gerardii*), church-mouse three-awn (*Aristida dichotoma*), slender three-awn (*A. longespica*), arrow-feather three-awn (*A. purpurascens*), side-oats grama (*Bouteloua curtipendula*), poverty oatgrass (*Danthonia spicata*), tufted hairgrass (*Deschampsia cespitosa*), tapered rosette grass (*Dichanthelium acuminatum*), deertongue (*D. clandestinum*), poverty panic-grass (*D. depauperatum*), cypress panic-grass (*D. dichotomum*), Heller's witchgrass (*D. oligosanthes*), round-seeded

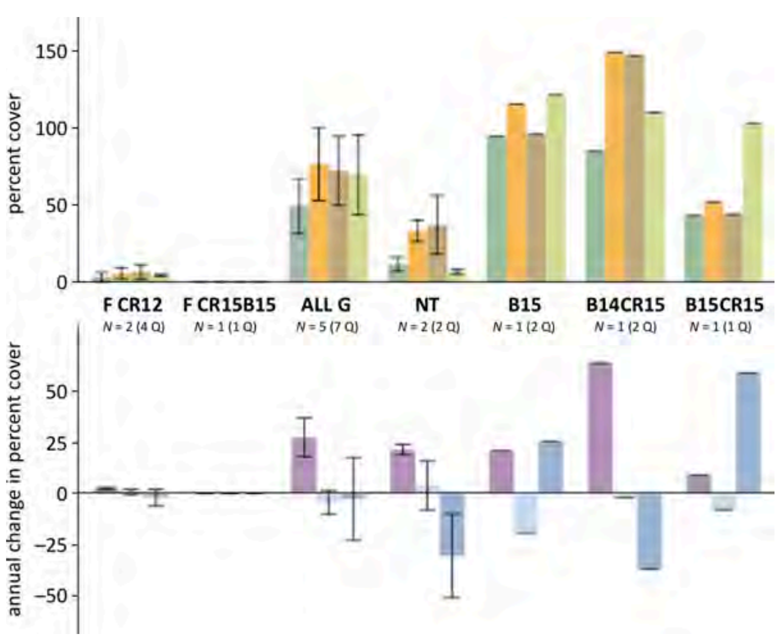
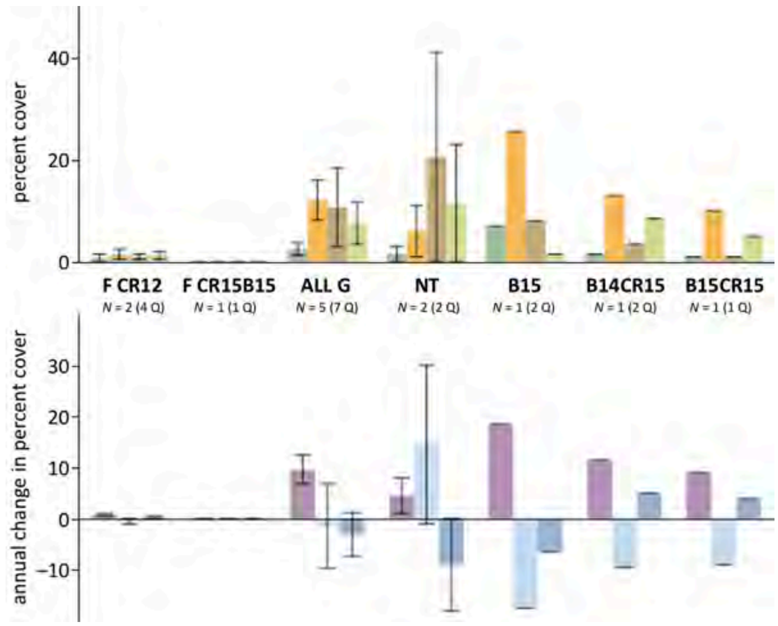


Figure F-9. **Trends in native characteristic serpentine barrens graminoid species percent cover** by treatment combination (see Table 1 for meaning of symbols). Cover of multi-species groups can exceed 100% because of overlap of leaves among different species. See the Figure 3 caption for meaning of bars and error bars in the two graphs.

Figure F-10. **Trends in native characteristic serpentine barrens annual and biennial species percent cover** by treatment combination (see Table 1 for meaning of symbols). See the Figure 3 caption for meaning of bars and error bars in the two graphs.



panic-grass (*D. sphaerocarpon*), long-haired panic-grass (*D. villosissimum*), purple lovegrass (*Eragrostis spectabilis*), Mexican muhly (*Muhlenbergia mexicana*), nimblewill (*M. schreberi*), fall panic-grass (*Panicum dichotomiflorum*), Philadelphia panic-grass (*P. philadelphicum*), little bluestem (*Schizachyrium scoparium* var. *scoparium*), knotroot foxtail (*Setaria parviflora*), Indian-grass (*Sorghastrum nutans*), prairie wedgegrass (*Sphenopholis obtusata* var. *obtusata*), poverty dropseed (*Sporobolus vaginiflorus*) and purpletop (*Tridens flavus*).

In intact grassland remnants, native characteristic serpentine barrens forb cover trends remained stable relative to untreated controls in the growing season following fire where there was no tree canopy thinning or removal, but they increased relative to controls with both fire and tree canopy removal. At the same time and in the same units, native characteristic serpentine barrens graminoid cover greatly increased relative to controls in the season following fire, with or without tree canopy thinning or removal, but matched controls with tree canopy removal alone (Figures F-8 and F-9). Because prescribed fires and tree canopy thinning/removal in intact remnant grasslands were conducted only in the last two years of the monitoring period, understanding of longer-term trends will need to wait for future monitoring cycles.

In the 12.4-acre grassland restoration area where trees were removed in 2012, cover of native characteristic serpentine barrens forbs and graminoids matched their trends in untreated intact grasslands. If the 2015 fire in the 2012 tree removal area affected native characteristic serpentine barrens forbs differently from graminoids, the difference was too subtle to be detected in the first season post-fire.

Short-lived (annual or biennial) plants are prominent in early grassland succession after severe disturbance. Desired high patch diversity of serpentine grassland includes maintaining multiple areas where these species are abundant at any given time, although the specific areas will change over time in a “shifting mosaic” of successional patches of varying ages since the most recent disturbance.

The native characteristic serpentine barrens annual and biennial species at the Unionville Barrens are the grasses church-mouse three-awn (*Aristida dichotoma*), slender three-awn (*A. longespica*), smooth panic-grass (*Panicum dichotomiflorum*), Philadelphia panic-grass (*P. philadelphicum*), poverty dropseed (*Sporobolus vaginiflorus*) and slender crabgrass

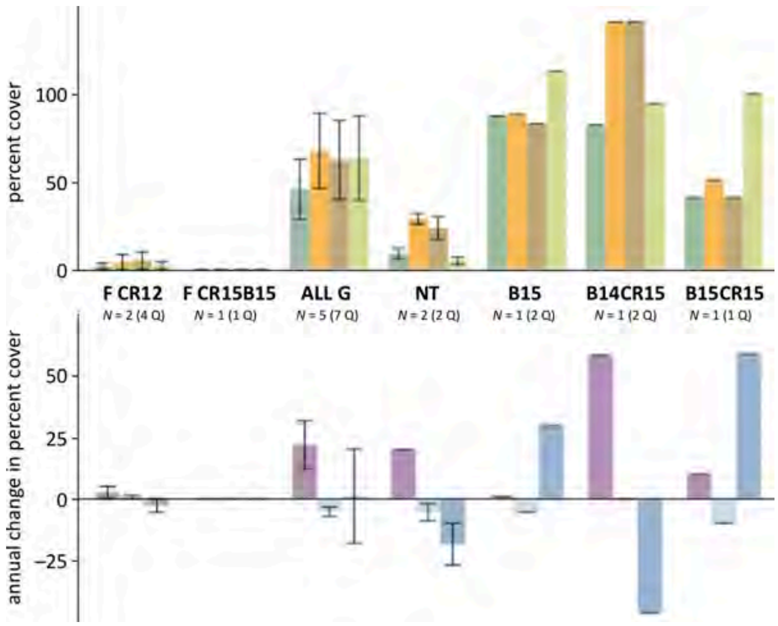


Figure F-11. **Trends in native warm-season (C_4) grass species percent cover** by treatment combination (see Table 1 for meaning of symbols). Cover of multi-species groups can exceed 100% because of overlap of leaves among different species. See the Figure 3 caption for meaning of bars and error bars in the two graphs.

(*Digitaria filiformis*), the sedge annual fimbry (*Fimbristylis annua*), and the forbs common ragweed (*Ambrosia artemisiifolia*), lyre-leaf rockcress (*Arabis lyrata*), swamp thistle (*Cirsium muticum*), rock sandwort (*Minuartia michauxii*), whorled milkwort (*Polygala verticillata*), slender knotweed (*Polygonum tenue*) and rose-pink (*Sabatia angularis*).

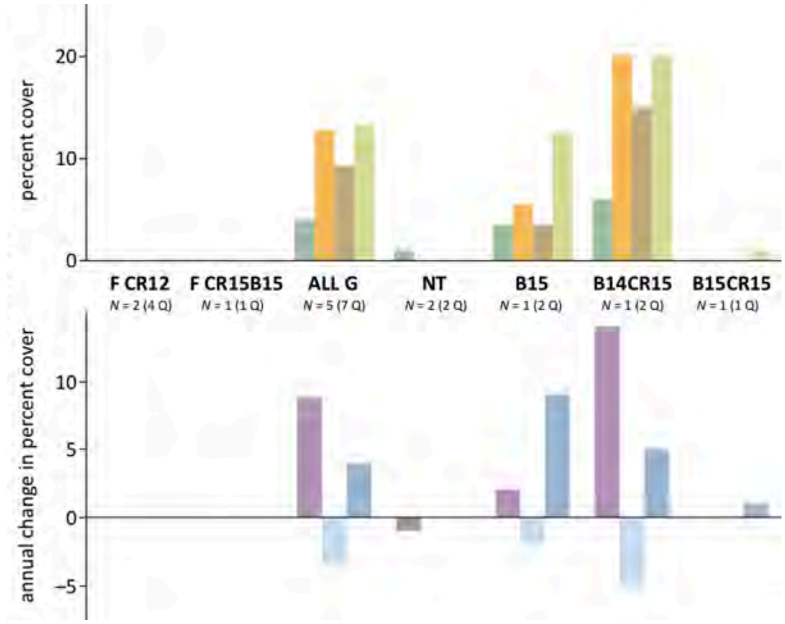
Native characteristic serpentine barrens annuals and biennials are key components of the serpentine gravel-forb community and most of them are among the first colonizers after fires that burn hot enough to reduce soil organic matter, or after mechanical soil disturbance that skims off a surface buildup of soil organic matter. Their lack of abundance in the first four years after the 2012 tree removal in Units 1 and 2 (Figure F-10) indicates that soil buildup during the invasion of forest trees since most of the area was occupied by grassland in the mid-twentieth century was substantial. The main initial colonizer—Japanese stiltgrass—is also an annual, but it has far lower tolerance of drought and serpentine soil chemical conditions than the native annuals and biennials characteristic of serpentine barrens.

