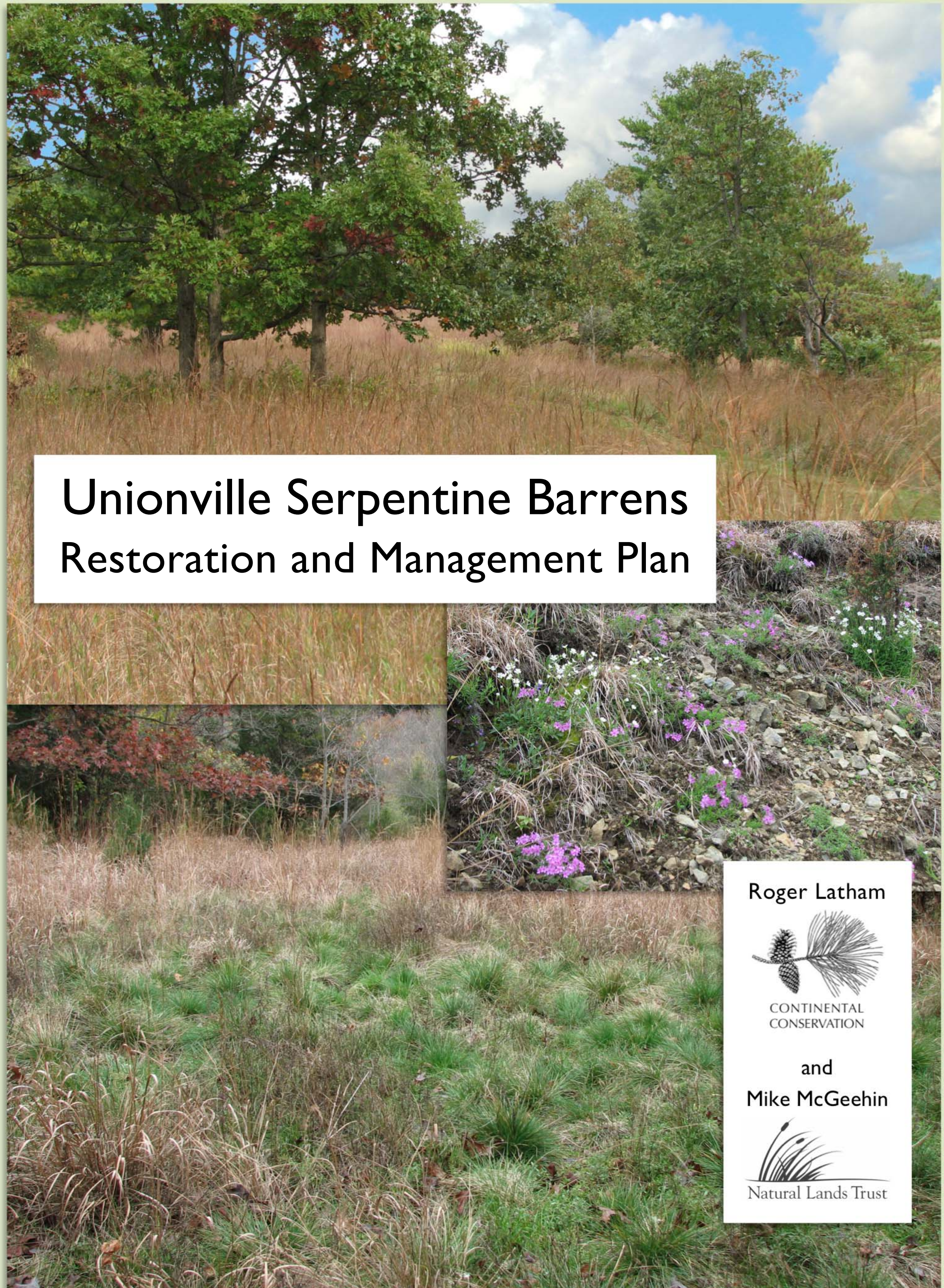


Unionville Serpentine Barrens
Restoration and Management Plan

Roger Latham
CONTINENTAL CONSERVATION

and

Mike McGeehin
Natural Lands Trust

Cover: The highest-priority targets for restoration and management at the Unionville Barrens are serpentine Indian-grass – little bluestem grassland (top), serpentine gravel forb community (right center) and serpentine seep (bottom). They are globally rare communities and harbor an extraordinary diversity of species of special conservation concern. (Photos by Roger Latham.)

Suggested citation for this document:

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.

Unionville Serpentine Barrens Restoration and Management Plan

Roger Latham

Continental Conservation
Rose Valley, Pennsylvania

and

Mike McGeehin

Natural Lands Trust

For

Natural Lands Trust

Media, Pennsylvania

2012

Table of Contents

Summary ... 1

1 Introduction ... 3
1.1 Background on serpentine barrens ... 3
1.2 Importance of grassland conservation ... 9
1.3 Significance of the Unionville Barrens ... 11
1.4 Purpose of the restoration and management plan ... 13

2 Project Area Description ... 15
2.1 Physiographic and geological setting ... 15
2.2 Land-use history ... 16
2.3 Ecosystem components ... 20
2.3.1 Historical vegetation ... 20
2.3.2 Soils ... 23
2.3.3 Present-day ecological communities ... 29
2.3.4 Species surveys ... 33
2.3.4 Vascular plant species of special conservation concern ... 37
2.3.5 Animal species of special conservation concern and their habitat needs ... 38

3 Desired Conditions, Indicators of Management Success, and Threats ... 41
3.1 Desired conditions ... 41
3.1.1 Qualitative summary of desired conditions ... 41
3.1.2 Species diversity and composition ... 42
3.1.3 Structural, patch and habitat diversity ... 43
3.1.4 Ecosystem processes ... 45
3.1.5 Landscape context ... 48
3.1.6 Metrics of ecosystem condition—the phytometer approach ... 49
3.2 Threats ... 61
3.2.1 Critically low population numbers associated with habitat area decline ... 61
3.2.2 Fire exclusion and forest succession ... 62
3.2.3 Invasive and aggressive plant species ... 63
3.2.4 Artificially elevated white-tailed deer population ... 64

4 Management Recommendations ... 67
4.1 Adaptive management ... 67
4.1.1 Selective tree removal and replacement ... 68
4.1.2 Prescribed burning ... 71
4.1.3 Invasive and aggressive species control ... 73
4.1.4 Deer management ... 78
4.1.5 Species reintroduction and augmentation ... 79
4.1.6 Maintaining esthetic and historical preservation standards ... 79
4.2 Monitoring ... 80
4.2.1 Quadrat monitoring of vascular plant species cover ... 80
4.2.2 Monitoring sparsely distributed plant species of special conservation concern ... 82
4.2.3 GIS metrics ... 82
4.2.4 Monitoring bird populations ... 82
4.2.5 Monitoring arthropod populations ... 82
4.2.6 Monitoring deer effects ... 83

4.2.7 Baseline surveys focusing on ecosystem components of special conservation concern 83
4.3 Stewardship task priorities and timeframe 84
4.3.1 Management units 84
4.3.2 Highest-priority stewardship tasks for 2012–2013 90

References Cited 92

Acknowledgments 100

Glossary 101

Appendices

Appendix A. Interpretation of rank and status codes for species of special conservation concern 109
Appendix B. Vascular plants of the Unionville Barrens 111
Appendix C. Arthropods of special conservation concern that may inhabit the Unionville Barrens 145
Appendix D. Notes on design of adaptive management trials 149
D.1 Replication 149
D.2 Randomization 150
D.3 Experimental control 151
D.4 Standards of evidence 152
Appendix E. Online information sources for major invasive species in the Unionville Barrens 154

Site Maps

Map 1. Landscape context 159
Map 2. Serpentine grasslands, 1937 161
Map 3. Serpentine grasslands, 1971 163
Map 4. Vegetation structure, 2008 165
Map 5. Grassland succession history, 1937–2010 167
Map 6. Estimated soil depth to bedrock 169
Map 7. Estimated soil A-horizon thickness 171
Map 8. Features of special conservation concern or historical significance 173
Map 9. Existing and potential trails, vehicular access and firebreaks 175
Map 10. Serpentine barrens restoration and management units 177

Tables

Table 1. Plants documented at the Unionville Barrens before 1912 but not found in recent (2002–2011) surveys 22
Table 2. Comparison of soil chemistry between soils derived from serpentinite and those derived from other bedrock types 25
Table 3. Summary of the vascular plant flora of the Unionville Barrens and adjacent forest 34

Table 4. Summary of the characteristic serpentine grassland species present at the Unionville Barrens 35
Table 5. Plants of special conservation concern recorded recently at the Unionville Barrens 35
Table 6. Plants of special conservation concern documented historically but not seen recently at the Unionville Barrens 37
Table 7. Desired conditions, metrics, target values and existing conditions of the Unionville Barrens 50
Table 8. Sizes of management units and their component grassland and forest management areas 85
Table 9. Prioritization of major recommendations for restoration and management of the Unionville Barrens 86
Table 10. Summary of highest-priority stewardship tasks for 2012–2013 91
Table A-1. Explanation of global and state rarity ranks 109
Table A-2. Explanation of Pennsylvania Biological Survey (PABS) status codes 110
Table A-3. Explanation of Pennsylvania conservation tier codes 110
Table B-1. List of the vascular plants of the Unionville Barrens 112
Index to Table B-1 132
Table C-1. Arthropods of special conservation concern that may inhabit Unionville Barrens 146

Figures

Figure 1. Ultramafic bedrock and estimated peak historical extent of serpentine barrens in the Northern Piedmont 5
Figure 2. Decline in serpentine grassland area at Unionville Barrens, 1937–2010, due to forest succession 23
Figure 3. Comparison of soil A-horizon thickness across succession history categories 28
Figure 4. Comparison of soil A-horizon thickness between wooded (forest and woodland) and open (grassland) areas 28
Figure 5. Autumn-olive removal plots 75

Summary

In value for biodiversity conservation, the Unionville Barrens rank among the highest-priority sites in southeastern Pennsylvania. A globally rare ecosystem and a cluster of rare species give the site national or even global significance. The ecosystem—temperate eastern North American serpentine barrens—consists of a species-rich set of ecological communities associated with soils weathered from serpentinite bedrock, a rare geological formation. The Unionville Barrens feature traces of prehistoric and historical human land uses that also contributed in crucial ways to the site's unique natural qualities. The flora and fauna include an exceptionally large number of rare, threatened and endangered species. However, the barrens vegetation has been losing ground for the past several decades, shrinking in area and declining in native species diversity with the waning of the disturbance regime that formerly sustained it, in all likelihood for a timespan of several thousand years. This plan offers an outline of how the decline of this treasured piece of our natural heritage can be reversed and key processes restored to insure the long-term sustainability of the serpentine barrens ecosystem and its component species.

Grasslands make up a small fraction of the total serpentine barrens area but they harbor nearly all of the rare species. Other serpentine barrens communities intermixed with and surrounding the patches of grassland include unusual woodland and wetland communities. The total serpentine grassland area at the Unionville Barrens has declined drastically from more than 63 acres in 1937, the earliest credible size estimate, to 7 acres in 2010. It is crucial to the conservation of the entire set of serpentine barrens communities to restore as much as is feasible of the area of grassland recently lost to forest succession.

The plan's underpinnings include two studies undertaken as part of the planning effort: (1) creation and analysis of a chronosequence of vegetation maps showing changes between 1937, 1958, 1971, 1990 and 2010 using air and satellite imagery and digital mapping (GIS) tools; (2) systematic sampling and mapping of soil physical characteristics. The GIS analysis documents the history of grassland loss to forest succession, providing signposts to the most suitable areas for grassland restoration. The soil study was based on research at another serpentine barren showing soil depth to be a key factor in grassland persistence and rate of loss due to forest succession. That finding was applied at the Unionville Barrens to explore the usefulness of simple, inexpensive soil measurements as a basis for evaluating areas where restoration and maintenance are likely to be cost-effective versus those where they may be prohibitively costly.

Specific, measurable objectives for desired conditions were developed based on what is known about the ecology and history of the Unionville Barrens and other native grasslands and serpentine barrens in the region. In the plan, desired conditions are itemized and compared with existing conditions to serve as the basis for strategies to narrow the gap between the two. Methods to achieve the desired conditions are outlined. Specific areas of land are prioritized for such tasks as invasive species eradication, selective tree removal, creation of standing dead snags, soil organic matter removal, seedbank augmentation, propagation and planting of selected species, restoration burning and maintenance burning.

The plan takes an adaptive management approach, which, in brief, consists of carrying out a set of actions, periodically monitoring the results, reconsidering the

methods in light of those results, and adjusting the next round of implementation accordingly. This approach is a way of reducing uncertainty without high-cost research. Trials of promising alternative methods for achieving objectives are carried out and results compared quantitatively as a part of routine management. Monitoring is an indispensible part of adaptive management, generating practical new knowledge that is promptly put to use.

Monitoring is in essence an audit—a systematic, disciplined approach to evaluate and improve the effectiveness of management. The plan outlines a strategy for monitoring a set of indicators to track changes in conditions resulting from both management actions and external causes and to improve consistency, rigor and efficiency in measuring progress toward achieving and sustaining the desired conditions.

1 Introduction

1.1 Background on serpentine barrens

The open grasslands, greenbrier thickets and oak woodlands at the Unionville Barrens are collectively called serpentine barrens: *barrens* because farmers long ago discovered that the soils were poor for growing crops, and *serpentine* because the main cause of the infertility—the bedrock from which the soils are weathered—is a rare rock formation called serpentinite. Serpentine grassland is one of the rarest natural communities in eastern North America. Grasslands, pine-oak and oak woodlands, and the other ecological communities that make up serpentine barrens live on thin soils overtop a geologic oddity, a metamorphic, light-green rock formed in deep cracks on the seafloor. Most of the earth's supply of serpentinite still lies buried under the seafloor, far beneath the surface of the world's oceans. It is rare on the continents, present in North America, for example, only in a few scattered, isolated patches from Georgia to Newfoundland and in Alaska, Oregon, California, Costa Rica and Cuba.

The Unionville Barrens are an example of a globally rare complex of related ecological communities known as temperate eastern North American serpentine barrens. Never very abundant, this ecosystem has declined through attrition from nearly 40 sites when botanists began keeping records to less than 20 sites today (Figure 1, p. 5). Around 93% of the total area remaining is on the Northern Piedmont of Pennsylvania (~ 49%), Maryland (~ 44%) and New York (very small remnants on Staten Island). The rest is on the Piedmont in northeastern Georgia (~ 6%) and on the Blue Ridge in western North Carolina (~ 1%).

Barrens cover a small fraction of the total bedrock area. Grasslands, in turn, make up a small fraction of the barrens, which are mainly woodland and forest with a canopy of blackjack oak, post oak and sometimes pitch pine, usually intermixed with other oak species, eastern red-cedar and Virginia pine. Serpentinite bedrock underlies approximately 15,500 acres in Pennsylvania[1], 23,400 acres in Maryland[2], and 400 acres in Delaware[3], a total of 39,300 acres or 86 square miles (Figure 1). In contrast, the total area of serpentine barrens vegetation totals approximately 1,800 acres in Pennsylvania and 1,600 acres in Maryland[4]; serpentine barrens vegetation has been extirpated from Delaware. The sum of the remaining area of all Northern Piedmont serpentine barrens is an estimated 3,400 acres or just over 5 square miles, covering less than 9% of the area underlain by serpentinite bedrock (Figure 1).

The serpentinite underlying the barrens and nearby forest and farmland (see Maps 1, 2 and 3) formed beneath the Iapetus Ocean, a predecessor to the Atlantic, most likely around a half-billion years ago. Serpentinite is a metamorphic rock, formed by slow chemical changes to the igneous rock peridotite, the main constituent of the earth's crust beneath the bottoms of the world's oceans. *Serpentinization* occurs where peridotite is exposed to seawater. Olivine and pyroxenes—the main mineral constituents of peridotite—are converted into *serpentine minerals* by the incorporation of water into their crystalline

[1] Pennsylvania Bureau of Geologic and Topographic Survey (2001)

[2] Cleaves *et al.* (1968)

[3] Plank *et al.* (2000)

[4] R. E. Latham, unpublished data

structures. Serpentine minerals have the general chemical formula $Mg_3Si_2O_3(OH_4)$. Serpentinite by definition is rock rich in serpentine minerals, but it has other chemical attributes that set it apart from most other types of rock, including higher iron, nickel, cobalt and chromium and lower calcium. Igneous peridotite and its metamorphic offspring, including serpentinite, are classified as *ultramafic* rocks, reflecting their very high magnesium ("ma") and iron ("f" for ferric) contents[1]. As a side note, serpentinization is gaining recognition as of vital importance for the original emergence of life on earth, and possibly on other planets, because the hydrogen released during the process was a key energy source for metabolism and with geothermal heating it combined with CO_2 to form organic compounds vital to cell formation, including hydrocarbons and fatty acids[2].

This begs the question, how did rock that formed beneath the bottom of the ocean end up at the surface of a continent? The answer involves plate tectonics. During an extremely slow but almost inconceivably colossal collision of North America with Africa that swept up a volcanic island arc similar to today's Japanese archipelago, the last remnant of the Iapetus Ocean was squeezed out of existence between 350 and 300 million years ago. Most of the sea-bottom rock was overridden by the drifting continents and pressed downward into the earth's molten interior, but a few broken pieces caught on the continent's edge and stuck there. Like cars crashing in slow motion, the two continents' crumpled leading edges compressed horizontally and rose vertically, forming a Himalaya-sized mountain range, much as the Himalayas are still forming today while greater India, once a huge island, continues its ongoing slow collision with the rest of Asia. The few fragments of ocean-bottom rock that had jumbled together with the continental rocks at the suture line lay deep inside the mountains. North America and Africa parted once again and at least 100 million years of erosion by runoff and landslides have slowly worn the mountains down, depositing most of their bulk as silt and rubble on the continental shelf off the Atlantic coastline and the bottom of the Western Interior Seaway, a shallow sea that covered the middle of North America. The igneous and metamorphic rocks at the surface of the present-day Northern Piedmont, including small, scattered areas of serpentinite (Figure 1), were deep inside the core of that long-gone mountain range.

The soil that forms overtop serpentinite bedrock is different from any other soil in the world. Its key characteristics from the plants' perspective are unusually high levels of magnesium (Mg) and nickel (Ni) and very low calcium (Ca) content. Because the plant life of serpentine barrens is stunted, the soil is often assumed to be overly well drained and sandy like the coastal plain soils of the New Jersey Pine Barrens. This is a misconception. Serpentine soil is actually a moist loam. Where it is not extremely thin or eroded, its texture and moisture content are comparable to those of a good agricultural soil[3]. It is the soil's peculiar chemical characteristics that make it a challenging medium for plant growth. Most plants need much more Ca than serpentine soil can provide. At the same time Mg, an essential mineral for plant growth, is present in such high concentrations that it can be toxic, a textbook case of "too much of a good thing." In parts of some serpentine barrens, Ni also may be abundant enough to deter the growth of many plant species.

The unusual soil mineral conditions, in particular high Mg and Ni and low Ca, are collectively known as the "serpentine soil

[1] Discussion of serpentinite mineralogy is based on Brooks (1987)

[2] Müntener (2010)

[3] Hull and Wood (1984); Latham (1993)

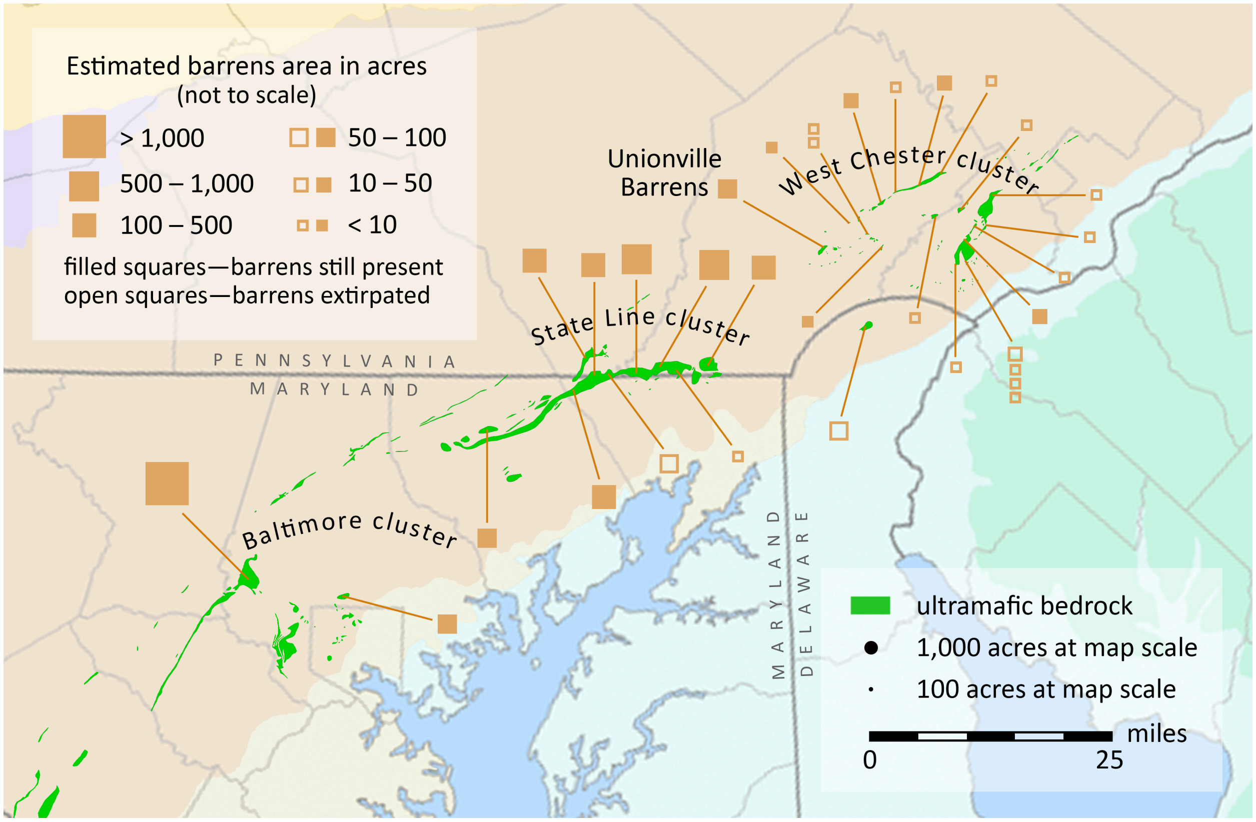


Figure 1. **Ultramafic bedrock (green) and estimated peak historical extent of serpentine barrens (square symbols) in the Northern Piedmont (light brown).** Serpentine vegetation is documented historically at 32 sites on the map (15 still exist) as covering a small fraction of the total area underlain by ultramafic bedrock (serpentinite). Sources: bedrock geology—Pearre and Heyl (1960); barrens locations and estimated peak historical acreages—R. E. Latham (unpublished data). Base map shows Level III ecoregions adjoining the Northern Piedmont (National Health and Environmental Effects Research Laboratory 2011)—Ridge and Valley (yellow); Blue Ridge (purple); Southeastern Plains (buff), Middle Atlantic Coastal Plain (light blue); Atlantic Coastal Pine Barrens (light green).

syndrome"[1]. Several studies have shown that Ca is the limiting factor for plant growth in serpentine soils[2], and other research points to high Mg or Ni levels as the primary constraints[3]. These findings are complementary rather than contradictory. High Mg levels are toxic only in the absence of sufficient levels of mitigating Ca[4] and many serpentine species have high calcium-use efficiency[5]. Ca has been shown to reduce the toxic effects of both Mg and Ni[6].

The serpentine soil syndrome is most pronounced where soils are eroded and shallow. Only a small fraction of the regional flora thrives under such conditions. By slowing plant growth, the serpentine soil syndrome promotes low macronutrient (nitrogen, phosphorus and potassium) turnover rates, hampering growth of macronutrient-demanding species, including most invasive nonnative species, even if they are tolerant of the

[1] Jenny (1980)
[2] E.g., Proctor and Woodell (1971)
[3] Nagy and Proctor (1997)
[4] Proctor (1970)
[5] Kruckeberg (1984)
[6] E.g., Gabrielli and Pandolfini (1984); Proctor and McGowan (1976)

serpentine soil syndrome[1]. The resulting sparse vegetation casts little shade, resulting in high soil surface temperatures, which in turn intensify drought stress. This combination of factors is a powerful deterrent to many plants and results in high levels of endemism as well as high local fidelity of many non-endemic species to serpentine soils[2]. Serpentine barrens can also provide important refugia for native flora and fauna not formerly limited to serpentine habitats but presently outcompeted by invasive species elsewhere in their range.

The thinner the soil over serpentinite bedrock, the more pronounced the effects are of low Ca and high Mg and Ni. Where the soil is thinnest at the Unionville Barrens, the plants that grow best are small, highly stress-tolerant grasses, graminoids and forbs, including many of the rare, threatened and endangered species living at the site. The typical cover on slightly thicker soils consists of perennial, warm-season prairie grasses such as little bluestem, Indian-grass and side-oats grama mixed with a variety of other grasses, sedges, rushes and wildflowers, including the rest of the Unionville Barrens' rare, threatened or endangered species. Serpentine grasslands are often called serpentine savannas because stunted trees, including post oak, blackjack oak and eastern red-cedar, grow sparsely among the grasses.

Relatively few species of plants are equipped to deal with the unusual chemistry of serpentine soil. Even the characteristic plants of serpentine barrens have stunted growth on serpentine soil, but unlike ordinary plants, they can "tough it out." Still, they pay a price for this ability. The anatomical and biochemical inner workings that enable some plants to tolerate extreme soil conditions are so costly in energy and resources that such plants are incapable of the rapid height growth needed to compete successfully with common plants on ordinary soil. They grow faster and larger on more fertile soil, but not as fast or as large as ordinary plants that lack the ability to endure on serpentine soil. This tradeoff is the key to why the serpentine barrens flora is very different from any other ecological community in the region. The characteristic plants of the serpentine barrens are poor competitors in forests and other commonplace habitats surrounding the barrens. Likewise, the plants that are good competitors on ordinary soil lack the ability to thrive on serpentine soil.