In areas of mature remnant grassland where no treatments were conducted during the monitoring period (control plots), this group of plants increased in cover from 2013 to 2014 and decreased from 2014 to 2015 (Figure F-10). The cause is unknown, but may have been related to each year's particular sequence of wetter than average and dryer than average periods from early spring through the growing season. Short-lived plants invest relatively little in root structure and can be set back or killed, especially when newly germinated early in the season, by short periods of low soil moisture that have little or no effect on perennial species. What is more, they have long-lived seeds and relatively exacting germination requirements; when conditions are suboptimal early in the season, they are inclined to put off germinating until a later year.

Compared with controls, native characteristic serpentine barrens annual and biennial cover responded to treatments by remaining stable with burning alone but by increasing with both burning and tree canopy clearing (Figure F-10).

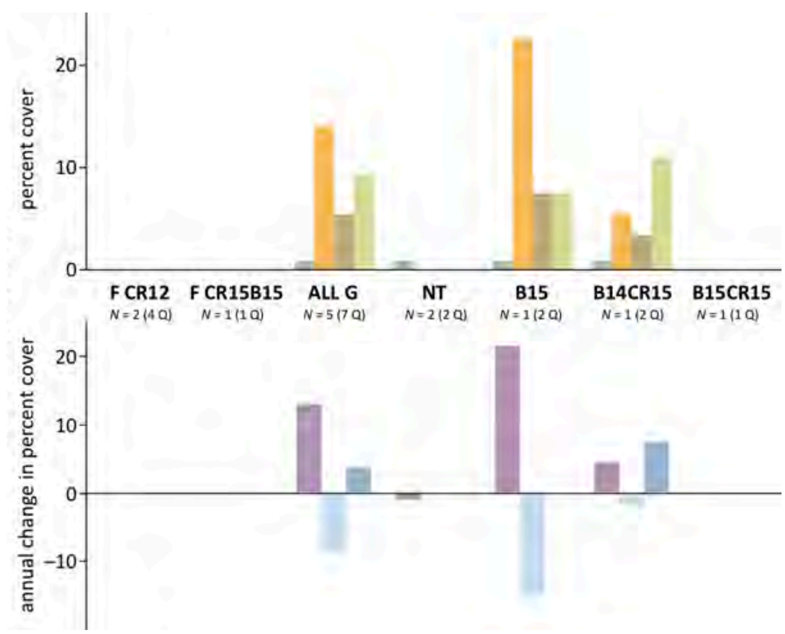
Native warm-season grasses—those with the C_4 photosynthetic pathway—are the mainstay of serpentine grasslands, typically constituting the majority of the species cover. At the Unionville Barrens the native warm-season grasses are the

Figure F-12. **Trends in serpentine aster (*Symphyotrichum depauperatum*) percent cover** by treatment combination (see Table 1 for meaning of symbols). See the Figure 3 caption for meaning of bars in the two graphs.



annuals church-mouse three-awn (*Aristida dichotoma*), slender three-awn (*A. longespica*), smooth panic-grass (*Panicum dichotomiflorum*), Philadelphia panic-grass (*P. philadelphicum*), poverty dropseed (*Sporobolus vaginiflorus*) and slender crabgrass (*Digitaria filiformis*), and the perennials big bluestem (*Andropogon gerardii*), Elliott's beardgrass (*A. gyrans*), broomsedge (*A. virginicus*), arrow-feather three-awn (*Aristida purpurascens*), side-oats grama (*Bouteloua curtipendula*), purple lovegrass (*Eragrostis spectabilis*), Mexican muhly (*Muhlenbergia mexicana*), nimblewill (*M. schreberi*), slim-flowered muhly (*M. tenuiflora*), beaked panic-grass (*Panicum anceps*), little bluestem (*Schizachyrium scoparium* var. *scoparium*), knotroot foxtail (*Setaria parviflora*), Indian-grass (*Sorghastrum nutans*) and purpletop (*Tridens flavus*). Most of the native warm-season grass cover in the Unionville Barrens grasslands consists of the long-lived perennial species little bluestem and

Figure F-13. **Trends in few-flowered nutrush (*Scleria pauciflora*) percent cover** by treatment combination (see Table 1 for meaning of symbols). See the Figure 3 caption for meaning of bars in the two graphs.



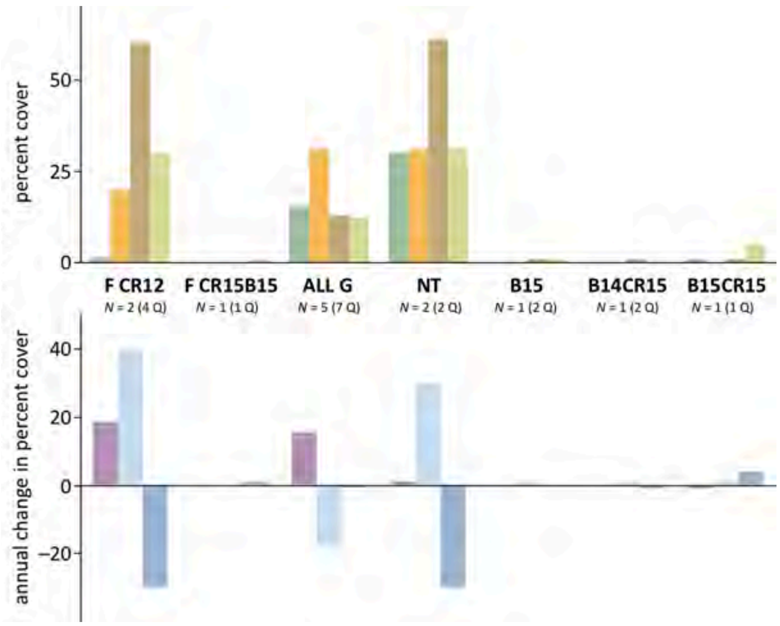


Figure F-14. **Trends in small-leaf white snakeroot (*Ageratina aromatica*) percent cover** by treatment combination (see Table 1 for meaning of symbols). See the Figure 3 caption for meaning of bars in the two graphs.

Indian-grass.

Year-to-year trends in native warm-season grass cover in the 2012 tree-removal area closely matched those in the untreated mature grassland remnants but with lower overall cover (Figure F-11). This species group's cover in the grassland remnants where prescribed fire and tree canopy thinning/removal were done was very high to begin with; randomization of monitoring quadrat locations happened to place the quadrats in those units in areas with heavy warm-season grass dominance. There appears to be no consistent pattern in the response of total native warm-season grass species cover to the 2014 and 2015 treatments. There is much to be learned from close examination of this metric in future monitoring cycles as fire and tree removal are applied over a wider area that includes more monitoring quadrats.

Serpentine aster, as the only globally rare species and the only serpentine barrens endemic found so far at the Union-

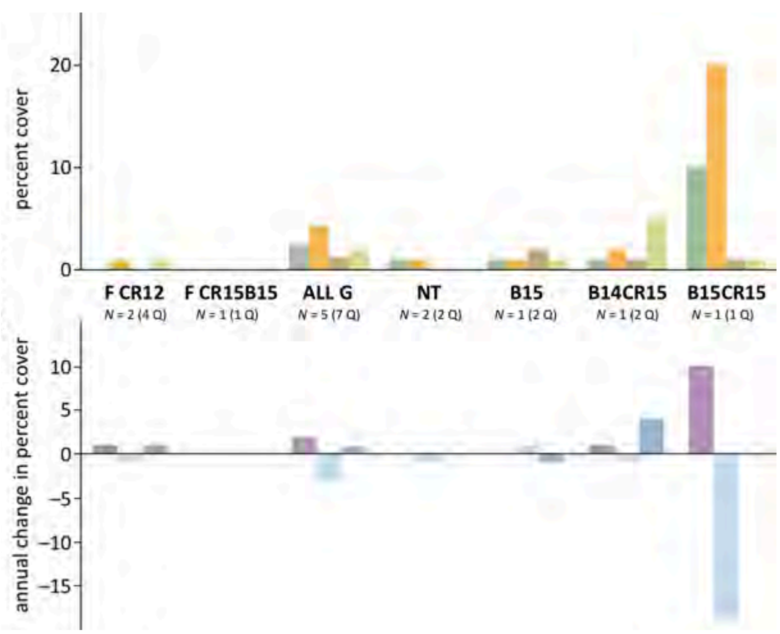


Figure F-15. **Trends in Small's ragwort (*Packera aurea*) percent cover** by treatment combination (see Table 1 for meaning of symbols). See the Figure 3 caption for meaning of bars in the two graphs.

ville Barrens, has outsized importance among the plant species growing there. It is also one of only four species ranked as endangered, threatened or rare (near-threatened) in Pennsylvania that were abundant enough in survey quadrats to document trends over time in their cover. Because most of the world's serpentine aster population lives in Pennsylvania serpentine barrens, it ranks not as endangered in the state but threatened (it is critically endangered in the two other states where it occurs).

Serpentine aster increased in percent cover from 2014 to 2015 in the two units that were burned in spring 2015 (Figure F-12), Units 2 and 4. Its cover decreased in percent cover from 2013 to 2014 following the Unit 5 fire in spring 2014; however it rebounded to its 2013 value in 2015. Through 2015, no serpentine aster was present in survey quadrats in the tree-removal sections of Units 1, 2 or 4.

Few-flowered nutrush, a threatened species in Pennsylvania, greatly increased from 2012 to 2013 in Units 2 and 5 grasslands, then decreased by 2014 (Figure F-13). The timing of those changes did not correspond with any treatments. It is possible that its increase again in 2015 in Unit 5 was a result of the removal of eastern red-cedars there early in 2015. Through 2015, no few-flowered nutrush was present in survey quadrats in the tree-removal sections of Units 1, 2 or 4.

Small-leaf white snakeroot, ranked as rare (near-threatened) in Pennsylvania, was present at very low cover in Units 2, 4 and 5 grasslands (Figure F-14). It was much more abundant in Unit 1 grasslands and in the tree-removal sections of Units 1 and 2. A spike in its percent cover in both remnant and restored grasslands in 2014 was not associated with any treatments.

Cover of **Small's ragwort**, ranked as rare (near-threatened) in Pennsylvania, showed no consistent pattern in relation to vegetation type or the trajectory of change following treatments (Figure F-15).

Non-serpentine woody species as a group, including both native non-serpentine species and nonnatives, pose the greatest threat to serpentine grassland persistence. Their encroachment is the reason why serpentine grassland area at the Unionville Barrens dwindled from more than 63 acres in 1937 to 7 acres in 2010.