Even though the serpentine barrens plants are unusually tolerant of the harsh conditions, the soil chemistry and erosion-maintained shallowness alone are not enough keep their competitors at bay in the long term. They depend on periodic disturbance to prevent the buildup of organic matter and gradual development of more favorable soil conditions, which lead to replacement by common forest vegetation. For tens of millions of years (with interruptions during the past two million years by more than a dozen ice ages), such disturbance for the most part probably resulted from foraging, trampling, bedding down and wallowing by large, plant-eating animals. In what is now Pennsylvania and the mid-Atlantic region, woolly mammoth, Columbian mammoth, American mastodon, Wheatley's ground sloth and Jefferson's ground sloth[3] shaped ecosystems by toppling trees, scarifying and compacting the soil, and starting a cascade of indirect effects[4], resulting in a patchwork of persistent grasslands within a matrix of forest. Herds of mid-sized herbivores would have kept some of the

[1] Huenneke, *et al.* (1990)

[2] Kruckeberg (1984)

[3] Guilday (1971); Kurtén and Anderson (1980); Williams *et al.* (1985); Russell Graham, personal communication (2007)

[4] Milchunas *et al.* (1988); Folke *et al.* (2005); Zimov *et al.* (1995)

areas disturbed by the giant herbivores open and in grass cover, just as they do in Africa today where the presence of elephants is associated with the persistence of grasslands even where there is enough rain to support forests[1]. In what is now southeastern Pennsylvania those mid-sized grazers and browsers were eastern elk, moose, white-tailed deer and a host of now-extinct species, among them the black bear-sized giant beaver, giant horse, complex-toothed horse, Cope's tapir, vero tapir, long-nosed peccary, Leidy's peccary, flat-headed peccary, fugitive deer and stag-moose[2]. The extinctions of the last native elephants and giant ground sloths and most of the mid-sized grazers and browsers occurred nearly simultaneously with a wave of human immigration or cultural change around 13,000 years ago, 1,000–2,000 years or more after humans first arrived in the area. Ironically, people began opening up grasslands in eastern North America thousands of years ago by setting fires, inadvertently restoring some of the habitat diversity that had declined when nearly all of the megaherbivores died out, a catastrophe that most likely had been caused, directly or indirectly, by them or their ancestors.

The dependence of grasslands in eastern North America on disturbance—first by megaherbivores, later by fire, and still later by livestock grazing and mining—involves the process ecologists call *succession*. Succession refers to the gradual replacement of one kind of ecological community by another on the same piece of land. The most familiar example of succession in eastern North America is what happens when a farm field is abandoned. There is a constant rain everywhere of seeds of many plant species, including trees. Abandoned cropland or pasture usually has a residue of nutrients added in fertilizer or manure, which fosters the rapid establishment and growth of seedlings. In early succession, plants of different growth forms, whether they are trees, shrubs, grasses or other herbs, are all small in stature. In mid-succession, trees and shrubs have grown taller than their herbaceous neighbors. Still later, the trees outstrip the shrubs in height and the community becomes a young woodland or forest. When some of the trees have reached full maturity, a forest has entered late succession. Any often-observed sequence of this type is called a successional pathway or trajectory.

The unusual soil chemistry together with crowding by the dense grasses make it hard for most of the tree species native to our region to germinate and survive in serpentine grassland. But in the absence of disturbance, a transformation occurs along the margins of the patches where grass meets forest. Each year, full-grown forest trees in our region deposit 10 to 20 tons or more of dead leaves per acre[3]. The leaves decompose and enrich the soil's upper layers in organic matter. These layers are rich in nutrients and available moisture and forest plant species concentrate most of their root growth there. Organic matter-rich soils also form beneath overhanging trees along the grassland edge, making the soil there suitable for colonization by trees, shrubs and invasive plants, including species sensitive to the unusual chemistry of serpentine soil[4]. Furthermore, the partial shade at the forest edge suppresses the native grassland plants, which are intolerant of shade, while favoring the growth of tree seedlings and other forest species, which are intolerant of the extreme summer heat in the middle of a patch of grassland. Disturbances that kill adult trees, remove tree seedlings, or consume or remove dead leaves and other organic

[1] Dublin *et al.* (1990)

[2] Guilday (1971); Kurtén and Anderson (1980); Williams *et al.* (1985); Russell Graham, personal communication (2007)

[3] José-Luis Machado, personal communication (2005)

[4] Barton and Wallenstein (1997)

matter inhibit soil buildup. Only with regular disturbance do grasslands such as those at the Unionville Barrens persist in spite of succession.

The Unionville Barrens' exceptional diversity of grassland-specialist plants and the large number of rare species are good indicators that grassland has existed there for a very long time. We have no direct evidence farther back than the earliest botanical records in the 1800s, but high grassland diversity and the cluster of rare species are solid clues that the grassland's age is at least on the order of a thousand years. Its origin may well date back to the most recent major episode of global warming, which occurred between 8,000 and 4,500 years ago. With warming came frequent drought—each drought was a setback for succession, with young trees dying for lack of water—together with more widespread and frequent fires. But the climate turned cooler and wetter around 4,500 years ago and stayed that way until the mid-twentieth century, reducing the incidence of lightning-ignited wildfires to what it has been during recorded history in the region, which is near zero. Some Native American cultural groups regularly burned their woods and fields and many ecologists accept that it was this practice that made it possible for the barrens to persist until European settlement. Indians who used fire to modify the landscape in eastern North America did it most likely to improve game habitat, encourage the growth of certain fire-enhanced sources of food such as blueberries, huckleberries, blackberries and raspberries, and extend visibility, which would have made it easier to hunt, travel and maintain "homeland security."

There is no direct evidence—no "smoking flint"—of Native American burning at the Unionville Barrens, but several lines of circumstantial evidence point to a strong likelihood that the grassland is, in essence, an Indian artifact. Despite what most of us were taught in history class, not all the Mid-Atlantic region was forested when Europeans first arrived. Evidence is still accumulating from pollen core analysis and other research to confirm what is implied in the earliest historical writings—grasslands and meadows were far more widespread in prehistoric eastern North America than has been generally appreciated. Even before Native Americans were largely displaced, nearly all of the grasslands and meadows succeeded into forests or were converted into plowed fields. Only where the soils were too poor to grow crops or to support rapid invasion by forest trees (for instance, the thin soil over serpentinite bedrock) were native grasslands sustained after the local demise of Indian cultural practices. Even most of those places were covered over by forest vegetation eventually. Only the few acres that were kept cleared by livestock grazing, wildfires or activity associated with mining still have native grassland vegetation today. The grasslands that persisted the longest were those where plant growth is slowest due to unfavorable soil or microclimate, because there it took fewer and less frequent disturbances to keep the normal process of forest establishment at bay.

Native grasslands in the northeastern United States stir esthetic and scientific interest because they are rare and beautiful landscapes and habitats for unusual clusters of rare species. But part of their value and appeal is also cultural, historic and anthropological. Despite their wild appearance they are relics of an ancient way of life, a part of our cultural heritage. Any formerly Indian-maintained grasslands that still persist in the northeastern United States have been preserved and maintained, however inadvertently, by Westerners ever since they replaced Native Americans as stewards of the land. It is only recently that conservation agencies and private groups like Natural Lands Trust have made the long-term stewardship of such places intentional.

1.2 Importance of grassland conservation

Scientists conducting a global study of conservation needs recently tallied the total areas of habitat converted or destroyed and of habitat protected in all of the major ecosystem categories worldwide[1]. The picture is upbeat for certain ecosystems—including tundra, boreal forest and taiga, montane grassland and shrubland, and temperate conifer forest—but it is bleak for many others. Of all ecosystem types evaluated, temperate grassland, the category that includes the open area at the Unionville Barrens, is in the direst straits. For temperate grassland (including savanna) and shrubland together, the ratio of acres destroyed to acres protected is ten to one, five times higher than even the beleaguered tropical rainforest. Worldwide, only 5% of the land in temperate grassland and shrubland has been protected to date while 46% has already been destroyed. The figures are even more dismal for the eastern United States, where native grasslands have been under extreme pressure for more than 300 years and most were converted long ago to agricultural, residential, commercial and other uses.

Historically, grasslands occurred as breaks in the eastern deciduous forest resulting from disturbances such as fire, periodic flooding, insect infestation and clearing by humans—first by American Indians and later by settlers from the Old World. Most grasslands and meadows in eastern North America are short-lived ecosystems. Without repeated disturbance, trees and other forest plants seed in rapidly and reestablish the forest.

Since the first European settlement, native grasslands have steadily declined. These ecological communities were once home to hundreds of native plant species that, for millions of years, provided the highest quality food and habitat for native grassland animal species. The typical grassland or meadow today is an abandoned field invaded by a few introduced species—multiflora rose, autumn-olive, Japanese honeysuckle, Amur honeysuckle, Canada thistle, mile-a-minute and stiltgrass are examples—that crowd out the native plants and degrade the habitat for most native animal species. Native grasslands are now rare indeed.

Simply protecting native grasslands in rainy eastern North America is not enough to sustain them. Where it is left unimpeded the processes of soil development and forest succession transform the unique native grassland communities, with their high species diversity and many rare species, to common forests of moderate to very low native species diversity and abundant introduced invasive species. Invasive nonnative plants that are common in the woods near the edges of the Unionville Barrens grasslands include autumn-olive, Oriental bittersweet, Japanese honeysuckle, Amur honeysuckle, multiflora rose and stiltgrass. Some native species also can take advantage of the soil-building and heat-shielding opportunities of the forest-grassland edge and begin overrunning the grassland, including red maple and greenbrier. Black locust, introduced from farther west in North America, invades the grassland in a different way—established trees in the surrounding woods send in underground runners, new stems shoot up from those runners in what would ordinarily be hostile territory, and the mother trees subsidize shoots' water and nutrient needs through the runners until they build up enough soil organic matter from shed, nitrogen-rich leaves to support healthy root systems of their own. The result of invasion by native and nonnative plants is the shrinkage and

[1] Hoekstra *et al.* (2004)

disappearance of the grassland ecosystem and all of its characteristic species. The eventual result would be the tragic and irreversible loss of an extraordinary ecosystem that has existed for thousands of years.

Most grasslands or meadows in southeastern Pennsylvania have a recent agricultural past—old hayfields or pasture—and are dominated by nonnative cool-season grasses planted for centuries as fodder, such as tall fescue, perennial ryegrass, Kentucky bluegrass, orchard grass and timothy. Grasslands and meadows of native warm-season grasses, native cool-season grasses and native forbs are now rare but they provide far better habitat for many species of native wildlife, especially birds, than do old fields dominated by nonnative plants, which have become much more common. Native grasses, both warm-season and cool-season, are mainly bunchgrasses, unlike the sod-forming growth habit of most nonnative hay, pasture and lawn grasses. Grasses growing in tufts with space in between provide high-quality nesting sites and allow grassland birds and other animals to move more easily and with better protection from predators in their search for food. The space between clumps also provides room for native forbs.

More importantly, native grasslands and meadows are more valuable to wildlife than old fields with mostly nonnative plants because they are also far better habitats for the local arthropod fauna, mainly insects. Insects are vital links in many of the food chains that make up the food web in ecosystems. Most insect species are specialist feeders on just one native plant species or a narrow range of species. The close associations between the insect and plant species native to our region developed over millions of years. Invasive nonnative plants seldom are utilized as a food resource by native insect species, which is one of the reasons why they are invasive. Insects are the richest source of fats and protein for birds and for many small animals that, in turn, are food for larger animals. The result is that far less of the total plant biomass is converted, via the food chains that make up the food web, into animal biomass where nonnative plants are abundant. The higher the cover and species richness of native plants in a patch of grassland or meadow, the higher the insect biomass will be, which, in turn, enables native wildlife species to reach and sustain full abundance and diversity.

Ancient native grassland remnants such as those at the Unionville Barrens have incalculable value as scientific, historical and esthetic resources, as reference sites for grassland restoration and reclamation, and as the last stands of many locally and regionally indigenous genotypes[1]. Native grasslands share two key distinctions with wetlands: they are crucial for biodiversity conservation out of proportion to their small total area and they declined severely during the twentieth century. Recognition of their importance lags behind that of wetlands, but is making steady gains. Pennsylvania's Wildlife Action Plan[2] identifies grasslands as a high priority for protection and stewardship.

Estimated from historical records, grasslands and meadows within the area of present-day Pennsylvania covered 230–240 square miles around the time of European contact, just over 0.5% of the state's land area[3]. To put that figure into perspective, the estimated present-day wetland cover is 380 square miles or 0.8%[4]. Surviving remnants of early grasslands, including those at the Unionville Barrens, now sum to less than 1 square mile (0.002% of the state's area)— a 99.6% decline, which

[1] Latham and Thorne (2007)

[2] Pennsylvania Game Commission and Pennsylvania Fish and Boat Commission (2005)

[3] Historical and present-day native grassland and meadow acreage estimates are from Latham (2005).

[4] Myers *et al.* (2000)

continues and is even accelerating at many sites. Open areas dominated by nonnative species, often with extremely low species diversity and little value as wildlife habitat, cover a much larger area in the state than grasslands and meadows dominated by diverse mixtures of native plants. A recent estimate based on satellite imagery places 19.5% of Pennsylvania's land in grassland cover and other cover types with similar signatures in satellite images such as pasture and recently cut forest[1]. The amount of land in grasslands dominated by native species is unknown, but likely accounts for well under 1% of the state's land area. The area in long-persistent grasslands, including serpentine grasslands (in contrast with short-lived, early successional grasslands, which typically exist for less than a decade), is roughly 0.01% of the state's land area[2].

These small areas harbor a vastly disproportionate number of species of conservation concern. Of Pennsylvania's endangered plants, 112 (38%) typically inhabit persistent grasslands and meadows, as do 35 (41%) of those classified as threatened, and 38 (35%) of the plants that have been extirpated from the state since European settlement. At least 94 (51%) of the butterfly and moth species classified as endangered, threatened or rare in the state are known to depend in part or wholly on grasslands and meadows[3].

1.3 Significance of the Unionville Barrens

The Unionville Barrens have been recommended three times for National Natural Landmark status[4], a testament to their special value, which has been recognized by botanists since at least as far back as the early 1800s[5]. Two members of Unionville's Seal family contributed botanical specimens from the Unionville Barrens to the herbarium of the Academy of Natural Sciences of Philadelphia from the 1850s through the 1890s. Francis Whittier Pennell, curator of botany at the Academy of Natural Sciences of Philadelphia and the foremost twentieth-century botanical authority on Pennsylvania's serpentine barrens, first visited the site in 1908. The barrens have been a mecca for botanists and ecologists for well over a century in spite of restricted access by private landowners. The value of the site was affirmed yet again in 2010 when the barrens, protected in part by Natural Lands Trust the previous year, were designated by the Pennsylvania Department of Conservation and Natural Resources as a Wild Plant Sanctuary.

The exceptional diversity of native plant species at the Unionville Barrens includes populations of at least 18 plant species of special conservation concern in Pennsylvania, including one globally threatened species (detailed later). This is a phenomenally large cluster of imperiled species for a natural community that is now seven acres in size, although less than 70 years ago the serpentine grassland at Unionville was almost ten times larger. Another nine plant species of special concern have been recorded from the Unionville Barrens but not seen in recent years. Their disappearance is in all

[1] The sum of "woody transitional (5% < cover of woody plant foliage < 40%), also shrubland or forest regeneration" and "perennial herbaceous (grasslands, pasture, forage, old fields < 5% shrubs)" (Myers *et al.* 2000)

[2] Latham (2005a)

[3] Species tallies are from Latham (2005a)

[4] Radford and Martin (1975); Erdman (1977); Latham (1984)

[5] Darlington (1826, 1837)

likelihood a consequence of the dire loss in area of grassland habitat due to forest succession with the interruption of the disturbance regime (see Figure 2, p. 23).

It is next to certain that animal species classified as endangered, threatened or rare are also present. However, to date no one has done a systematic animal survey at the Unionville Barrens. There are nearly 50 animal species of special concern known so far at the State Line Barrens, a series of serpentine grasslands and woods along the Mason-Dixon Line in Pennsylvania and Maryland. Scientists expect to find many more kinds of rare animals on serpentine barrens eventually. So far, even at the State Line Barrens relatively little effort has been put into wildlife surveys except to search for butterflies and moths. Searches have been made of the Unionville Barrens specifically targeting three rare insect species, two plant bugs that feed on creeping phlox and one beetle whose larvae feed on the native grasses little bluestem and big bluestem[1]. The rare plant bugs were not found at Unionville but the rare beetle, which lives mainly in the prairies of the Midwest and West, was found there in 1987 (see Appendix C, p. 148).

Except for serpentine aster, the only serpentine barrens endemic living in the barrens, the species of special conservation concern are—or were in the case of extirpated species—at the edges of their main ranges or disjunct (separated) from them. Most live mainly in the drier Midwest, or in the hotter South, or on the sandy Atlantic Coastal Plain. The ranges of a few of the special-concern plants even extend into the Southwestern deserts and parts of Mexico. Disjunct and peripheral populations are of special conservation concern in part because their members usually are genetically distinct from individuals of the same species living elsewhere. In many cases these populations are where the most rapid evolution is taking place. Any mutation that happens to increase survival or reproduction under local conditions can quickly spread throughout a small, isolated population. If they have been isolated for long enough and far enough from their species' main range, some disjunct and peripheral populations when studied intensively are determined to be new varieties or subspecies or even new species. This likelihood is higher the more specialized the habitat is; grassland underlain by serpentine soils is a prime example.

The Unionville Barrens rank high in conservation importance among the few serpentine barrens that still exist. Part of the reason is that site quality, species and habitat diversity, and potential long-term viability are high relative to the other remaining serpentine barrens in the region. Landscape context also makes the Unionville Barrens uniquely important. Temperate eastern North American serpentine barrens occur in four widely separated areas—the core area in Pennsylvania and Maryland (and formerly Delaware), with 14 extant sites, and three outliers in Georgia, North Carolina and New York, consisting of one large, one small and two or three very small sites, respectively. The core area, in turn, is divided into three discrete clusters (Figure 1, p. 5), which coincide with the former mining districts associated with serpentinite bedrock, identified in the mining literature as the Baltimore (southwestern), State Line (central) and West Chester (northeastern) districts[2]. Each of the clusters has a distinctive flora. The Unionville Barrens are, and probably always were, the largest single area of serpentine vegetation and historically harbored the largest diversity of serpentine barrens-restricted plant species in the West Chester cluster. Its location at the southwestern end of the cluster nearest to the larger State Line

[1] Wheeler (1988, 1995)

[2] Pearre and Heyl (1960)

Barrens complex potentially makes it a critical steppingstone for species that occasionally find their way from one serpentine barrens "island" to another.

For thousands of years, when a wild population was extirpated from one of the local group of serpentine barrens, the species had a chance of regaining its lost foothold by chance recolonization from one of the other sites in the group. Ecologists term this the *rescue effect*. Species of serpentine grassland-restricted animals and plants have always been distributed among the "archipelago" of serpentine barrens as metapopulations—groups of partially isolated populations belonging to the same species. The subpopulations of a metapopulation are interconnected by occasional cross-migration. Individuals can recolonize a site where a species has died out locally. Gene flow among habitat islands is maintained, lessening the deleterious effects of inbreeding. Now that only 6 are left of the serpentine grasslands that once numbered 21 in the West Chester cluster, spontaneous "rescue" of extirpated species or replenishment of a diminished gene pool is much less likely. "Assisted migration" as part of an ecosystem restoration program may be the only way to mitigate such losses. As the largest and most species-rich of those remaining sites, the Unionville Barrens' role as a regional source and safe haven for imperiled species populations is more crucial than ever.

1.4 Purpose of the restoration and management plan

The primary purpose of this plan is to provide guidance to Natural Lands Trust (NLT) for the restoration and management of the serpentine barrens ecosystem at the Unionville Barrens. The overarching goal is to restore and maintain a suite of habitats that sustains the long-term integrity of the serpentine barrens ecosystem, including the imperiled species of flora and fauna and a diversity of serpentine barrens communities.

A secondary purpose of the plan is to serve as an educational and fundraising tool. Detailed background on the natural history, scientific significance and conservation importance of this ancient remnant of our natural heritage—and of native grasslands in general—is presented in a non-technical way, in recognition of the value of imparting this information to a broader audience beyond NLT conservation and stewardship staff.

2 Project Area Description

2.1 Physiographic and geological setting

The Unionville Barrens lie in the Piedmont Uplands (Level IV ecoregion) of the Northern Piedmont (Level III), within the Eastern Temperate Forests (Level I)[1]. Rounded hills, low ridges and narrow valleys characterize the Piedmont Uplands, which extend from the falls on the Delaware River near Trenton, New Jersey to a point about 40 miles southwest of Charlottesville, Virginia, reaching a width of about 40 miles between the Susquehanna and Potomac Rivers. The local section is the 330 square-mile watershed of Brandywine Creek, whose West Branch passes within 3,000 feet northeast of the barrens. Elevations typically range from 200–1,000 feet above mean sea level, with relatively sharp local relief of 130–330 feet[1]. Elevations in the Unionville Barrens and immediate surroundings range from 300 feet just downstream along Corundum Run to nearly 470 feet where Cannery Road crosses the top of Corundum Hill (labeled on Map 8).

The Piedmont Uplands are underlain by metamorphic rocks, principally schist, gneiss and quartzite, with small areas of serpentinite and marble and narrow dikes of the igneous rocks diabase and pegmatite. The barrens occupy nearly half of the largest serpentinite outcrop in central Chester County, an area of approximately 260 acres in Newlin Township (Map 1). Two pegmatite dikes running north-south split the serpentinite bedrock area and the barrens. One is close to and roughly parallels the courses of Feldspar Run and lower Corundum Run and the other is aligned with Serpentine Run along the barrens' east side (Maps 2, 3 and 4).

The nearest serpentinite outcrops of greater size are 9 miles southeast in Christiana Township, New Castle County, Delaware and 9 miles northeast, where a long, narrow band crosses East Goshen, Willistown and Eastttown Townships in eastern Chester County (see Figure 1, p. 5). The nearest extant serpentine barrens are on smaller outcrops: Marshallton Barrens, 3½ miles northeast (less than 1 acre in size; part of NLT's Stroud Preserve); Brintons Quarry, 6 miles east (about 2 acres; owned and managed by the Quarry Swimming Association); and Fern Hill, 7 miles northeast (approximately 30 acres; mostly owned by a developer and proposed to be turned over to a homeowners association[2]). Historically, there were two more serpentine barrens within that distance range but they no longer exist; they were at Sconnelltown and Strodes Mill, about 4½ and 5 miles east-northeast (areas unknown)[3].

The West Chester cluster of serpentine barrens, which formerly numbered at least 21 sites, extended from the Unionville Barrens and Mt. Cuba Barrens, the extirpated site in Delaware, at the cluster's western and southern ends to a site (now also extirpated) 18 miles away at the cluster's northeastern corner. The nearest site within the State Line Barrens—the largest serpentine barrens cluster in temperate eastern North America in terms of acreage—lies 16 miles southwest of the Unionville Barrens (Figure 1).

Culturally, the area surrounding the Unionville Barrens is a rural but suburbanizing landscape, a mosaic of cultivated fields—mainly used to grow hay,

[1] Wood *et al.* (1999)

[2] Conestoga-Rovers & Associates (2010)

[3] Pennell (1910; 1912)

corn and soybeans—alternating with small to medium-size blocks of forest. Other surrounding land uses and cover types include orchards, pastures, reclaimed native grasslands and single-family residences. Land protection efforts have been intensive and highly successful. NLT, Brandywine Conservancy, Chester County, townships and the Pennsylvania Agricultural Conservation Easement Purchase Program have protected one-third of the area within the 6 mile-wide square centered on the barrens (nearly 30,000 acres) by acquiring fee interest and easements (Map 1). Most of the protected land is forested or actively farmed.

2.2 Land-use history

Nothing is known of the prehistory of the Unionville Barrens before European settlement except a reasonable inference—from the existence of a highly diverse assemblage of rare grassland-dependent plants in a mostly forested landscape—that the site was regularly included in presumably much larger areas subjected to repeated burning by American Indians. The practice of burning to create and maintain landscapes favorable for game habitat, travel, security and production of useful plants likely waxed and waned locally many times through the millennia as people of different cultural traditions came and went.

Archaeologists can confidently date only the most recent events in the chronology of human habitation in the Brandywine Creek watershed. Village-dwelling Shenks Ferry people, who lived mainly in the lower Susquehanna Valley starting sometime after A.D. 1000, expanded into the Brandywine Valley soon after 1350[1]. Their culture collapsed throughout its territory in the early 1500s, likely because of social and economic chaos resulting from mass deaths caused by European diseases transmitted indirectly from faraway European settlements. The Lenape, who were culturally very different from the Shenks Ferry people and lived mainly in seasonal camps, expanded into the Brandywine Valley from along the Delaware River and Atlantic coastal areas sometime after 1550, filling the vacuum left by the disintegration of Shenks Ferry society[1]. Nothing is known of the burning practices of the Shenks Ferry people or of any of their predecessors living in the region. The nearest place where there is a well-documented timeline of the incidence of fire is southeastern New York State, where landscape-scale burning first spiked around 9,000 years ago and was variable but persistent until falling steeply at the time of European settlement[2].

Pehr Lindeström, an engineer in 1654–1656 for the New Sweden colony in present-day southeastern Pennsylvania, Delaware and southwestern New Jersey, was an eyewitness to local burning practices by the native Lenape. In his memoir, he wrote an account, later translated into English:

> Now as soon as the winter bids good night, they [the Lenape] begin with their hunts, which is done with a fine innovation. Now at that time of the year the grass which grows there, as has been said, is as dry as hay. When now the sachem wants to arrange his hunt, then he commands his people [to take a position] close together in a circle of ½, 1 or 2 miles [the Swedish mile was 36,000 feet], according to the number of people at his command. In the first place each one roots up the grass in the position, [assigned to him] in the circumference, to the width of about 3 or 4 ells [forearm lengths], so that the fire will not be able to run back, each one then beginning to set fire to the grass, which is mightily ignited, so that the fire travels away, in towards the center of the circle, which the Indians follow with great noise, and all the animals which are found

[1] Custer (1996).