Across all Unionville Barrens grasslands samples the most abundant non-serpentine woody species are, in order of average percent cover, black oak (*Quercus velutina*), sassafras (*Sassafras albidum*), Oriental

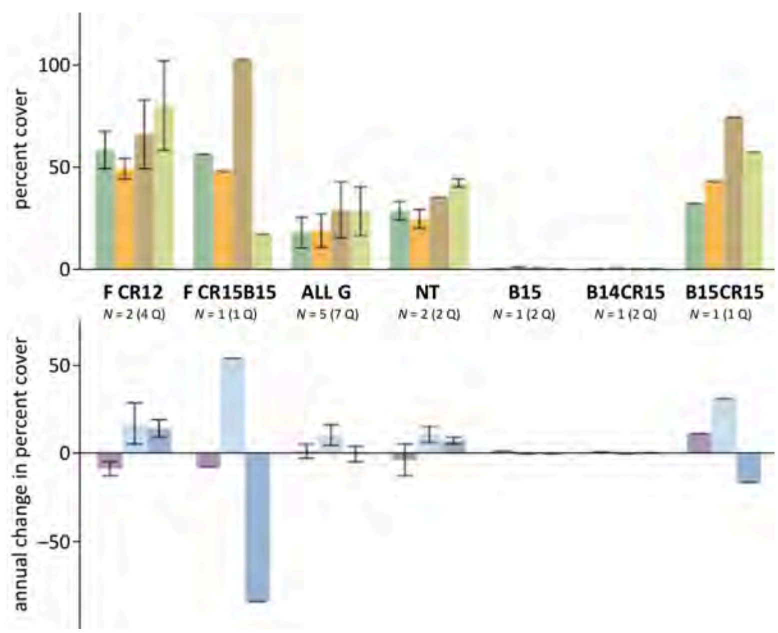


Figure F-16. **Trends in total non-serpentine (native and nonnative) woody species percent cover** by treatment combination (see Table 1 for meaning of symbols). See the Figure 3 caption for meaning of bars and error bars in the two graphs.

bittersweet (*Celastrus orbiculatus*), red maple (*Acer rubrum*), Japanese honeysuckle (*Lonicera japonica*), autumn-olive (*Elaeagnus umbellata*), tuliptree (*Liriodendron tulipifera*), wineberry (*Rubus phoenicolasius*), blackhaw (*Viburnum prunifolium*), black cherry (*Prunus serotina*), Amur honeysuckle (*Lonicera maackii*) and Allegheny blackberry (*Rubus allegheniensis*).

Two trends in non-serpentine woody species cover are apparent in the monitoring results (Figure F-16). In mature remnant grasslands with no treatment, woody species cover increased incrementally in 2014 and 2015, underscoring the importance of tree-killing disturbance (fire, drought, or herbivory) in long-term grassland maintenance. In the Units 1 and 2 2012 tree-removal area, non-serpentine woody species cover started out high and incrementally increased in 2014 and 2015. Part of the increase was due to stump-sprouting by non-serpentine trees such as red maple and black oak that had been cut down, pointing to the importance of extracting the stumps or flush-cutting them and applying herbicide to the cambium where sprouts are emerging.

Serpentine grasslands are unusually resistant to invasion by most **nonnative species**, The parts of grassland that are most vulnerable to nonnative species invasion are those with strong forest and woodland influence, either near an edge, where partial shade and abundant annual organic matter input are the norm, or in a grassland restoration area, where forest succession caused decades worth of soil organic matter buildup. All of the units showing high levels of nonnative species cover have one or both of these characteristics; the first and second sets of bars in Figure F-17 present data collected in the 2012 tree-removal area and the set of bars at extreme right are from the Unit 4 remnant grassland, which is a small fragment surrounded by forest that is essentially all edge. There is one encouraging note in these graphs—the 2015 fire cut nonnative species cover by well over half in both units where cover was high pre-burn.

Across all Unionville Barrens grassland samples the most abundant invasive species are, in order of average percent cover, Japanese stiltgrass, Oriental bitter-sweet (*Celastrus orbiculatus*), sweet vernal grass (*Anthoxanthum odoratum*), Japanese honeysuckle (*Lonicera japonica*), Kentucky bluegrass (*Poa pratensis*), autumn-olive and wineberry (*Rubus phoenicolasius*). Of these,

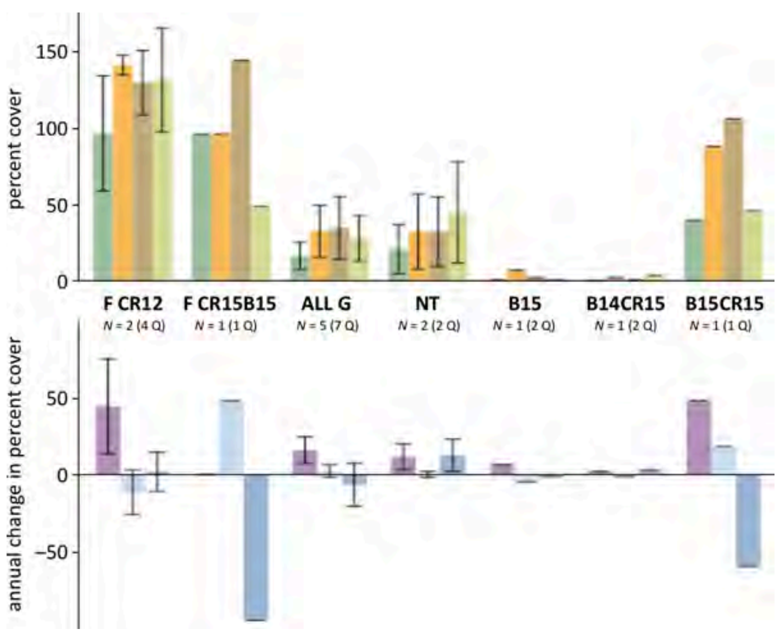


Figure F-17. **Trends in total nonnative species percent cover** by treatment combination (see Table 1 for meaning of symbols). Cover of multi-species groups can exceed 100% because of overlap of leaves among different species. See the Figure 3 caption for meaning of bars and error bars in the two graphs.

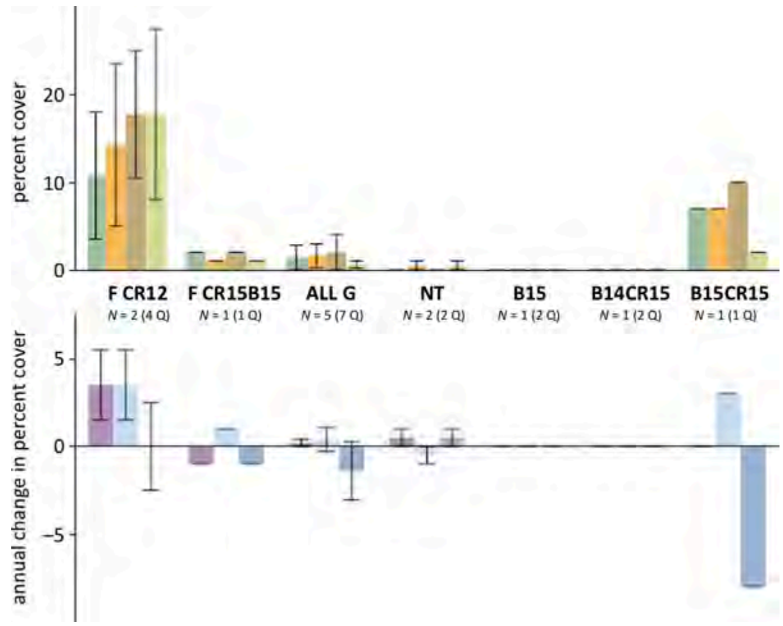


Figure F-18. **Trends in autumn-olive (*Elaeagnus umbellata*) percent cover** by treatment combination (see Table 1 for meaning of symbols). See the Figure 3 caption for meaning of bars and error bars in the two graphs.

Japanese stiltgrass, Oriental bittersweet, Japanese honeysuckle and autumn-olive are highly invasive.

The main exception at the Unionville Barrens to the rule that intact, mature serpentine grassland strongly resists invasion by nonnative species is **autumn-olive**, which has proven relatively immune to serpentine soil chemistry and other conditions that keep most invasive nonnatives out. Anecdotally, it appears to thrive only in partial shade but it has been wildly successful in moving in from the edges to displace many acres of native-species-rich serpentine grassland. The species poses an even larger threat than its relatively high cover in survey quadrats would suggest (Figure F-18) because of its apparently exponential invasion rate, especially in Unit 6a (the Kramkowski tract), and its ability to transform serpentine soil by enriching it with organic matter that is especially high in nitrogen, due to the nitrogen-fixing bacteria it hosts

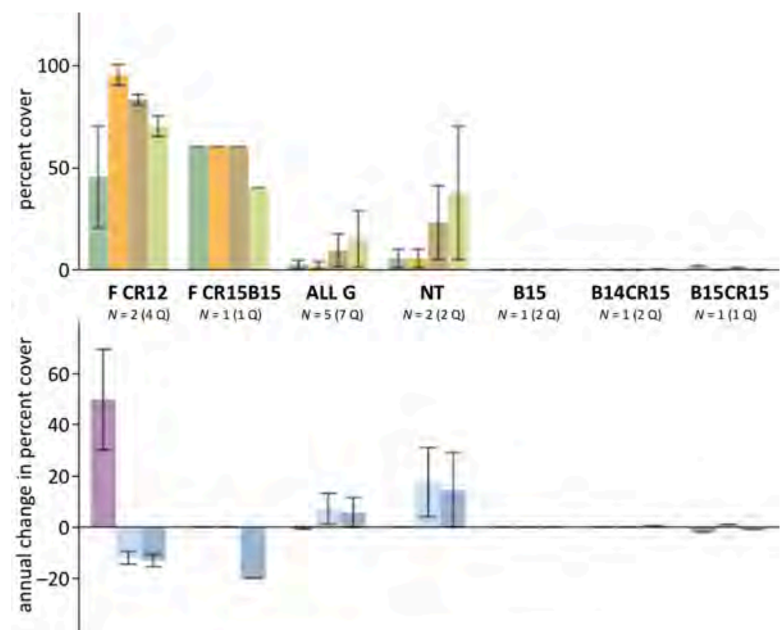


Figure F-19. **Trends in Japanese stiltgrass (*Microstegium vimineum*) percent cover** by treatment combination (see Table 1 for meaning of symbols). See the Figure 3 caption for meaning of bars and error bars in the two graphs.

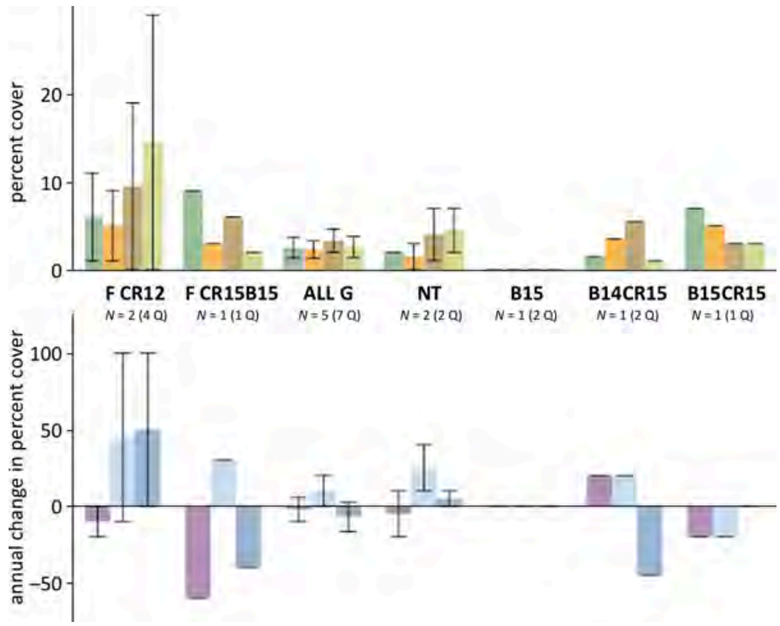


Figure F-20. **Trends in total greenbrier (*Smilax rotundifolia, S. glauca*) percent cover** by treatment combination (see Table 1 for meaning of symbols). See the Figure 3 caption for meaning of bars and error bars in the two graphs.

in root nodules.