[2] Robinson *et al.* (2005)

> within the circle, flee from the fire and the cries of the Indians, traveling away, whereby the circle through its decreasing is more and more contracted towards the center. When now the Indians have surrounded the center with a small circle, so that they mutually cannot do each other any harm, then they break loose with guns and bows on the animals which they then have been blessed with, that not one can escape and thus they get a great multitude of all kinds of animals which are found there.[1]

There might also have been prehistoric exploitation of the unusual mineral resources of the Unionville Barrens. Some of the serpentinite outcrops of the Northern Piedmont have been identified as the locations of ancient soapstone (steatite) quarries[2]. Soapstone is a lustrous, highly heat-resistant, soft, easily carved rock composed mainly of the mineral talc, a hydrated magnesium silicate, and often found with serpentinite. It has been used for thousands of years by Native Americans (and others worldwide) to make figurines and durable cookware. Any evidence of such exploitation would in all probability have been eradicated by intensive mining in the nineteenth century, described later in this document.

Likewise, we can only make educated guesses about the Unionville Barrens' early history after European settlement. Present-day Newlin Township was first outlined in a survey in 1688 by the provincial government as one large parcel, the whole of which was purchased in 1724 by Nathaniel Newlin for £800. He and his heirs soon subdivided the land and resold much of it. Beginning in 1730, the area of the present-day barrens stood in the middle of a 548-acre farm owned by Ellis Lewis[3]. By 1883 and probably well before then, the land had been subdivided to its current configuration of three tracts[4] (Map 4).

These tracts were farms from around 1730 until the mid-1800s, during which time the barrens were presumably used mainly for pasture, as a source of wood and for hunting. Any attempt to grow crops in the thin serpentine soils would likely have been unsuccessful and short-lived. Grazing would have kept most of the invading woody plants at bay and inadvertently served to protect most of the native grassland species, at least those capable of regenerating with repeated top-removal (mainly grasses) and others with chemical or physical defenses that make them unpalatable to most grazers. Because of the soil conditions, the pasture would have been low in productivity relative to more typical grazing lands nearby. We can guess that this situation may have led to overgrazing in some patches, resulting in erosion and removing the source of organic matter required for normal soil development and maintenance. In this way, low-competition refugia for serpentine barrens-restricted species were maintained over a larger area than would have been the case without grazing.

The ridge running through the middle of the Unionville Barrens was known as Corundum Hill starting in the early nineteenth century, after the discovery of massive deposits of that mineral. Corundum consists of aluminum oxide crystals of nearly diamond-like hardness. Gem-quality corundum crystals are rubies if red and sapphires if blue, purple or any other appealing color, but the output of the Unionville mines was mostly a dull gray or gray-brown. It was crushed and used as an industrial abrasive. At the Unionville Barrens,

> [c]orundum was first found in large masses lying on the surface; these were a nuisance to farmers plowing their fields. Smaller boulders of corundum were used in stone fences. The farmers tried to drill holes in the larger masses for blasting, but they were too hard. They finally resorted to digging holes and burying the boulders deep enough so that they would not

[1] Lindeström and Johnson (1925): p. 215
[2] Pearre and Heyl (1960)
[3] Futhey and Cope (1881)
[4] W. H. Kirk and Company (1883)

be struck by the plow. John and Joel Bailey claimed to have first recognized corundum on their farm sometime between 1822 and 1825.[1]

The first corundum mine at the Unionville Barrens was the Williams and Platt mine (later known as the Patterson mine), in operation from the late 1830s through the mid- to late 1860s under various ownerships. The raw mined corundum sold for up to $60 a ton (comparable to around $840 in 2011 dollars[2]). Based on maps compiled by mining historians[3], the pit and mine waste dumping area at the northeast end of one of the largest remnant grasslands (Map 8) are most likely the visible remains of the Patterson mine.

Businessmen George Chandler, Spencer Ball and Samuel Pusey bought the Patterson property in 1867 and sank a new shaft in what they believed was promising ground, but they failed to find any corundum. With funding from another investor they hired a local mineralogist, John Smedley, in 1872 to explore for a new lode elsewhere on the property.

> Smedley traced scattered boulders to a hilltop, where he found a very large mass of corundum 5 feet below the surface … The mass was estimated to weigh 150 tons and was exposed by trenching. This large mass of corundum attracted much attention and was visited by many prominent mineralogists of the day. … The corundum was very difficult to mine. It could not be penetrated by drills, and the best steel-faced sledges lasted only a few hours. It was broken up at fractures into boulders weighing from a few pounds to a few tons. The corundum was valued at $300 a ton uncrushed and $500 a ton crushed … [4] [roughly $5,400 and $9,000 in 2011 dollars].

Known as the Chandler-Ball mine, the site was north of Corundum Run (Map 8), where pits, spoil piles and other remnants can still be seen.

The other corundum mining effort of note at the Unionville Barrens was a series of shafts, trenches and pits operated for 10 years beginning in 1879 by John W. Elliot. The main center of activity was around the intersection of Cannery and Kelsall Roads, including several trenches still visible in the woods on the northeastern side of Cannery Road. Pits in the grassland and woods east of Feldspar Run also are probably remnants of Elliot's mining activities. At its peak the main shaft of the Elliot mine was 160 feet deep and the complex included a mill on the north side of Kelsall Road next to Cannery Road where the corundum was crushed and cemented onto grinding wheels. The mines and mill were abandoned by 1895. In that same decade, a Pittsburgh chemist, Edward Acheson, invented an industrial process to make synthetic silicon carbide, as hard as corundum but rare in nature. He founded the Carborundum Company and went into full-scale production at Niagara Falls, New York, which quickly made the mining of corundum obsolete[5].

Another mineral mined in commercial quantities at the Unionville Barrens was feldspar, a calcium sodium aluminum silicate used in the making of high-grade ceramics including false teeth and enamel finishes for stoves. In powdered form, it was, and still is, used as the "no scratch" abrasive in household cleansers. Johnson and Patterson's quarries were dug into the pegmatite dike that bisects the barrens (Map 8). Beginning in the early 1850s its output was shipped to New York where it was sold for the manufacture of porcelain teeth[6]. Large pits, some with permanent standing water at the bottom, and heaps of mine waste are scattered in the woods around the upper reaches of Feldspar Run. Other quarries were dug in the pegmatite

[1] Sloto (2009): p. 98

[2] S. M. Friedman, The Inflation Calculator (www.westegg.com/inflation)

[3] Pearre and Heyl (1960); Sloto (2009)

[4] Sloto (2009): p. 104

[5] Gigliotti (2010)

[6] Specific details on the site's mining history are from Sloto (2009).

dike along the eastern edge of the barrens and operated until around the turn of the twentieth century.

The Corundum Hill serpentine quarry produced serpentine building stone, the light green-colored stone that is familiar to many residents of Chester County from scattered houses, barns, churches and public buildings dating mainly from the nineteenth century, including some prominent buildings on the campuses of the University of Pennsylvania and West Chester University. It is apparently unknown where the stone from the Corundum Hill quarry was used or how much was extracted there[3]. The quarry is still visible in the woods near the source of Corundum Run as an amphitheater-shaped depression in the hillside (Map 8).

Chromite was a minor product at Unionville but the chief output of mines in the State Line and Baltimore serpentinite outcrops (Figure 1, p. 5). For much of the nineteenth century those mines were the world's principal source of chromium. At that time, before the invention of stainless steel and the reinvention of chrome plating (employed more than 2,000 years earlier in China[1]), chromium was used mainly as a yellow pigment in paints and dyes and as a leather tanning agent. Reportedly about 50 tons of chromite were extracted from the Baily mine at the Unionville Barrens. Its location is unknown except that it was somewhere on the Howell Baily farm (the property now owned by the Heckert family), which encompasses the barrens' southeastern margin (Map 4).

Without a doubt, mining had a profound and long-lasting effect on the Unionville Barrens ecosystem. For about 60 years, mining operations and transport of equipment and ore removed vegetation and soil in the most severely affected areas. Over a broader area mining-related activity compacted and scarified soil, promoted soil erosion, and created piles of mine tailings. This greatly expanded the amount of ground where subsoil and rock was exposed at or near the surface. Such disturbance would have enlarged and stabilized areas where the plant species most narrowly restricted in their regional distribution to serpentine barrens could persist, including most of the rare species. Such plants can persist in this region only on thin soils where there is little competition from the prevailing species of the surrounding forests and meadows, which are intolerant of the serpentine soil syndrome.

The expansion of this highly specialized habitat in the late nineteenth century in the aftermath of mining may have compensated to some degree for the presumed loss of habitat that resulted after regular burning stopped two centuries earlier when the local Native American residents were forced out. Because the serpentine soil syndrome was exceptionally severe in areas that had been disturbed by mining, the serpentine grassland communities in those areas have been unusually stable even in the absence of burning. In all likelihood, most of the 7 acres that remain of the more than 60 acres of serpentine grassland documented in 1937 aerial photographs has survived the scarcity of sustaining fire over the past 70 years only because of the severe soil conditions brought about by mining disturbance well over a century ago.

Based on aerial photography beginning in 1937 (Maps 2, 3 and 4) we can infer that the barrens—after the mining era ended around 1900—were used partly for pasture but increasingly abandoned to forest succession with little or no human use, except possibly for hunting and occasional small-scale tree cutting. In the post-mining period grazing must have had much the same effect as it did before mining began, slowing invasion by woody plants and the soil development that comes with it. It is

[1] Cotterell (2004): p. 102

likely that forest succession would have chipped away at the grasslands faster through the first half of the twentieth century without the benefit of livestock grazing. It appears on the aerial photos that grazing may have continued in parts of the barrens as late as the 1970s. Since then, there has been little human use of the land except for hunting and illicit "off-roading" by all-terrain vehicle users.

2.3 Ecosystem components

2.3.1 Historical vegetation

Early 1700s to 1930s. Little is known of the history of the Unionville Barrens before the nineteenth century, when they began attracting the attention of botanists. It is possible that the Philadelphia botanist John Bartram (1699-1777), the first botanist of European descent born in the Americas, might have been aware of the site in the eighteenth century but there is no direct evidence. A letter dated 6 December 1745 from him to the Dutch naturalist John Frederic Gronovius evidently refers to the entire extent of serpentinite outcrops and serpentine barrens in the Northern Piedmont:

> Ye Loadstone [magnetite] lieth in a vein of a particular kind of stone that runs near east and west for sixty or seventy miles or more, appearing even with, or a little higher than its surface, at three, five, eight, or ten miles distance, and from ten to twenty yards broad, generally mixed with some veins of cotton [asbestos]. Ye earth of each side is very black, and produceth a very odd, pretty kind of *Lychnis* [moss phlox], with leaves as narrow and short as our Red Cedar, of humble growth, perennial, and so early as to flower, sometimes, while the snow is on the ground; also a very pretty *Alsine* [barrens chickweed]. Hardly anything else grows here. Our people call them Barrens ...[1]

Members of Unionville's Seal family and Francis Whittier Pennell of the Academy of Natural Sciences of Philadelphia were among the botanists who frequented the Unionville Barrens in the nineteenth and early twentieth centuries. Plant specimens collected by them and others and deposited in various herbaria are the earliest record we have of the site's flora. Pennell's published work on the serpentine barrens of Pennsylvania and Delaware listed 99 plant species at the Unionville Barrens[2]. Using that list, we can roughly reconstruct the Unionville Barrens flora as it was before the twentieth-century drastic decline in area of the serpentine grasslands and wetlands—communities accounting for virtually all of the barrens' species richness.

Pennell's species list from over 100 years ago reflects a flora similar to that existing today in the site's grasslands and woodlands, except for 32 species that have not been found in recent (2002–2011) site surveys (Table 1, pp. 22–23). It is worth evaluating those "missing" species in pursuit of insights about what has been lost. Not surprisingly, 11 of the 32 are species Pennell ranked as having some regional fidelity to the specialized habitat; in other words, in this part of the Northern Piedmont they occur more often than not on serpentine barrens. Also predictably, a high proportion (eight) are now ranked by the Vascular Plants Technical Committee of the Pennsylvania Biological Survey as species of special conservation concern in the state. Unexpectedly, 10 are species of wetlands including 4 serpentine barrens specialists, one of which, forked rush, is designated as endangered in Pennsylvania. The losses represent a substantial decline in serpentine barrens species diversity and are disproportionately species of wetlands.

[1] Berkeley and Berkeley (1992): pp. 265–266

[2] Pennell (1910, 1912)

1930s to the present. The earliest time when the extent of serpentine vegetation at the Unionville Barrens is known with any precision is 15 September 1937, the day the earliest available aerial photos were taken of the site. By comparing a series of aerial photos taken at intervals—a chronosequence—much can be learned about the dynamics of the barrens vegetation. Useful information generated in this way includes rates of succession from grassland to woodland or forest, how succession rates varied among landscape features, and whether there has been any disturbance-caused expansion since 1937 of grassland into formerly wooded areas.

The study area was defined as the historical extent of grassland overlying serpentinite bedrock as determined from 1937, 1958, 1971 and 1992 aerial photography, plus the mostly oak-dominated woods between the grassland patches and in a narrow strip, generally less than 100 feet wide, along segments of the perimeter. Only the area northeast of Cannery Road was included; serpentine grassland also once may have existed southwest of the road—most likely covering a small area, judging from 1937 aerial photos—but no trace of that vegetation persists there today and no practical means of estimating its historical extent has been identified. The study area encompasses 95 acres (Map 4).

Spatial analyses of historical and recent vegetation were done using ESRI's ArcGIS Desktop (version 10) image classification tool and QCoherent's LP360 LiDAR extension for ArcGIS. Supervised image classification (employing on-the- ground knowledge of the vegetation occurring in the study area to "train" the digital classification software) was performed on the georeferenced 1937, 1958, 1971 and 1992 aerial photos to delineate the spatial extent of grassland vegetation. Recent (2008) LiDAR (light detection and ranging technology, using laser illumination) imagery was used to distinguish among grassland, low woody vegetation and tall woody vegetation by extracting accurate height values from the LiDAR data and delineating their spatial extents. NDVI (normalized difference vegetation index) classification was used on 2010 multi-channel satellite imagery to differentiate between conifers (mainly eastern red-cedar) and deciduous vegetation.

Maps of historical and recent vegetation generated by the various GIS methods were overlain to discern spatial patterns in succession from 1937 to 2010. Sampling points were classified into six categories of past succession from grassland to woodland or forest (Map 5):

- wooded since before 1937
- wooded since between 1937 & 1958
- wooded since between 1958 & 1971
- wooded since between 1971 & 1990
- wooded since between 1990 & 2010
- still grassland in 2010

None of the categories involves wooded areas becoming grassland in 1937–2010 because only a very small acreage appeared to undergo such transformation. The soil heterogeneity study (to be discussed later) involved determining succession history from the chronosequence of vegetation maps for soil sampling points covering nearly the entire site in a uniform grid with nearest neighbors separated by 65 m (213 feet). Of the 105 sampling points, the digital classification software labeled 14 as having open grassland replace tree cover at some point in 1937–2010. A meticulous analysis of distance to the nearest wooded polygon from each point showed that 10 of those fell close enough to the edge to be within the margin of error expected from such sources as lens distortion, relief displacement of vertical features or parallax between flight lines in older, non-orthorectified aerial photos, or from digital classification error in categorizing vegetation near edges, where there is a blending of reflectance

(continued on p. 23)

Table 1. **Plants documented at the Unionville Barrens before 1912 but not found in recent (2002–2011) surveys.** Source: Pennell (1910, 1912). Species marked "S" under regional fidelity were ranked by Pennell as "much more frequent" on serpentine barrens than in other habitats in the region (none are among the 15 species he identified as "Nearly or quite restricted in Delaware and Chester Counties to [serpentine] Barrens"). Wetland status is based on Rhoads and Block (2007). Boldface type indicates species of special conservation concern (see Table 6, p. 37 for more information on them).

species presumed extirpated from Unionville Barrens in last 100 years	common name(s)	regional fidelity to serpentine barrens	often or always found in wetlands
Aletris farinosa	**colic-root, white colic-root**		
Angelica venenosa	deadly angelica, hairy angelica	S	
Aristida longespica var. *longespica*	slender three-awn, slimspike three-awn	S	
Aureolaria pedicularia	cut-leaf false-foxglove, fernleaf yellow false-foxglove		
Carex hystericina	bottlebrush sedge	S	W
Carex scoparia	broom sedge		W
Chamaecrista nictitans	wild sensitive-plant, sensitive partridge pea		
Cyperus strigosus	straw-colored flatsedge		W
Desmodium obtusum	**stiff tick-trefoil**		
Desmodium paniculatum	panicled-leaf tick-trefoil		
Digitaria filiformis	**slender crabgrass**		
Eragrostis pectinacea	Carolina lovegrass, tufted lovegrass		
Eupatorium perfoliatum	common boneset		W
Juncus acuminatus	sharp-fruited rush, tapertip rush		W
Juncus dichotomus	**forked rush**	S	W
Leersia oryzoides	rice cutgrass		W
Lespedeza capitata	round-headed bush-clover, roundhead lespedeza	S	
Linum virginianum	slender yellow flax		
Malus coronaria	sweet crabapple		
Muhlenbergia sylvatica	woodland muhly, woodland dropseed		W
Prenanthes serpentaria	**lion's-foot, cankerweed**	S	
Quercus prinoides × *alba*	Faxon oak		
Rubus pensilvanicus	Pennsylvania blackberry		
Salix humilis var. *humilis*	dwarf upland willow, sage willow, prairie willow		
Scirpus atrovirens	black bulrush, green bulrush	S	W

(Table continues on next page.)

species presumed extirpated from Unionville Barrens in last 100 years	common name(s)	regional fidelity to serpentine barrens	often or always found in wetlands
Scleria triglomerata	**whip nutrush, whip-grass**	S	
Spiraea latifolia	white meadowsweet	S	W
Symphyotrichum ericoides* ssp. *ericoides	**white heath aster**		
Symphyotrichum laeve var. *laeve*	smooth blue aster	S	
Vitis aestivalis	summer grape, pigeon grape		
Zizia aptera	golden-alexander, meadow zizia		

characteristics from adjoining vegetation types. Of the remaining four points, one appears to have been cleared to expand a pasture at the barrens' far eastern edge and the other three may represent actual disturbance events converting wooded land to open grassland, one between 1958 and 1971 and the other two between 1971 and 1990. No records were kept of wildfires or tree clearing, so there is no practical way to double-check these findings.

One of the outcomes of the succession history analysis was quantification of the rate of serpentine grassland loss to forest succession over the period 1937–2010 (Figure 2, p. 23). The decline was nearly linear at an average rate of ¾ acre per year. A distinct succession history pattern (Map 5) stands out in the difference between the Kramkowski parcel (the northeastern part of the barrens, labeled on Map 4) and the rest of the barrens. The contrast between the diffuse succession on the Kramkowski parcel and the more highly localized succession on most of the NLT and Heckert parcels most likely reflects different historical land-use patterns. Based on the aerial photos, the Kramkowski parcel appears to have been grazed by livestock more consistently and more recently than the rest of the barrens and over nearly all of its area. Succession patterns on the NLT and Heckert parcels are consistent with the idea that late nineteenth-century mining activity, confined to relatively small areas,

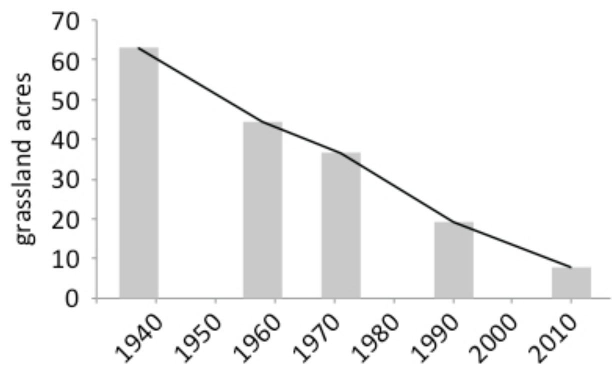


Figure 2. **Decline of serpentine grassland at Unionville Barrens, 1937–2010, due to forest succession.** Data are from supervised classification of aerial photos taken in 1937, 1958, 1971 and 1990 and analysis of satellite imagery from 2010 (see methods, p. 21).

was the main historical land-use structuring later vegetation dynamics.

The map of succession history is a key tool for determining the configuration and size of the areas to be targeted as the ultimate objective for grassland restoration. Setting measurable objectives such as this is part of the desired condition analysis, the subject of section 3 of this document.

2.3.2 Soils

Serpentine soil data from other sites. Worldwide, soils weathered from serpentinite characteristically have unusually high levels of magnesium (Mg), nickel (Ni), chromium (Cr) and cobalt (Co) and low calcium (Ca) content. The amounts and forms of Cr and Co have consistently shown little or no affect on plant growth but high Ni concentration, low Ca-to-Mg ratio, or both have emerged as key to the serpentine soil syndrome[1]. Relative to soils in the same region weathered from other types of bedrock, serpentine soils often are also lower in the macronutrients (those taken up in the largest amounts by plants)—nitrogen (N), phosphorus (P) and potassium (K). These features are trends; serpentine soil mineral concentrations vary from one region to another, from place to place within a single serpentinite outcrop, between adjacent patches of different vegetation type, and even within a small, relatively uniform patch[1].

Serpentine soils in the Northern Piedmont are moist loams with texture and moisture content comparable to a good agricultural soil[2]. They tend to be rapidly draining and drought-prone only where very shallow. At the Nottingham Barrens in southern Chester County, the soil depth to serpentinite bedrock has been found to be correlated with community type. The shallowest soils are inhabited only by herbaceous plants strongly associated with serpentine barrens; the deepest soils support common trees and other plant species of ordinary forests typically found over other kinds of bedrock; and intermediate soil depths are typified by mixed species assemblages[3]. This finding, together with the fact that serpentine grasslands have been steadily and rapidly shrinking for 70 years or more at all sites due to forest succession (see Figure 2, p. 23), suggests that soil depth over serpentinite bedrock is inversely associated with serpentine barrens stability. Or to put it another way, soil depth may be a rough predictor of the opposite of stability, namely the speed of serpentine barrens loss by succession to ordinary forest.

[1] Brooks (1987); Rajakaruna *et al.* (2009)

[2] Hull and Wood (1984)

[3] Dubinsky (1995); R. E. Latham, unpublished data

Most of the barrens area is underlain by Chrome series soils[4], derived from serpentinite parent material and described taxonomically as fine, mixed, superactive, mesic Typic Hapludalfs[5]. Deconstructing that classification[6]:

- Alfisols (the soil order) form mostly in cool to hot climates under deciduous forests and are characterized by medium weathering, an argillic horizon—a clay-rich subsurface layer where clays have accumulated by water transport from higher layers—and a medium to high concentration of base cations, in this case, mainly Mg^{2+}.
- Udalfs (the soil suborder) are Alfisols that have a udic moisture regime—year-round high precipitation but not extremely wet.
- Hapludalfs (the soil great group) are Udalfs that do not possess distinguishing features of other Udalfs such as a cemented horizon or a leached horizon.
- Typic Hapludalfs (the soil subgroup) are Hapludalfs with characteristics intermediate between those of 17 other variant subgroups of Hapludalfs; those intermediate characteristics include an argillic horizon with an indistinct or gradual upper boundary, relatively quick water drainage, relatively high base saturation, and a texture that is loamy or clayey, not sandy.
- Fine, mixed, superactive, mesic Typic Hapludalfs (the soil family) further describes the soil in terms of:
  - texture relative to other soils with similar characteristics—*fine*;
  - composition of the sand, silt and clay components—*mixed*;
  - cation exchange activity relative to clay content—*superactive*;
  - annual mean and variation of soil temperature—*mesic*, which means strongly fluctuating seasonally with an average over the entire year between 8°C (47°F) and 15°C (59°F).

[4] Kunkle (1963)

[5] Natural Resources Conservation Service (2008)

[6] Paraphrased from Natural Resources Conservation Service (1999)

Table 2. **Comparison of soil chemistry between soils derived from serpentinite and those derived from other bedrock types in the Northern Piedmont.** Sources of data: NCSS—National Cooperative Soil Survey (undated); Nottingham Barrens—McCandless (1998); R. E. Latham, unpublished data. "Other" parent materials are schist, gneiss, granite, sandstone and shale. NCSS data are from the uppermost mineral horizon: median thickness 9 cm (range 5–10 cm) on serpentinite, 10 cm (range 8–13 cm) on limestone, and 8.5 cm (range 5–19 cm) on other soils; samples with a plow layer (Ap horizon) were omitted from the analysis. Nottingham Barrens data are from the upper 10 cm of mineral soil.

		NCSS data from counties with serpentine barrens			Nottingham Barrens
soil characteristic	statistic	**serpentinite parent material**	limestone parent material	other parent materials	**serpentinite parent material**
number of samples →		**4**	3	14	**25**
pH	median	**5.9**	5.0	4.4	(not assayed)
	range	**4.1–6.6**	4.9–5.9	3.8–6.4	
Ca-to-Mg ratio	median	**0.55**	3.7	2.0	**0.24**
	range	**0.20–1.1**	1.1–4.6	0.25–6.5	**0.064–0.61**
exchangeable Ni (µg/g)	median	(not assayed)			**379**
	range				**32.4–597**

Chrome series soils tend to be mildly acidic, in contrast to the prevailing soils of the Northern Piedmont (see Table 2), which tend to be moderately to strongly acidic (except soils derived from calcareous bedrock—limestone, dolomite and marble—or mafic rocks such as diabase). As in other serpentinite-derived soils worldwide, Ca-to-Mg ratios are lower and exchangeable (plant-available) Ni concentrations higher in Chrome series soils than in nearby soils derived from other parent materials.

Soil heterogeneity study at Unionville Barrens. A soil study[1] was undertaken in 2010 by the authors of this document and a master's student in environmental studies at the University of Pennsylvania to quantify landscape-scale soil heterogeneity in the area where historical aerial photos taken as early as 1937 showed serpentine grassland cover. It is presented here in abbreviated scientific paper format.