The **Japanese stiltgrass** population exploded in the Units 1 and 2 grassland restoration area immediately following tree removal (Figure F-19) but one of the best pieces of news from the first four years of monitoring is the trend since 2013 of declining Japanese stiltgrass in that area. Stiltgrass is sensitive to drought and extreme heat where there is no shade. The 2012–2015 monitoring period had wet summers with no significant drought periods and the trees left behind in the grassland restoration area (now considered a failed experiment) provided partial shade, which protects stiltgrass from prolonged extreme heat. This species' cover is expected to decline faster in serpentine grassland with moderate drought and drop dramatically in the case of a severe drought, which occurs sporadically and is predicted to increase in frequency with current trends in global climate. The sustained presence of stiltgrass in the untreated remnant grassland units (middle set of bars in Figure F-19) is one of several lines of evidence pointing to the likely benefit of introducing growing-season fire, at least on a trial basis.

Even though it is native and a characteristic species of the Northern Piedmont serpentine barrens, **common greenbrier** (*Smilax rotundifolia*) is one of the threats to serpentine grassland persistence and species diversity at most sites. It is less abundant at the Unionville Barrens than at many other sites, but it still covers fairly extensive areas with a monoculture than excludes all other native characteristic serpentine barrens species. Research at other barrens has documented that many nearly pure patches of common greenbrier are on the march, expanding at their edges into grassland and displacing herbaceous species. Catbrier (*S. glauca*) is considerably less abundant at all barrens but it usually co-occurs with common greenbrier and can form part of a "phalanx" of encroaching thicket. The trending increase of common greenbrier in the Units 1 and 2 tree-removal area (Figure F-20) is a call to action. Its response to fire is variable—in woodlands fire has little effect but in open grassland where there is no shade from an overtopping tree canopy repeated burning can cause greenbrier to retreat. Growing-season fire has not yet been attempted as a greenbrier control method. Future monitoring results of the effects of growing-season fire on greenbrier, for which evidence is lacking in the published literature, will be an especially interesting and useful application of the adaptive management approach.

F.8.2.3 Breeding bird metrics

Of 47 bird species seen or heard in timed point counts at 20 observation points during the breeding seasons of four consecutive years, 24 are considered as belonging to habitat specialist "guilds" (Table F-6). No species ranked as endangered, threatened or near-threatened were observed but three are listed in the current state wildlife action plan (SWAP) as species of greatest conservation need.

The habitat guild expected to benefit most from grassland restoration and management is open habitat bird species. The trends are encouraging in this regard; in all of the vegetation change trajectories affected by restoration and management activities (Figure F-21), observations of open habitat bird species as a group increased substantially from 2012 to 2015.

Several bird species that are rare locally or are of conservation concern in Pennsylvania and are known to have affinities for Northern Piedmont serpentine barrens (Table F-7) have not yet been observed at the Unionville Barrens. However, one or more may well colonize the site as restoration progresses. This possibility underscores the importance of systematic and frequent avian monitoring. Because of the popularity of birding and the high level of knowledge and sophistication of many of its recreational practitioners, volunteers could be recruited, trained and supervised to carry out the bird point-count protocol as often as every year and two or more times during the breeding season.

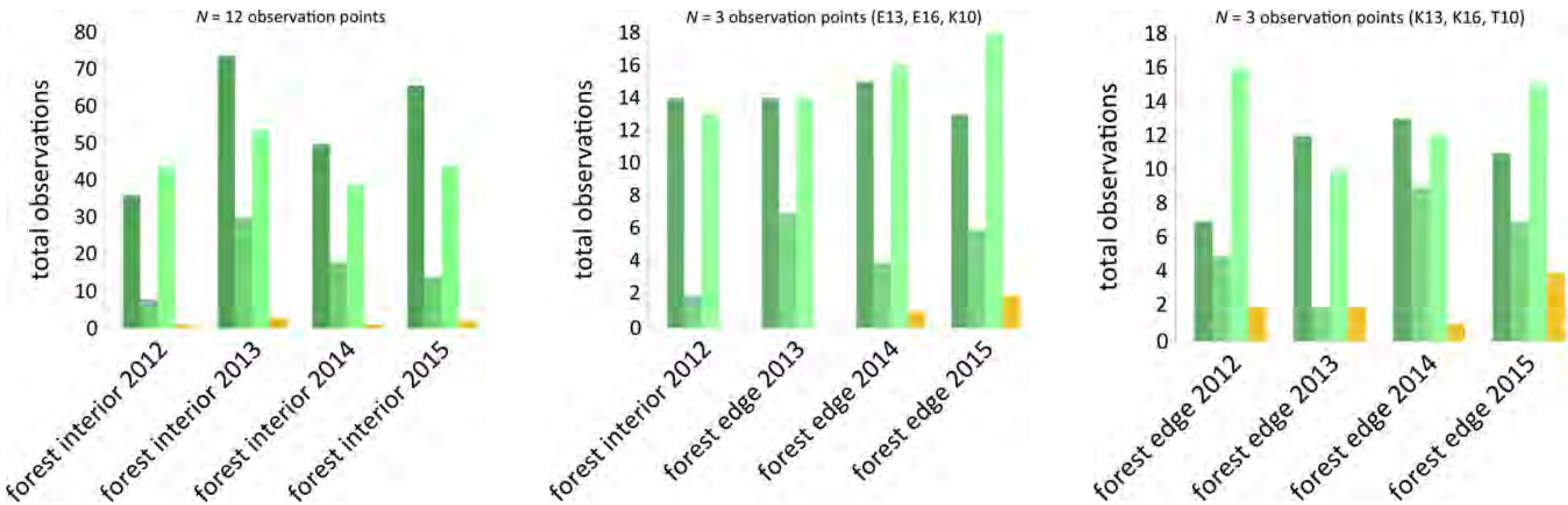
Table F-6. **Habitat specialist bird species observed during the breeding season** at the Unionville Barrens in 2012–2015 point counts. Trends of each guild in relation to restoration and management activity are shown in Figure F-21.

forest interior	open woodlands	thickets	open habitats
Acadian flycatcher ovenbird pileated woodpecker scarlet tanager veery wood thrush*	Baltimore oriole blue-gray gnatcatcher cedar waxwing downy woodpecker great crested flycatcher yellow-billed cuckoo	brown thrasher common yellowthroat eastern towhee* gray catbird* northern cardinal northern mockingbird	American goldfinch eastern bluebird field sparrow* indigo bunting red-winged blackbird song sparrow

* Listed as a species of greatest conservation need in the *Pennsylvania Wildlife Action Plan 2015–2025*.

Table F-7. **Bird species of conservation concern that have habitat affinities for Northern Piedmont serpentine barrens.** PA SWAP is the *Pennsylvania State Wildlife Action Plan 2015–2025*; PABS is the Pennsylvania Biological Survey. SGCN = species of greatest conservation need. List is not exhaustive.

species	scientific name	PA SWAP status	PABS status
northern bobwhite	*Colinus virginianus*	?	possibly extirpated as breeder
common nighthawk	*Chordeiles minor*	SGCN	near-threatened
eastern whip-poor-will	*Caprimulgus vociferus*	SGCN	
white-eyed vireo	*Vireo griseus*		
prairie warbler	*Setophaga discolor*	SGCN	
yellow-breasted chat	*Icteria virens*	SGCN	
summer tanager	*Piranga rubra*	SGCN	near-threatened
blue grosbeak	*Passerina caerulea*		



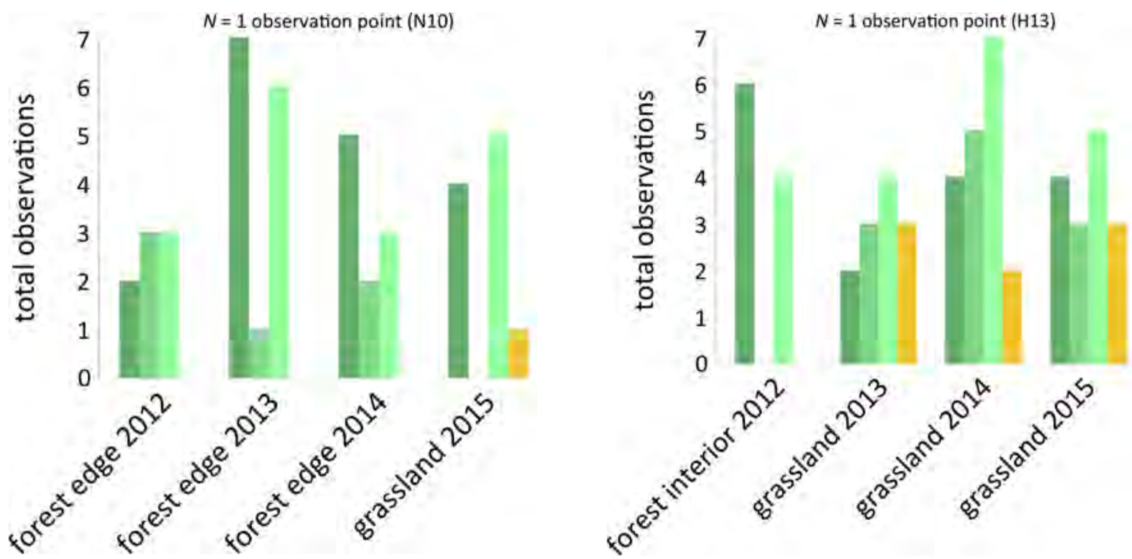


Figure F-21. **Trends in numbers of observations of birds in 4 habitat guilds categorized by 5 different vegetation change trajectories resulting from restoration and management activities.** Members of each guild are listed in Table F-6. Timed point counts were conducted three times each year during the breeding season. Total observations are assumed to be correlated with numbers of breeding bird pairs, although they do not represent actual counts of successful nesting attempts.

F.9 Updated existing conditions metrics and desired conditions targets

Analysis of the 2012–2015 monitoring data has produced the first comprehensive, quantitative audit of the outcomes of restoration and management activities at the Unionville Barrens. The results are given on Table F-8 in terms of the desired conditions metrics and target values listed in the *Unionville Serpentine Barrens Restoration and Management Plan* (Latham and McGeehin 2012). In a few instances the first four years' results have also provided the basis for refining the desired conditions metrics and target values.

The first cycle of science-based management at the Unionville Barrens demonstrated the key importance of regular, quantitative auditing of management results and background trends in terms of selected vital metrics. It showcased several examples of how crucial systematic monitoring is to success in ecosystem stewardship and endangered species recovery. One example: the monitoring data showed a steady decline from 2012 to 2015 in Japanese stiltgrass cover and simultaneous increases in characteristic native serpentine species cover and diversity in the 12.4 acres where trees were removed in 2012 to restore grassland. Both trends were subtle and would have been missed by a non-quantitative ("eyeball") assessment. The data, together with the knowledge that Japanese stiltgrass is highly vulnerable to drought and growing-season fire in unshaded grassland habitat and that the period 2012–2015 had a run of wet summers, led to the conclusion that trying to reduce stiltgrass using herbicide—to all superficial appearances a high stewardship priority—would have been harmful, likely resulting in a long delay in recolonization by desired species and the local extirpation of several species of greatest conservation need.

The first four years of monitoring documented both positive gains and negative trends, leading to a reordering of stewardship priorities since the original plan was written. This cyclic feedback between monitoring data and stewardship priorities is a key feature of the adaptive management approach.

Table F-8. **Updated Unionville Barrens desired conditions metrics and target values.** Revised from Table 7 (pp. 50-59) in *Unionville Serpentine Barrens Restoration and Management Plan* (Latham and McGeehin 2012). See Table A-2, Appendix A (p. 110) in that document for meanings of codes in parentheses after species names and Section 3.2 (pp. 60-61) for methods used to derive target values. The sequence of numbers under "desired condition" (first column) correspond with those in Table 7 of the original plan, with newly added items labeled "b," "c," etc.

desired condition	metric (= indicator) & suggested monitoring interval	target values		change 2012→2015
ECOLOGICAL COMMUNITIES AND LANDSCAPE				
1. **Total area of grassland**, including gravel forb community and serpentine wetland, approaching limits imposed by site conditions	GIS computation using recent high-resolution (1-m/3-foot or better) aerial and lidar imagery—every 3–5 yr	EXCELLENT GOOD FAIR POOR	≥ 45 acres 35–44.9 acres 25–34.9 acres < 25 acres	POOR→POOR (improving) 7 acres→19 acres
2. **High serpentine gravel forb community area** comprising an ample proportion of total grassland	GIS computation using recent high-resolution (1-m/3-foot or better) aerial and lidar imagery, *assuming image classification software can be used to reliably separate the communities*—every 3–5 yr	EXCELLENT GOOD FAIR POOR	≥ 20% 15%–19.9% 10%–14.9% < 10%	?→? unknown→still unknown pending development of sufficiently sensitive GIS vegetation classification method
3a. **Balance between open (treeless) prairie and savanna favoring open prairie** in blocks > 10 m from forest edge	GIS computation using fragmentation analysis software on recent high-resolution (1-m/3-foot or better) aerial and lidar imagery of ratio of "core" (prairie) area to "perforated" (savanna) area using 10-m buffer—every 3–5 yr	EXCELLENT GOOD FAIR POOR	1.0–4.0 0.67–0.99 or 4.01–6.0 0.40–0.66 or 6.01–9.0 < 0.40 or > 9.0	GOOD (2010)→? (2015) 0.71→unknown pending GIS analysis of 2015 data
3b. **High connectivity/ low fragmentation of grassland**: low ratio of grassland-forest edge area to minimum possible given total grassland area	GIS fragmentation analysis on recent high-resolution (1-m/3-foot or better) aerial and lidar imagery of percentage of total grassland area in "edge" and "patch" categories using 10-m buffer, compared with the minimum edge area possible given the measured total area; connectivity index value varies from 0 to 1, where 0 represents total grassland fragmentation and 1, the highest possible connectivity (see connectivity index formula in Table F-4)—every 3–5 yr	EXCELLENT GOOD FAIR POOR	0.75–1.00 0.50–0.74 0.25–0.49 < 0.25	POOR (2010)→? (2015) 0.04→unknown pending GIS analysis of 2015 data

(Table continues on next page.)

desired condition	metric (= indicator) & suggested monitoring interval	target values		change 2012→2015
4a. **Dominance in pre-2012 *remnant* grassland by native herbaceous serpentine grassland plant species** in ground layer (0–2 m above ground surface)	Aggregate percent cover in ground layer (< 2 m height) of herbaceous serpentine grassland species among 25-m² monitoring quadrats within each management unit (can exceed 100% because of overlap among leaves of different species)—every 3–5 yr	EXCELLENT GOOD FAIR POOR	> 90% 80%–89.9% 70%–79.9% < 70%	POOR–EXCELLENT→POOR–EXCELLENT 5 units (7 quadrats): 1—20%→12% 2—106%→148% 3—50%→67% 4—62%→119% 5—99%→134%
	Herbaceous serpentine grassland species cover as a fraction of all species plant cover in ground layer (< 2 m height) among 25-m² monitoring quadrats within each management unit (100 × sum of percent cover of those species ÷ sum of all species)—every 3–5 yr	EXCELLENT GOOD FAIR POOR	90%–100% 80%–89.9% 70%–79.9% < 70%	POOR–EXCELLENT→POOR–EXCELLENT 5 units (7 quadrats): 1—15%→8% 2—99%→98% 3—39%→34% 4—50%→63% 5—78%→84%
4b. **Dominance in *restored* grassland by native herbaceous serpentine grassland plant species** in ground layer (0–2 m above ground surface)	Aggregate percent cover in ground layer (< 2 m height) of herbaceous serpentine grassland species among 25-m² monitoring quadrats within each management unit (can exceed 100% because of overlap among leaves of different species)—every 3–5 yr	EXCELLENT GOOD FAIR POOR	> 90% 80%–89.9% 70%–79.9% < 70%	POOR→POOR (improving) 3 units (5 quadrats): 1—0.00%→6.0% 2—12%→24% 4—1.0%→2.0%
	Herbaceous serpentine grassland species cover as a fraction of all species plant cover in ground layer (< 2 m height) among 25-m² monitoring quadrats within each management unit (100 × sum of percent cover of those species ÷ sum of all species)—every 3–5 yr	EXCELLENT GOOD FAIR POOR	90%–100% 80%–89.9% 70%–79.9% < 70%	POOR→POOR (improving) 3 units (5 quadrats): 1—0.00%→3.2% 2—11%→13% 4—0.76%→2.9%
	Aggregate percent cover in ground layer (< 2 m height) of herbaceous serpentine grassland species among 1-m² monitoring quadrats within each management unit (can exceed 100% because of overlap among leaves of different species)—every 3–5 yr	EXCELLENT GOOD FAIR POOR	> 90% 80%–89.9% 70%–79.9% < 70%	POOR→POOR (improving) 200 quadrats along 600-m transect (change 2013–2015): on average 6.8%→7.8% ranging from 0%–118%→0%–143%

(Table continues on next page.)

desired condition	metric (= indicator) & suggested monitoring interval	target values		change 2012→2015
5. **High local (within-patch) native serpentine grassland plant species diversity**	Average richness (α) of native serpentine grassland plant species among 25-m² monitoring quadrats in *remnant* and *restored* grasslands—every 3–5 yr	EXCELLENT GOOD FAIR POOR	≥ 15 12–14.9 9–11.9 < 9	GOOD→FAIR 7 remnant quadrats: 13.3→11.4
				POOR→POOR (improving) 5 restored quadrats: 2.8→4.6
	Average evenness (100 × $E_{1/D}$) of all plant species among 25-m² monitoring quadrats in *remnant* and *restored* grasslands—every 3–5 yr	EXCELLENT GOOD FAIR POOR	30–100 24–29.9 18–23.9 < 18	FAIR→FAIR 7 remnant quadrats: 20.0→22.7
				FAIR→FAIR 5 restored quadrats: 24.8→19.6
	Upper quartile of evenness (100 × $E_{1/D}$) of all plant species among 25-m² monitoring quadrats in *remnant* and *restored* grasslands—every 3–5 yr	EXCELLENT GOOD FAIR POOR	36–100 30–35.9 24–29.9 < 24	FAIR→FAIR 7 remnant quadrats: 26.5→27.1
				GOOD→FAIR 5 restored quadrats: 30.4→32.8
6. **High whole-site (between-patch) diversity in native serpentine grassland plant species composition**	Herbaceous serpentine grassland plant species turnover (β_H) among 25-m² monitoring quadrats in *remnant* and *restored* grasslands—every 3–5 yr	EXCELLENT GOOD FAIR POOR	15–100 12–14.9 9–11.9 < 9	EXCELLENT→GOOD 7 remnant quadrats: 18.6→14.7
				FAIR→EXCELLENT 5 restored quadrats: 9.4→20.5
	Upper quartile of herbaceous serpentine grassland plant species richness among 25-m² monitoring quadrats in *remnant* and *restored* grasslands—every 3–5 yr	EXCELLENT GOOD FAIR POOR	≥ 18 15–17.9 12–14.9 < 12	GOOD→FAIR 7 remnant quadrats: 15.5→13.0
				POOR→POOR 5 restored quadrats: 5.0→5.0

(Table continues on next page.)

desired condition	metric (= indicator) & suggested monitoring interval	target values		change 2012→2015
7. **Herbivory by white-tailed deer at a level that does not depress diversity of native grassland forbs**	Average $\alpha_E - \alpha_A$ as a percentage of α_E, where α_E = native grassland forb richness per fenced deer exclosure and α_A = grassland forb richness per adjacent monitoring quadrat	EXCELLENT GOOD FAIR POOR	≤ 5% 5.1%–10% 10.1%–15% > 15%	data collected but not yet digitized or analyzed
	Average $E_E - E_A$ as a percentage of E_E, where E_E = total grassland species evenness per fenced deer exclosure and E_A = total grassland species evenness per adjacent monitoring quadrat	EXCELLENT GOOD FAIR POOR	≤ 5% 5.1%–10% 10.1%–15% > 15%	data collected but not yet digitized or analyzed
8. **Dominance or co-dominance by a mixture of oak species in forest and woodland canopy and subcanopy**	Oak species cover as a fraction of all species cover in forest canopy and subcanopy layer (> 2 m height) among 25-m² monitoring quadrats within each management unit (100 × sum of percent cover of those species ÷ sum of all species)—every 3–5 yr	EXCELLENT GOOD FAIR POOR	75%–100% 50%–74.9% 25%–49.9% < 25%	POOR TO GOOD→ POOR TO EXCELLENT 5 units (20 quadrats): 1—0.0%→0.20% 2—39%→74% 3—0.75%→0.25% 4—71%→81% 5—18%→56%
9. **Dominance by native plants in forest and woodland shrub and ground layer**	Native species cover as a fraction of all species cover in forest shrub and ground layer (< 2 m height) among 25-m² monitoring quadrats within each management unit (100 × sum of percent cover of native species ÷ sum of all species)—every 3–5 yr	EXCELLENT GOOD FAIR POOR	90%–100% 80%–89.9% 70%–79.9% < 70%	POOR→POOR 5 units (20 quadrats): 1—13%→15% 2—12%→18% 3—16%→16% 4—17%→23% 5—12%→12%
10a. **High density of native tree seedlings and saplings**	Average aggregate percent cover of native tree seedlings and saplings in forest shrub and ground layer among 25-m² monitoring quadrats within each management unit—every 3–5 yr	EXCELLENT GOOD FAIR POOR	> 30% 20%–29.9% 10%–19.9% < 10%	POOR→POOR TO FAIR 5 units (20 quadrats): 1—5.4%→18% 2—6.8%→17% 3—4.8%→2.0% 4*—55%→46% 5—7.0%→7.0%

* Forest in Unit 4 is represented by only one quadrat; density of native trees in that quadrat is skewed by a single beech root sprout.