Introduction. The soil study's goal was to apply the results of earlier research at the Nottingham Barrens, which showed a strong association between soil characteristics and ecosystem traits, to promote the success of grassland restoration at the Unionville Barrens by identifying units of land where restoration is most likely to be successful and cost-effective. At the Nottingham Barrens open grassland was found to be associated with the thinnest soils, forest with the thickest, and greenbrier thickets and woodland with intermediate soil depths[2]. Research conducted at the New Texas Barrens in Lancaster County[3] and decades of observation at several serpentine barrens[4] point to the conclusion that areas cleared of trees where soils are relatively thick are likely to support fast-growing weedy growth and a higher abundance of invasive nonnatives, which can interfere with reestablishment of the slower-growing serpentine grassland species.

We surmised that the 50-plus acres at the Unionville Barrens that were grassland 20–75 years ago but are now wooded could be classified by soil attributes along a restoration-feasibility continuum. The

[1] Haegele (2011)

[2] Dubinsky (1995); R. E. Latham, unpublished data

[3] Barton and Wallenstein (1997)

[4] R. E. Latham, personal observation

thicker the soil, the faster succession is likely to take place after tree removal, making grassland maintenance relatively more expensive because disturbance would have to be more frequent (prescribed burning) or more intensive and severe (removal of upper soil layer). In such situations, further interventions such as spot-herbiciding, burning in consecutive years and partial soil removal may be needed to keep invasives from setting seed and to approach the desired condition in a reasonable timeframe. In areas with thinner soil, grassland should be more stable, requiring less frequent, less severe disturbance for its upkeep and fostering a good grassland restoration result more rapidly, cheaply and sustainably. We expected ranking areas in this way to be a useful tool for cost and feasibility analysis.

The study's research objective was to measure soil depth and other easily measured physical characteristics of the soil (excluding any that require expensive laboratory analysis) across the entire Unionville Barrens area, and test what combination of the measurements, if any, best discriminates among several categories of succession history. The test was carried out using methods of spatial analysis to compare the soil data with the patterns of succession history revealed in the GIS study described earlier (pp. 21, 23).

Methods. A square grid of 105 sampling points spaced 65 meters apart was overlain on the map of the study area (described on p. 21) using digital mapping technology (GIS). Grid point locations were programmed into a hand-held global positioning system unit (GPS) to enable navigation to each point in the field. Near some points, despite repeated attempts on different days, it was not possible to obtain clear GPS satellite signals. Where such points were within 65 m of a GPS-located point, we approximated their locations using a 100-m measuring tape and a sighting compass. Ten of the points had to be discarded, some because they landed in neighboring farm fields and others because they were at least 130 m from the nearest GPS-located point.

At each sampling point, the thickness and composition of the Oa horizon or ground litter (dead leaves, bark and wood) was recorded and several soil measurements were made. A 60-inch, ⅜-inch diameter, stress-relieved, high-carbon steel soil probe was inserted to take three depth-to-bedrock measurements roughly one foot apart; the largest of the three measurements was considered as the best estimate of true soil depth. A 19-inch long, ¾-inch diameter soil tube sampler was used to extract a soil core and examine its profile. Depths to the bottoms of the Oi+Oe (combined Oi and Oe horizons, roughly equivalent to the humus layer), A and B horizons were measured and the *hue* (position on the red-orange-yellow-green-blue-purple spectrum), *value* (reflectivity or lightness) and *chroma* (color intensity) of the A, B and C horizons were determined using a Munsell soil color chart. Dominant plant species were recorded and vegetation described in the area immediately surrounding each sampling point, classified into one of five vegetation types:

- grassland, including savanna (< 25% tree cover)
- oak woodland (25%–60% tree cover)
- oak forest (> 60% tree cover)
- edge (at the transition between grassland and forest or woodland)
- mesic forest (dominated by non-oaks)

Box-and-whisker plots were used to compare the central tendency and variability of each variable across vegetation categories to determine visually which variables differ most among ecological communities, with particular attention to variables that distinguish grasslands from the other categories. The variables so selected were maximum depth to bedrock, Oi+Oe-horizon thickness, A-horizon thickness, A-horizon value and A-horizon chroma.

We performed discriminant function analyses (DFA) to determine what combination, if any, of the measured soil variables best differentiates among the six succession history categories (described on p. 21). To put it another way, we wished to find out what soil physical factors are associated with fast or slow succession from grassland to woods over the last 75 years, grassland persistence, or woods established from the start. We also did DFA of the same soil variables' ability to distinguish the six present-day vegetation categories.

We used forward stepwise DFA, in which the software builds a model of discrimination step-by-step, at each step reviewing all variables and adding in the one that contributes most to discrimination between groups. It then repeats the process with the remaining variables. When it reaches the point where adding another variable increases the model's discriminating ability by less than some threshold amount, it stops, omitting that variable and any others that are left.

We did DFA twice for each set of categories (succession history and present-day vegetation)—once with all 95 usable points where we have data on maximum total depth, A-horizon thickness and Oi+Oe-horizon thickness and again with the 91 points where we also have data on the A-horizon Munsell color variables.

The soil measurements found to significantly discriminate among each set of categories were then interpolated for the entire ground surface between sampling points using a computation-intensive method called kriging. The resulting map layers show spatial trends in those soil characteristics across the landscape, much as the topographic map of the barrens shows spatial trends in slope and aspect.

Results. Only one of the measured variables contributes significantly to discriminating among succession history categories (in the statistical sense of significance, using a cutoff maximum Type I error probability of 1 in 20; see explanation in Appendix D under *Standards of evidence*, pp. 152–153). Also, only one variable contributes significantly to discriminating among present-day vegetation types. It is the same variable in both cases—thickness of the A horizon (Figures 3 and 4, opposite). It does equally well at distinguishing succession history and present-day vegetation because both ways of classifying the soil sampling points have one class in common, encompassing essentially the same set of points. It is present-day (successionally stable) grassland, which has a thicker A horizon than all the other classes. The statistics associated with A-horizon thickness significantly discriminating among categories were:

- succession history—partial Wilks' $\lambda = 0.88$; $F = 2.50$; $P = 0.036$ ($N = 95$)
- present-day vegetation—partial Wilks' $\lambda = 0.88$; $F = 3.14$; $P = 0.018$ ($N = 95$)

Partial Wilks' λ (lambda) represents the unique contribution of the variable to the discriminatory power of the DFA model. It can take any value between 0 and 1, with 0 indicating perfect discrimination and 1, no discrimination. The high values above indicate that the discrimination power of A-horizon thickness is weak, whether applied to succession history categories or present-day vegetation type.

In the succession history analysis, the DFA software included Oi+Oe-horizon thickness and A-horizon hue in the model, as well as A-horizon thickness, because their *F*-values exceed the arbitrary threshold of 1, although they do not reach the threshold of statistical significance (at $\alpha = 0.05$, or 1 in 20). In the present-day vegetation analysis, Oa-horizon thickness ranks higher than A-horizon thickness, and A-horizon value and A-horizon chroma are included, although only the *F*-value of A-horizon thickness is statistically significant.

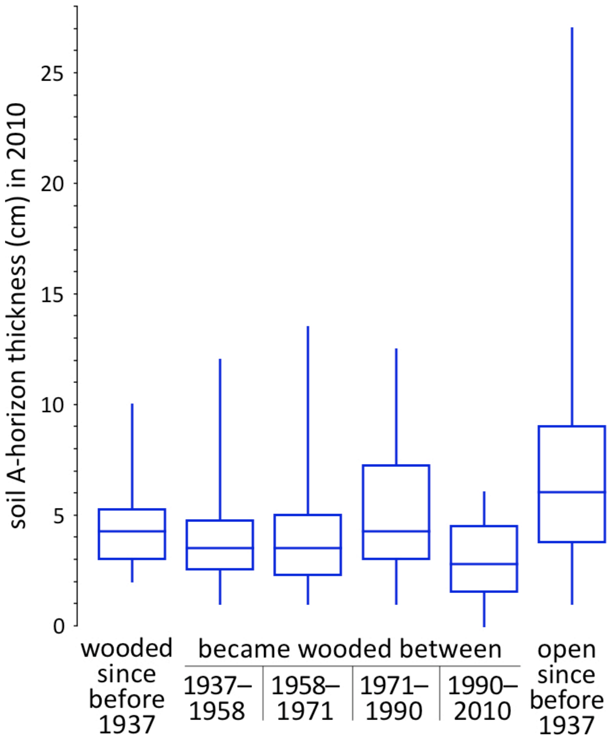


Figure 3. **Comparison of soil A-horizon thickness across succession history categories.** "Open" refers to grassland. Sampling points were classified by analysis of aerial photos taken in 1937, 1958, 1971 and 1990 and supervised classification of satellite imagery from 2010 (see methods, p. 21). Box-and-whisker plots show median (centerline), upper and lower quartiles (box top and bottom) and minimum and maximum values (ends of "whiskers").

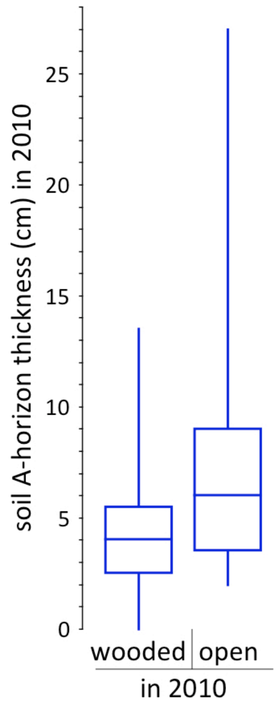


Figure 4. **Comparison of soil A-horizon thickness between wooded (forest and woodland) and open (grassland) areas.** Sampling points were classified by on-the-ground observation at the time of soil sampling. See Figure 3 caption (at left) for interpretation of box-and-whisker plots.

Spatial trends were mapped for soil depth to bedrock (Map 6) and A-horizon thickness (Map 7).

Discussion. We had reason to expect that total soil depth would be strongly associated with present-day vegetation type and succession history, based on the earlier research at Nottingham Barrens. We also thought it likely that other soil variables would add nuance to our understanding of the soil-succession relationship. The Unionville Barrens study was in many ways more sophisticated and elaborate than the Nottingham Barrens study was, but—unexpectedly—it has given rise to more questions than answers. The main question is: Why was total depth to bedrock strongly associated with community type at the Nottingham Barrens but not at the Unionville Barrens?

It seems improbable that there are major differences in the soil-forming or successional processes between the two sites; they are both serpentine barrens and lie only 21 miles apart. In all likelihood the apparent disparity is due in large part, if not entirely, to the very different scales of the two studies. In the 1995 Nottingham Barrens study, soil depth was measured at 1-m intervals along 51 transects each 10 m long, in 17 sets of three transects located close together, each set consisting of one in grassland, another in adjacent woodland with greenbrier understory, and the third in nearby forest. In the current study, the 95 sampling points (blue dots on Maps 6 and 7) were evenly spaced across a grid at 65-m (213-foot) intervals.

The seeming disparity in results highlights the importance of scale. The 65-m spacing of the sampling points in our study makes them suited to mapping large-scale trends but not small-scale details. The kriged (interpolated) maps of total soil depth and A-horizon thickness (Maps 6 and 7) should be interpreted with this caveat in mind. An analogy is comparing a topographic map with 2-foot contours (Maps 2–10 are examples) with a topographic map of the same area with only 50-foot contours; the 50-foot contours would give an idea of where the largest hills and valleys are, but they would not reveal details made clearly visible by the 2-foot contours such as localized steep slopes, flat areas, old quarries or abandoned roadbeds. The kriged soil maps show large-scale trends but on the ground it is easy to find visible differences that do not conform to the local trend. For instance, some obvious localized occurrences of very shallow soils and even exposed rock are in areas shown on the total soil depth map (Map 6) as having generally deep soils.

The results also suggest that A-horizon degradation may be a fast process, comparable to the rate of forest succession and without much lag time (see Map 7). Temperate grasslands in general are well known to have thick A horizons and temperate forests to have thin A horizons or none at all. Our study suggests that serpentine grassland succession to forest may cause rapid change in the uppermost layer of mineral soil. It remains to be demonstrated how long it will take to reverse that process and build up a typical grassland A horizon after serpentine grassland restoration. It is not yet known if, or to what degree, a thicker A horizon affects non-grassland species' ability to invade serpentine grasslands, either negatively or positively.

Maps of large-scale trends in total soil depth (Map 6) and A-horizon thickness (Map 7) can serve an adaptive management purpose. They constitute a baseline against which the relative success of future grassland restoration efforts may be compared. The first restoration trials, which will take place only on the NLT parcel (the section added to the ChesLen Preserve in 2009), are likely to have spatially heterogeneous results such as more invasive species proliferation in some areas than in others. If the mapped soil data show an association across the landscape between trends in soil characteristics and differences in restoration results, then that pattern could be used to predict outcomes of later restoration work on other areas of the barrens. This would give managers another clue, in addition to vegetation history, about how best to tailor management methods to local conditions, or at least about what to expect in different parts of the landscape. The specifics will have to wait until several years after the start of restoration work on the NLT parcel, when early monitoring results are in and comparisons with large-scale soil trends can be made.

2.3.3 Present-day ecological communities

In the following paragraphs the communities in the study area are named, briefly described and prioritized in one of four categories by conservation significance and priority—*highest, high, intermediate* and *low*—based on global, statewide and regional rarity and degree of threat.