(Table continues on next page.)

desired condition	metric (= indicator) & suggested monitoring interval	target values		change 2012→2015
10b. **High oak regeneration**	Average aggregate percent cover of oak seedlings and saplings in forest shrub and ground layer among 25-m² monitoring quadrats within each management unit—every 3–5 yr	EXCELLENT GOOD FAIR POOR	> 15% 10%–14.9% 5%–9.9% < 5%	POOR→POOR 5 units (20 quadrats): 1—0.0%→0.20% 2—0.50%→1.8% 3—0.75%→0.25% 4—1.0%→1.0% 5—1.5%→1.5%
11. **High density of native shrubs**	Average aggregate percent cover of native shrubs in forest shrub and ground layer among 25-m² monitoring quadrats within each management unit—every 3–5 yr	EXCELLENT GOOD FAIR POOR	> 50% 35%–49.9% 20%–34.9% < 20%	POOR TO FAIR→ POOR TO FAIR 5 units (20 quadrats): 1—23%→24% 2—14%→18% 3—8.8%→11% 4—5.0%→9.0% 5—33%→33%
12. **High within-patch species diversity of native plants in forest understory**	Average richness (α) of native tree seedlings, saplings, shrubs and herbaceous plant species in forest shrub and ground layer among 25-m² monitoring quadrats within each management unit—every 3–5 yr	EXCELLENT GOOD FAIR POOR	≥ 20 15–19.9 10–15.9 < 10	FAIR→GOOD 20 quadrats: 13.2→17.2
13a. **High within-patch species diversity of all plants in forest understory**	Average evenness ($E_{1/D}$) of all plant species in forest shrub and ground layer among 25-m² monitoring quadrats within each management unit—every 3–5 yr	EXCELLENT GOOD FAIR POOR	30–100 24–29.9 18–23.9 < 18	EXCELLENT→FAIR 20 quadrats: 70.5→18.8
	Upper quartile of evenness of all plant species in forest shrub and ground layer among 25-m² monitoring quadrats within each management unit—every 3–5 yr	EXCELLENT GOOD FAIR POOR	36–100 30–35.9 24–29.9 < 24	EXCELLENT→POOR 20 quadrats: 42.4→21.6
13b. **High between-patch species diversity of native plants in forest understory**	Native plant species turnover (β_H) in forest shrub and ground layer among 25-m² monitoring quadrats—every 3–5 yr	EXCELLENT GOOD FAIR POOR	15–100 12–14.9 9–11.9 < 9	EXCELLENT→EXCELLENT 20 quadrats: 17.5→30.2
	Upper quartile of native plant species richness in forest habitat per 25-m² monitoring quadrat—every 3–5 yr	EXCELLENT GOOD FAIR POOR	≥ 25 20–24.9 15–19.9 < 15	FAIR→GOOD 20 quadrats: 16.3→21.0

(Table continues on next page.)

desired condition	metric (= indicator) & suggested monitoring interval	target values		change 2012→2015
14. **Dominance by native herbaceous plant species in wetlands**	Average percent of total herbaceous plant cover in native herbaceous species among wetland monitoring quadrats (100 × sum of percent cover of those species ÷ sum of all species)—every 3–5 yr	EXCELLENT GOOD FAIR POOR	90%–100% 80%–89.9% 70%–79.9% < 70%	wetland mapping and monitoring have not been started
15a. **High within-patch species diversity of native herbaceous plants in wetlands**	Average richness (α) of native herbaceous plants among wetland monitoring quadrats—every 3–5 yr	EXCELLENT GOOD FAIR POOR	≥ 20 15–19.9 10–15.9 < 10	wetland mapping and monitoring have not been started
15b. **High within-patch species diversity of all plants in wetlands**	Average evenness ($E_{1/D}$) of all plant species among wetland monitoring quadrats—every 3–5 yr	EXCELLENT GOOD FAIR POOR	30–100 24–29.9 18–23.9 < 18	wetland mapping and monitoring have not been started
	Upper quartile of evenness of all plant species among wetland monitoring quadrats—every 3–5 yr	EXCELLENT GOOD FAIR POOR	36–100 30–35.9 24–29.9 < 24	wetland mapping and monitoring have not been started
16. **High between-patch species diversity of native herbaceous plants in wetlands**	Native herbaceous plant species turnover (β_H) among wetland patches—every 3–5 yr	EXCELLENT GOOD FAIR POOR	15–100 12–14.9 9–11.9 < 9	wetland mapping and monitoring have not been started
PLANT SPECIES OF GREATEST CONSERVATION NEED				
17. **Secure population status of Bicknell's sedge** (*Carex bicknellii*; PE)	Discrete clusters at least 500 apart—every 2–3 yr until GOOD, then every 3–5 yr	EXCELLENT GOOD FAIR POOR	≥ 4 3 2 1	POOR→FAIR 1→2 known
	Estimated total number of tufts—every 2–3 yr until GOOD, then every 3–5 yr	EXCELLENT GOOD FAIR POOR	≥ 10,000 1,000–9,999 100–999 < 100	POOR→POOR 13 in 2011→ ?

(Table continues on next page.)

desired condition	metric (= indicator) & suggested monitoring interval	target values	change 2012→2015
18. **Secure population status of Richardson's sedge** (*Carex richardsonii*; PE)	Discrete clusters at least 500 apart—every 2–3 yr until GOOD, then every 3–5 yr	EXCELLENT ≥ 4 GOOD 3 FAIR 2 POOR 1	POOR→FAIR (new find) 1→2 known
	Estimated total number of tufts—every 2–3 yr until GOOD, then every 3–5 yr	EXCELLENT ≥ 10,000 GOOD 1,000–9,999 FAIR 100–999 POOR < 100	POOR→POOR est. 10–100→10–100
19. **Secure population status of long-haired panic-grass** (*Dichanthelium villosissimum*; PE)	Discrete clusters at least 500 apart—every 2–3 yr until GOOD, then every 3–5 yr	EXCELLENT ≥ 4 GOOD 3 FAIR 2 POOR 1	unknown; not seen recently
	Estimated total number of tufts—every 2–3 yr until GOOD, then every 3–5 yr	EXCELLENT ≥ 10,000 GOOD 1,000–9,999 FAIR 100–999 POOR < 100	unknown; not seen recently
20. **Secure population status of Bicknell's hoary rockrose** (*Helianthemum bicknellii*; PE)	Discrete clusters at least 500 apart—every 2–3 yr until GOOD, then every 3–5 yr	EXCELLENT ≥ 4 GOOD 3 FAIR 2 POOR 1	POOR→GOOD (new find) 1→3 known
	Estimated total number of stems—every 2–3 yr until GOOD, then every 3–5 yr	EXCELLENT ≥ 1,000 GOOD 100–999 FAIR 10–99 POOR < 10	POOR→FAIR (new find) est. < 10→10–100
21. **Secure population status of arrow-feather three-awn** (*Aristida purpurascens*; PT)	Discrete clusters at least 500 apart—every 3–5 yr	EXCELLENT ≥ 4 GOOD 3 FAIR 2 POOR 1	GOOD to EXCELLENT→ GOOD to EXCELLENT
	Estimated total number of tufts—every 3–5 yr	EXCELLENT ≥ 100,000 GOOD 10,000–99,999 FAIR 1,000–9,999 POOR < 1,000	FAIR to GOOD→ FAIR to GOOD est. > 5,000

(Table continues on next page.)

desired condition	metric (= indicator) & suggested monitoring interval	target values	change 2012→2015
22. **Secure population status of side-oats grama** (*Bouteloua curtipendula*; PT)	Discrete clusters at least 500 apart—every 3–5 yr	EXCELLENT ≥ 4 GOOD 3 FAIR 2 POOR 1	FAIR→GOOD 2→3 (third cluster planted from seed collected onsite)
	Estimated total number of tufts—every 3–5 yr	EXCELLENT ≥ 100,000 GOOD 10,000–99,999 FAIR 1,000–9,999 POOR < 1,000	FAIR to GOOD→ FAIR to GOOD est. > 5,000
23. **Secure population status of tufted hairgrass** (*Deschampsia cespitosa*; PT)	Discrete clusters at least 500 apart—every 3–5 yr	EXCELLENT ≥ 4 GOOD 3 FAIR 2 POOR 1	EXCELLENT→EXCELLENT > 4
	Estimated total number of tufts—every 3–5 yr	EXCELLENT ≥ 10,000 GOOD 1,000–9,999 FAIR 100–999 POOR < 100	GOOD→GOOD est. 1,000–5,000
24. **Secure population status of Heller's rosette grass** (*Dichanthelium oligosanthes*; PT)	Discrete clusters at least 500 apart—every 3–5 yr	EXCELLENT ≥ 4 GOOD 3 FAIR 2 POOR 1	FAIR to EXCELLENT→ FAIR to EXCELLENT est. 2–4
	Estimated total number of tufts—every 3–5 yr	EXCELLENT ≥ 10,000 GOOD 1,000–9,999 FAIR 100–999 POOR < 100	FAIR→FAIR est. 100–1,000
25. **Secure population status of annual fimbry** (*Fimbristylis annua*; PT)	Discrete clusters at least 500 apart—yearly	EXCELLENT ≥ 4 GOOD 3 FAIR 2 POOR 1	FAIR to EXCELLENT→ FAIR to EXCELLENT est. 2–4
	Estimated total number of individuals—yearly	EXCELLENT ≥ 10,000 GOOD 1,000–9,999 FAIR 100–999 POOR < 100	GOOD→GOOD est. 1,000–5,000

(Table continues on next page.)

desired condition	metric (= indicator) & suggested monitoring interval	target values		change 2012→2015
26. **Secure population status of round-leaf fameflower** (*Phemeranthus teretifolius*; PT)	Discrete clusters at least 500 apart—every 3–5 yr	EXCELLENT GOOD FAIR POOR	≥ 4 3 2 1	EXCELLENT→EXCELLENT > 4
	Estimated total number of stems—every 3–5 yr	EXCELLENT GOOD FAIR POOR	≥ 1,000 100–999 10–99 < 10	FAIR to EXCELLENT→ FAIR to EXCELLENT est. 50–1,000
27. **Secure population status of few-flowered nut-rush** (*Scleria pauciflora*; PT)	Discrete clusters at least 500 apart—every 3–5 yr	EXCELLENT GOOD FAIR POOR	≥ 4 3 2 1	EXCELLENT→EXCELLENT >4
	Estimated total number of tufts—every 3–5 yr	EXCELLENT GOOD FAIR POOR	≥ 10,000 1,000–9,999 100–999 < 100	GOOD to EXCELLENT→ GOOD to EXCELLENT est. 5,000–10,000+
28. **Secure population status of serpentine aster** (*Symphyotrichum depauperatum*; PT; globally rare)	Discrete clusters at least 500 apart—every 3–5 yr	EXCELLENT GOOD FAIR POOR	≥ 4 3 2 1	EXCELLENT→EXCELLENT >4
	Estimated total number of stems—every 3–5 yr	EXCELLENT GOOD FAIR POOR	≥ 10,000 1,000–9,999 100–999 < 100	EXCELLENT→EXCELLENT est. > 10,000
29. **Secure population status of small-leaf white-snakeroot** (*Ageratina aromatica*; PR)	Discrete clusters at least 500 apart—every 3–5 yr	EXCELLENT GOOD FAIR POOR	≥ 4 3 2 1	EXCELLENT→EXCELLENT >4
	Estimated total number of stems—every 3–5 yr	EXCELLENT GOOD FAIR POOR	≥ 10,000 1,000–9,999 100–999 < 100	EXCELLENT→EXCELLENT est. > 10,000

(Table continues on next page.)

desired condition	metric (= indicator) & suggested monitoring interval	target values	change 2012→2015
30. **Secure population status of Elliott's beardgrass** (*Andropogon gyrans*; PR)	Discrete clusters at least 500 apart—every 2–3 yr until GOOD, then every 3–5 yr	EXCELLENT ≥ 4 GOOD 3 FAIR 2 POOR 1	POOR→GOOD (2 new finds) 1→3 known
	Estimated total number of tufts—every 2–3 yr until GOOD, then every 3–5 yr	EXCELLENT ≥ 10,000 GOOD 1,000–9,999 FAIR 100–999 POOR < 100	POOR→POOR to FAIR est. 10–100+
31. **Secure population status of Small's ragwort** (*Packera aurea*; PR)	Discrete clusters at least 500 apart—every 3–5 yr	EXCELLENT ≥ 4 GOOD 3 FAIR 2 POOR 1	EXCELLENT→EXCELLENT >4
	Estimated total number of stems—every 3–5 yr	EXCELLENT ≥ 10,000 GOOD 1,000–9,999 FAIR 100–999 POOR < 100	EXCELLENT→EXCELLENT est. > 10,000
32. **Secure population status of New Jersey tea** (*Ceanothus americanus*; SP)	Discrete clusters at least 500 apart—every 2–3 yr until GOOD, then every 3–5 yr	EXCELLENT ≥ 4 GOOD 3 FAIR 2 POOR 1	unknown→POOR ? →2 known
	Estimated total number of stems—every 2–3 yr until GOOD, then every 3–5 yr	EXCELLENT ≥ 2,500 GOOD 500–2,499 FAIR 100–499 POOR < 100	POOR→POOR <10
33. **Secure population status of barrens chickweed** (*Cerastium velutinum* var. *velutinum*; SP)	Discrete clusters at least 500 apart—every 3–5 yr	EXCELLENT ≥ 4 GOOD 3 FAIR 2 POOR 1	EXCELLENT→EXCELLENT >4
	Estimated total number of stems—every 3–5 yr	EXCELLENT ≥ 10,000 GOOD 1,000–9,999 FAIR 100–999 POOR < 100	EXCELLENT→EXCELLENT est. > 10,000

(Table continues on next page.)

desired condition	metric (= indicator) & suggested monitoring interval	target values		change 2012→2015
34. **Secure population status of rock sandwort** (*Minuartia michauxii*; SP)	Discrete clusters at least 500 apart—every 3–5 yr	EXCELLENT GOOD FAIR POOR	≥ 4 3 2 1	EXCELLENT→EXCELLENT >4
	Estimated total number of individuals—every 3–5 yr	EXCELLENT GOOD FAIR POOR	≥ 10,000 1,000–9,999 100–999 < 100	EXCELLENT→EXCELLENT est. > 10,000
35a. **Secure population status of shortleaf pine** (*Pinus echinata*; PT)	Each species: discrete clusters at least 500 apart	EXCELLENT GOOD FAIR POOR	≥ 4 3 2 1	POOR 1 individual known
	Each species: estimated total number of stems	EXCELLENT GOOD FAIR POOR	≥ 300 100–299 50–100 < 50	POOR 1 individual known
35b. **Secure population status of lion's-foot** (*Prenanthes serpentaria*; PT)	Each species: discrete clusters at least 500 apart	EXCELLENT GOOD FAIR POOR	≥ 4 3 2 1	POOR 1 cluster known
	Each species: estimated total number of stems	EXCELLENT GOOD FAIR POOR	≥ 300 100–299 50–100 < 50	POOR ~ 10 individuals known
35c. **Secure population status of each other plant species of conservation concern found in surveys or reintroduced from nearby seed sources**	Each species: discrete clusters at least 500 apart	EXCELLENT GOOD FAIR POOR	≥ 4 3 2 1	
	Each species: estimated total number of stems	EXCELLENT GOOD FAIR POOR	contingent on species	

(Table continues on next page.)

desired condition	metric (= indicator) & suggested monitoring interval	target values		change 2012→2015
36a. **Secure population status of Virginia snakeroot** (*Aristolochia serpentaria*)	Discrete clusters at least 500 apart	EXCELLENT GOOD FAIR POOR	≥ 4 3 2 1	POOR→POOR 1 cluster known
	Estimated total number of plants	EXCELLENT GOOD FAIR POOR	≥ 10,000 1,000–9,999 100–999 < 100	POOR→POOR < 10
36b. **Secure population status of moss phlox** (*Phlox subulata* var. *subulata*)	Discrete clusters at least 500 apart	EXCELLENT GOOD FAIR POOR	≥ 4 3 2 1	GOOD to EXCELLENT→ GOOD to EXCELLENT 3–4+
	Estimated total number of plants	EXCELLENT GOOD FAIR POOR	≥ 10,000 1,000–9,999 100–999 < 100	FAIR to GOOD→ FAIR to GOOD est. 500–5,000
36c. **Secure population status of false indigo** (*Baptisia tinctoria*)	Discrete clusters at least 500 apart—every 2–3 yr until GOOD, then every 3–5 yr	EXCELLENT GOOD FAIR POOR	≥ 4 3 2 1	unknown→POOR ? →2 known
	Estimated total number of stems—every 2–3 yr until GOOD, then every 3–5 yr	EXCELLENT GOOD FAIR POOR	≥ 2,500 500–2,499 100–499 < 100	POOR→POOR est. 50–100
36d. **Secure population status of dwarf chinkapin oak** (*Quercus prinoides*)	Discrete clusters at least 500 apart—every 2–3 yr until GOOD, then every 3–5 yr	EXCELLENT GOOD FAIR POOR	≥ 4 3 2 1	unknown→FAIR ? →2 known
	Estimated total number of stems—every 2–3 yr until GOOD, then every 3–5 yr	EXCELLENT GOOD FAIR POOR	≥ 500 250–499 100–250 < 100	POOR→POOR < 10
36e. **Secure population status of all native warm-season grasses in aggregate**	Use total area dominated by native serpentine grassland plant species as proxy	EXCELLENT GOOD FAIR POOR	≥ 45 acres 35–44.9 acres 25–34.9 acres < 25 acres	POOR→POOR 7 acres→8 to 9 acres

(Table continues on next page.)

desired condition	metric (= indicator) & suggested monitoring interval	target values	change 2012→2015
ARTHROPOD SPECIES OF CONSERVATION CONCERN			
37. **Presence and detection frequency of individual arthropod species of conservation concern**	Each species: number of individuals captured by standardized methods—every 3–5 yr	EXCELLENT GOOD contingent FAIR on species POOR	quantitative monitoring of arthropod species of conservation concern has not been started
	Each species: variation from previous surveys in number of individuals captured by standardized methods (population increase, decrease or stability)	EXCELLENT GOOD contingent FAIR on species POOR	quantitative monitoring of arthropod species of conservation concern has not been started
BIRD SPECIES OF CONSERVATION CONCERN (LISTED AS ENDANGERED, THREATENED OR NEAR-THREATENED IN PENNSYLVANIA)			
38a. **Secure breeding status of individual bird species** found nesting at the site in surveys	Each species: verified nesting pairs in Unionville Barrens—yearly	EXCELLENT ≥ 15 GOOD 10–14 FAIR 5–9 POOR < 5	no such species observed during breeding season to date
	Each species: variation in number of verified nesting pairs from average over previous 3 yr (short-term population increase, decrease or stability)	EXCELLENT < 10% decline GOOD 10%–14.9% decline FAIR 15%–19.9% decline POOR ≥ 20% decline	no such species observed during breeding season to date
	Each species: variation in number of verified nesting pairs from average over previous 15 yr (long-term population increase, decrease or stability)	EXCELLENT ≤ 0% decline GOOD 0.1%–5% decline FAIR 5.1%–10% decline POOR > 10% decline	no such species observed during breeding season to date

(Table continues on next page.)

desired condition	metric (= indicator) & suggested monitoring interval	target values	change 2012→2015
BIRD SPECIES LISTED IN CURRENT STATE WILDLIFE ACTION PLAN (SWAP 2015) AS SPECIES OF GREATEST CONSERVATION NEED			
38a. **Secure breeding status of field sparrow**	Average number of birds seen or heard in at least three timed point counts at 20 observation points during the breeding season—yearly	EXCELLENT ≥ 10 GOOD 6–9 FAIR 3–5 POOR < 3	POOR→POOR 0→0
	Variation in number of observations during breeding season from average over previous 3 yr (short-term population increase, decrease or stability)	EXCELLENT < 10% decline GOOD 10%–14.9% decline FAIR 15%–19.9% decline POOR ≥ 20% decline	POOR (intermittent) 2012: 0 2013: 0.67 2014: 0.67 3-yr average: 0.45 2015: 0
	Variation in number of observations during breeding season from average over previous 15 yr (long-term population increase, decrease or stability)	EXCELLENT ≤ 0% decline GOOD 0.1%–5% decline FAIR 5.1%–10% decline POOR > 10% decline	unknown until 2027
38b. **Secure breeding status of gray catbird**	Average number of birds seen or heard in at least three timed point counts at 20 observation points during the breeding season—yearly	EXCELLENT ≥ 10 GOOD 6–9 FAIR 3–5 POOR < 3	EXCELLENT→EXCELLENT 14.7→15.3
	Variation in number of observations during breeding season from average over previous 3 yr (short-term population increase, decrease or stability)	EXCELLENT < 10% decline GOOD 10%–14.9% decline FAIR 15%–19.9% decline POOR ≥ 20% decline	EXCELLENT (stable or increasing) 2012: 14.7 2013: 16.0 2014: 13.7 3-yr average: 14.8 2015: 15.3
	Variation in number of observations during breeding season from average over previous 15 yr (long-term population increase, decrease or stability)	EXCELLENT ≤ 0% decline GOOD 0.1%–5% decline FAIR 5.1%–10% decline POOR > 10% decline	unknown until 2027

(Table continues on next page.)

desired condition	metric (= indicator) & suggested monitoring interval	target values	change 2012→2015
38c. **Secure breeding status of eastern towhee**	Average number of birds seen or heard in at least three timed point counts at 20 observation points during the breeding season—yearly	EXCELLENT ≥ 10 GOOD 6–9 FAIR 3–5 POOR < 3	GOOD→GOOD 8.7→8.7
	Variation in number of observations during breeding season from average over previous 3 yr (short-term population increase, decrease or stability)	EXCELLENT < 10% decline GOOD 10%–14.9% decline FAIR 15%–19.9% decline POOR ≥ 20% decline	EXCELLENT (stable) 2012: 8.7 2013: 9.7 2014: 8.7 3-yr average: 9.0 2015: 8.7
	Variation in number of observations during breeding season from average over previous 15 yr (long-term population increase, decrease or stability)	EXCELLENT ≤ 0% decline GOOD 0.1%–5% decline FAIR 5.1%–10% decline POOR > 10% decline	unknown until 2027
38d. **Secure breeding status of wood thrush** NOTE: Wood thrush is a forest-interior species, therefore serpentine grassland restoration is incompatible with enhancing its habitat on the same tract of land. Like indicators 8–13, wood thrush status is an indicator of the quality of forest stands surrounding the grasslands.	Average number of birds seen or heard in at least three timed point counts at 20 observation points during the breeding season—yearly	EXCELLENT ≥ 10 GOOD 6–9 FAIR 3–5 POOR < 3	EXCELLENT→EXCELLENT 14.0→11.7
	Variation in number of observations during breeding season from average over previous 3 yr (short-term population increase, decrease or stability)	EXCELLENT < 10% decline GOOD 10%–14.9% decline FAIR 15%–19.9% decline POOR ≥ 20% decline	EXCELLENT (stable) 2012: 14.0 2013: 11.7 2014: 8.7 3-yr average: 11.5 2015: 11.7
	Variation in number of observations during breeding season from average over previous 15 yr (long-term population increase, decrease or stability)	EXCELLENT ≤ 0% decline GOOD 0.1%–5% decline FAIR 5.1%–10% decline POOR > 10% decline	unknown until 2027

(Table continues on next page.)

desired condition	metric (= indicator) & suggested monitoring interval	target values	change 2012→2015
OPEN-HABITAT BIRD SPECIES AS A GROUP			
38d. **Secure abundance of open-habitat bird species guild**	Average number of birds seen or heard in at least three timed point counts at 20 observation points during the breeding season of American goldfinch, eastern bluebird, field sparrow, indigo bunting, red-winged blackbird, song sparrow and any others that may appear—yearly	EXCELLENT ≥ 45 GOOD 30–44 FAIR 15–29 POOR < 15	POOR→POOR 3→12
	Variation in number of observations from average over previous 3 yr (short-term population increase, decrease or stability)	EXCELLENT < 10% decline GOOD 10%–14.9% decline FAIR 15%–19.9% decline POOR ≥ 20% decline	EXCELLENT (increasing) 2012: 1.0 2013: 3.0 2014: 1.7 3-yr average: 1.9 2015: 4.0
	Variation in number of observations from average over previous 15 yr (long-term population increase, decrease or stability)	EXCELLENT ≤ 0% decline GOOD 0.1%–5% decline FAIR 5.1%–10% decline POOR > 10% decline	unknown until 2027
ECOSYSTEM RESILIENCE			
39. **Relatively rapid recovery of indicators 4–38 (above) following severe drought or other major disturbance**	Each indicator: speed of recovery after disturbance severe enough to cause degradation of at least 50% of indicators to lower target values category	EXCELLENT ≤ 3 years GOOD 4–5 years FAIR 6–7 years POOR > 7 years	to be calculated across sequential monitoring intervals after drought or other major disturbance occurs
LANDSCAPE CONTEXT			
40. **Protected smoke and safety buffer within 1,000 feet of all management units**	Land area within 1,000 feet of management unit perimeter (out of 301 total acres in this zone) protected against additional building construction by zoning, easement, land trust ownership or public ownership	EXCELLENT 298–301 acres GOOD 271–297 acres FAIR 226–270 acres POOR < 226 acres	smoke and safety buffer mapping and monitoring have not been started
41. **Low populations of bird- and wind-dispersed invasive nonnative plant species within 500 feet of all management units**	Estimated area within 500 feet of management unit perimeter (out of 135 total acres in this zone) where cover of invasive nonnative plants of species with bird- and wind-dispersed seeds (see list of locally common species on p. 64) exceeds 10%.	EXCELLENT 0–6 acres GOOD 7–13 acres FAIR 14–20 acres POOR > 20 acres	invasive species buffer mapping, monitoring and treatment have not been started

Table F-9. **Prioritized summary of Unionville Barrens stewardship tasks for 2016–2020.** PSGCN stands for plant species of greatest conservation need.

task (numbers reflect priority level: 3–high, 2–higher, 1–highest)		completion target date	location(s)
1	Contract consulting expertise or training for staff in order to make sure a participant is always present and active during every major stewardship activity who knows all species of conservation concern on sight and the locations of every known stand of all highest-priority PSGCN, to help prevent accidental mortality in critically low populations and to continue searching for new stands and monitoring known stands of highest-priority PSGCN on a regular basis.		entire barrens area
1	Temporarily mark stands of highest-priority PSGCN at risk for accidental harm because they are in or near customary equipment travel lanes, in an area slated for tree removal or soil organic matter reduction, etc., and make sure all equipment operators are familiar with those locations.		scattered locations
1	Continue applying prescribed fire to at least one burn unit at the Unionville Barrens every year.		entire barrens area
1	Contract with timber harvester to remove trees of non-serpentine barrens species from grassland restoration areas.		orange & green hatched areas on Fig. F-2
1	Eradicate autumn-olive from most severely affected remnant (pre-2012) grasslands and grassland restoration areas.		Unit 6a
1	Explore options and costs of sharpshooter deer culling by requesting proposals from multiple contractors specializing in deer management (see examples in endnote 5).		entire barrens area
1	Georeference wetlands, including serpentine wetlands, marshes, spring seeps, and intermittent streams.		scattered locations
1	Continue monitoring the quantitative desired conditions metrics, analyzing trends and differences among treatments, and adjusting stewardship practices as needed.		entire barrens area
2	Eradicate autumn-olive from other remnant (pre-2012) grasslands and grassland restoration areas.		Units 1–5, 7
2	Apply soil organic matter reduction method to largest greenbrier patch in grassland.		Unit 2
2	Conduct trials of growing-season (late summer/early fall) fire in grassland restoration areas with high cover of Japanese stiltgrass.		grassland restoration areas
2	Work with partner organizations and Force of Nature volunteers to collect seed, propagate plants, and plant into grassland restoration area of the 6 to 10 most severely imperiled of the highest-priority PSGCN.		seed source locations & grassland restoration areas

(Table continues on next page.)

task (numbers reflect priority level: 3–high, 2–higher, 1–highest)		completion target date	location(s)
2	Partner with entomologists at regional universities, museums and state agencies to begin quantitative monitoring of selected grassland arthropod species of highest conservation need.		entire barrens area
3	Conduct trials of burning in consecutive years in the same burn units in grassland restoration areas with high cover of Japanese stiltgrass or other invasive species, varying the fire footprint between years to separate the effects of year and repeat burning.		grassland restoration areas
3	Begin eradication of autumn-olive from forest management areas.		mainly Units 1, 3
3	Establish permanent quadrats in at least three of the largest serpentine wetlands dominated by tufted hairgrass in order to track wetland desired conditions indicators.		Units 2a, 6a
3	Work with partner native-plant horticultural experts and Force of Nature volunteers to collect seed, propagate plants, and plant into grassland restoration area of the remainder of the highest-priority PSGCN, after augmentation of the first set of species (priority level 2, above) is underway.		seed source locations & grassland restoration areas

Endnotes

[1] M.H. Meyer. Undated. Fact sheet and management of *Miscanthus sinensis*. University of Minnesota. 2 pp. (cels.uri.edu/docslink/ceoc/documents/Eulalia.pdf; accessed 2016-04-16).

[2] Flory, S. L. and J. Lewis. 2009. Nonchemical methods for managing Japanese stiltgrass (*Microstegium vimineum*). *Invasive Plant Science and Management* 2: 301-308.

[3] Quoted in Fryer, J. L. 2011. *Microstegium vimineum*. Fire Effects Information System [online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, Montana. (www.fs.fed.us/database/feis/plants/graminoid/micvim/all.html; accessed 2016-04-16)

[4] Latham, R. E., J. Beyea, M. Benner, C. A. Dunn, M. A. Fajvan, R. R. Freed, M. Grund, S. B. Horsley A. F. Rhoads and B. P. Shissler. 2005. *Managing White-tailed Deer in Forest Habitat from an Ecosystem Perspective: Pennsylvania Case Study*. Audubon Pennsylvania and the Pennsylvania Habitat Alliance, Harrisburg. 340 pp. (pa.audubon.org/managing-white-tailed-deer-forest-habitat-ecosystem-perspective; accessed 2016-04-16)

[5] Options include:
- Wildlife Specialists LLC, Wellsboro, Pennsylvania (www.wildlife-specialists.com)
- Eccologix BioDiversity Consulting Group, Bedminster, Pennsylvania (www.eccologix.com)
- White Buffalo Inc., East Haddam, Connecticut (www.whitebuffaloinc.org)
- APHIS (Animal and Plant Health Inspection Service), U.S. Department of Agriculture, Pennsylvania office, Harrisburg (www.aphis.usda.gov/aphis/ourfocus/wildlifedamage)

[6] Jason Ryndock, Ecological Information Specialist, Pennsylvania Department of Conservation and Natural Resources, Bureau of Forestry—personal communication, 2013

[7] Pickens, B. Undated. Fire ecology of shortleaf forests. Shortleaf Pine Initiative [online]. 3 pp. (shortleafpine.net/growing-shortleaf-pine/stand-management/prescribed-fire; accessed 2016-04-19)

[8] Betsy Leppo, Invertebrate Zoologist, Western Pennsylvania Conservancy—personal communication, 2007

[9] Smith, S. R. 2012. Checklist of the Lepidoptera of the Unionville Serpentine Barrens (prior to the restoration and management program). Submitted by author to Natural Lands Trust, Media, Pennsylvania. 126 pp.

[10] Haffner, C. and D. Day (eds.). 2015. Pennsylvania Wildlife Action Plan, 2015-2025. Pennsylvania Game Commission and Pennsylvania Fish and Boat Commission, Harrisburg, Pennsylvania. 2,118 pp. (fishandboat.com/swap.htm; accessed 2016-04-19)

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Center for Land Use Education and Research. 2015. Landscape Fragmentation Tool (LFT) v 2.0. Deptartment of Natural Resources Management and Engineering, University of Connecticut, Storrs. (accessed 2016-04-19)

Latham, R. E. and M. McGeehin. 2012. *Unionville Serpentine Barrens Restoration and Management Plan*. Continental Conservation, Rose Valley, Pennsylvania and Natural Lands Trust, Media, Pennsylvania. 157 pp. + 10 maps.