An ecological community (also called community type) is an assemblage of interacting plants, animals, fungi and other organisms that is fairly consistent in species composition and relative abundance in similar environments throughout a region. Communities are named and grouped in hierarchical classification systems analogous to the classification of species and their grouping into genera, families, orders, classes, phyla, kingdoms and domains. But unlike most species, communities are not discrete entities. They blend into each other and where one community ends and another starts is a matter of judgment and consensus among experts. Not all ecologists believe that classifying communities produces a useful product or is even feasible, but enough do that there is a nationwide community classification project underway. It is a work in progress, with committees in each state contributing to a system coordinated by NatureServe, an international nonprofit conservation organization whose mission is to provide the scientific basis for effective conservation action[1].

The classification presented here of the communities within the Unionville Barrens study area (see study area boundaries on Map 4, description on p. 21) is based on qualitative observation and should be regarded as provisional until such time as quantitative data on the relative abundance of species may be collected in the future. Brief descriptions include distribution across the site, dominant and diagnostic species, in some cases with mention of a few examples of typical subordinate species, and comments on the community's dynamics over time at the site, if known.

The communities are classified according to Pennsylvania's community classification system, a joint project of the Pennsylvania Biological Survey and Pennsylvania Natural Heritage Program working together with NatureServe. The most recent treatment in book form of the state's terrestrial and palustrine communities was published in 1999[2]. The classification system is currently undergoing revision for online publication and is still in flux. The names given below (in boldface type) are provisional, pending final adoption. The aquatic communities at the barrens are classified in accordance with the current (2007) aquatic community classification for the state[3].

Serpentine Indian-grass – little bluestem grassland and **serpentine gravel forb community**. HIGHEST CONSERVATION PRIORITY. Scattered throughout study area in patches of a few hundred square feet up to 1–2 acres (yellow areas on Map 4); gravel forb community occurs as patches, mainly in the range of 10–1,000 square feet, scattered within the larger grassland matrix in areas where soils are thinnest.

The shorthand *serpentine grassland* is used throughout this document for these two communities together with serpentine seep (next page). All three occur interspersed in a fine-scale mosaic and are mapped together as grassland (Map 4; also see photos on cover).

Several variants of grassland exist in localized areas. One is restricted to the eastern part of the Unionville barrens (Kramkowski parcel) and includes side-oats grama as a co-dominant (see Map 8). This variant is found only at a few serpentine barrens and only in the West Chester cluster; it is not currently recognized as a separate community type. Other patches of serpentine grassland include arrow-feather three-awn as a co-dominant. Additional diagnostic species of Northern Piedmont serpentine grasslands include all of those listed in black (not gray) type in Table 5 (pp. 35–36).

The serpentine gravel forb community occurs where the soil is thinnest over bedrock. Dominant species, all very short in stature or prostrate, include church-mouse three-awn (an annual warm-season grass), serpentine aster (a globally threatened serpentine barrens endemic), barrens chickweed, rock sandwort and moss phlox.

At present all serpentine grassland at the Unionville Barrens is in the form of savanna (where scattered trees or tall shrubs make up between 10% and 25% of the total cover) but with restoration it is expected to become savanna interspersed with patches of prairie (expansive areas with less than 10% tree or tall shrub cover), as historical aerial photos show it in the mid-twentieth century. Most of the trees in the savanna are eastern red-cedar, post oak and either blackjack oak or Bush's

[1] www.natureserve.org

[2] Fike (1999)

[3] Walsh *et al.* (2007)

oak (a natural hybrid between blackjack oak and black oak).

This community in all of its several variants is globally rare, has exceptionally high plant species diversity, and is the main habitat for species that are regionally restricted to serpentine barrens, including nearly all of the species of special conservation concern inhabiting the Unionville Barrens (the subject of subsections 2.3.5 and 2.3.6, pp. 37–40). It can fairly be said to be in "critical condition" at the site, having declined by more than 88% between 1937 and 2010, from 63 acres (not including the area southwest of Cannery Road) to 7 acres.

Serpentine seep. HIGHEST CONSERVATION PRIORITY. Highly localized—typically 50–500 square feet or less—scattered throughout matrix of serpentine grassland (and mapped together with it in yellow areas on Map 4), in full sun or light shade in swales and spring seeps, usually on slopes.

The dominant species is tufted hairgrass, a native cool-season grass (see photo on cover). There is usually an admixture of plants from the surrounding grassland and other species associated with wetlands such as swamp thistle, slender spikerush and New York ironweed. The soil surface typically does not appear wet for much of the year. Presumably there were many more occurrences at the Unionville Barrens before most of the open grassland succeeded to forest and woodland.

Oak – red maple – greenbrier serpentine forest. HIGH CONSERVATION PRIORITY. Mainly on ridgetop and upper slopes of Corundum Hill (ridge labeled on Map 8) surrounding remnant serpentine grasslands.

Dominant species are several oaks (including post oak, blackjack or Bush's oak, scarlet oak and black oak), red maple and common greenbrier; sassafras is also frequent. Red maple co-dominance is likely an artifact of fire exclusion since the mid-twentieth century. The diagnostic species of this forest type range-wide are post oak and blackjack oak, but at the Unionville Barrens it is still uncertain whether pure blackjack oak is present. Blackjack oak or Bush's oak (blackjack oak-black oak hybrid), or possibly both, are found at the forest-grassland edge. Few serpentine barrens-restricted species occur in this community. Exceptions include post oak, blackjack or Bush's oak and the shrub-size dwarf chinkapin oak.

Common greenbrier is moderately to extremely abundant. The largest area of dense greenbrier understory lies in a long strip along the northwest-facing slope of Corundum Hill, mostly within 150 feet of the remnant grasslands along the ridgetop (on Map 9, between the grasslands and the dashed line marked *potential footpath*). It is likely that greenbrier is more abundant here than elsewhere because of an "edge effect" in which sunlight penetrates farther into forest edges on the north sides of openings than on other sides because of the angle of the sun at Northern Hemisphere mid-latitudes. Another large greenbrier thicket extends along both sides of Corundum Run upstream and downstream from the Feldspar Run confluence.

This community presumably differs from other oak-dominated forest types in having a stronger influence of the serpentine soil syndrome (low Ca-to-Mg ratio, high Ni) because the soils are shallower. It also has generally higher soil moisture and milder soil acidity than the others, with the probable exception of *red oak – mixed hardwood forest*.

Oak – red maple – greenbrier serpentine woodland. HIGH CONSERVATION PRIORITY. Like preceding community except for lower density of canopy—25%–60% tree cover for woodland versus 60%–100% for forest—and associated higher density and diversity of understory plants, which often include species typically found in serpentine grassland.

Mixed forb marsh. HIGH CONSERVATION PRIORITY. Highly localized in full sun or light shade on level ground in or adjacent to the floodplains of Corundum Run and Feldspar Run, in some cases adjacent to *red maple – black-gum palustrine forest*.

Diagnostic species include New York ironweed, marsh fern and skunk-cabbage. Other species may include slender spikerush, jewelweed, cutleaf coneflower, spotted water-hemlock, tall meadow-rue, Georgia bulrush and royal fern. The soil typically appears wet for most of the year. This community is inferred to have declined precipitously at the Unionville Barrens over the past century, based on the extirpation of 10 mostly non-forest wetland species (see Table 1, pp. 22–23).

Sparsely vegetated vernal pool. INTERMEDIATE CONSERVATION PRIORITY. Sparsely scattered in shallow depressions in forest understory, including spring-fed remnants of quarries near upper reaches of Feldspar Run.

Vascular plant life is sparse or absent due to the double stresses of shade and prolonged inundation. Vernal pools are important to amphibian populations because they do not support most of the predators that eat frog and toad tadpoles and salamander larvae such as fish, diving beetles, dragonfly larvae and crayfish.

Forested headwater stream. INTERMEDIATE CONSERVATION PRIORITY. Corundum Run (3,100 feet from source to ChesLen Preserve boundary), Feldspar Run (1,680 feet) and segment of Serpentine Run along east end of barrens above farm pond (600 feet inside Kramkowski parcel boundary).

Forested headwater streams are the uppermost reaches of perennial streams, with rocky bottoms and relatively high gradients (5.0% for upper Corundum Run to the confluence with Feldspar Run and 2.1% from there to the preserve boundary; 4.8% for Feldspar Run; 3.2% for Serpentine Run from the Heckert-Kramkowski parcels' boundary to the pond). No aquatic surveys have been conducted on these streams but this community throughout its range tends to have cool water temperatures and high water quality and support populations of small aquatic animals that are intolerant of organic pollution and other alterations to habitat and stream function. Diagnostic organisms include little yellow stonefly (genus *Alloperla*), tipulan crane fly (*Tipula*) and dark brown spinner mayfly (*Ameletus*). Species diversity is generally low. The community is considered to be rare.

Red maple – black-gum palustrine forest. INTERMEDIATE CONSERVATION PRIORITY. Highly localized within forest matrix at spring seeps and on narrow floodplains of Corundum Run and Feldspar Run (most of the wetlands labeled on Map 8).

The dominant species in the canopy, shrub and herbaceous layer are most often red maple, spicebush and skunk-cabbage, respectively. Other species include black-gum, white ash, American sycamore, common winterberry, American elder, false nettle and Pennsylvania bittercress. The largest and most diverse swamp lies just north of Corundum Run where it crosses the four-way trail intersection (Maps 8 and 9). It has been in continuous forest cover since well before 1937 (compare Maps 2, 3 and 4).

Dry oak – heath forest. INTERMEDIATE CONSERVATION PRIORITY. Localized near where NLT-Kramkowski parcel boundary crosses ridgetop of Corundum Hill (Map 8).

Dominant and diagnostic species are chestnut oak, mountain-laurel, lowbush blueberry, deerberry and black huckleberry. Scarlet, northern red, black and white oaks are also important canopy species. This community is uncommon in the Northern Piedmont. Although a comparative soil analysis has not been done, this is in all likelihood the driest and most acidic of the oak-dominated forest types at the site.

Dry oak – mixed hardwood forest. INTERMEDIATE CONSERVATION PRIORITY. Mainly on mid- to upper forested slopes south and east of Corundum Run.

Dominant and diagnostic species are white, northern red and black oaks, pignut hickory, black-gum, flowering dogwood and maple-leaf viburnum. This community is most likely intermediate in soil droughtiness and acidity among the oak-dominated forest types at the site.

Red oak – mixed hardwood forest. INTERMEDIATE CONSERVATION PRIORITY. Mainly on lower forested slopes south and east of Corundum Run.

Dominant and diagnostic species are northern red oak, white oak, American beech and American hornbeam. Other canopy species include black cherry, red maple and tuliptree. The species composition indicates that the community has moister soils and milder soil acidity than the two preceding oak-dominated forest types, with little or no serpentine soil syndrome influence due to its deep, relatively organic matter-rich soils.

Sluggish headwater stream. LOW CONSERVATION PRIORITY. 500-foot segment of Serpentine Run at east end of barrens, from below farm pond dam to Oak School Road.

Sluggish headwater streams are small perennial streams with silty and rocky bottoms flowing past farm fields, pastures or residential areas with intermediate gradients (1.0% for this stream segment). No aquatic surveys have been conducted on this stream but this community throughout its range tends to have warm water temperatures and fair to poor water quality due to the effects of agriculture or suburbanization on the watershed and riparian area. It typically supports populations of small aquatic animals that are tolerant of organic pollution, siltation and other alterations to habitat and stream function. Diagnostic organisms include common pond snail (genus *Physidae*), leech (*Hirudinea*), ram's-horn snail (*Planorbidae*), midge (*Chironomidae*), agabian predaceous diving beetle (*Agabus*) and dextral pond snail (*Lymnaeidae*). Species diversity is generally low.

Tuliptree – beech – maple forest. LOW CONSERVATION PRIORITY. Small areas around headwaters of Corundum Run, surrounded by *successional tuliptree forest (acidic type)*.

Tree canopy species include tuliptree, American beech, red maple, black cherry and white ash. The occurrence is depauperate, missing sugar maple and sweet birch among the community's usual dominant and diagnostic species. It is a small part of what is referred to elsewhere in this document as *mesic forest*.

Successional tuliptree forest (acidic type). LOW CONSERVATION PRIORITY. Most of forested area north and west of Corundum Run.

The tree canopy is overwhelmingly dominated by tuliptree. The nonnative invasive shrub autumn-olive makes up most of the understory. This community comprises most of what is referred to elsewhere in the document as *mesic forest*. Originating in the abandonment of cultivation (compare Maps 2, 3 and 4), it is marked by an even-age canopy, low species diversity and highly disturbed soils.

2.3.4 Species surveys

Only one group of organisms at the Unionville Barrens has been the subject of a survey to date—vascular plants. The Brandywine Conservancy contracted a plant survey, conducted in 2002–2003, for what is now the ChesLen parcel within the barrens area. Results of this survey have been augmented since then by observations throughout the 95-acre barrens study area (summarized in Table 3, next page; full list is in Appendix B, pp. 111–143).

Of the 356 plant species identified so far, 84 are characteristic native species of Northern Piedmont serpentine grasslands (summarized in Table 4, p. 35). They are marked in Appendix B according to how tightly their distribution in southeastern Pennsylvania is tied to serpentine grasslands. Some are nearly or quite restricted, some are found more often in serpentine grasslands than in other habitats, and some are characteristic of serpentine grasslands but found no less often in other grassland habitats. The majority, 73 species, are herbaceous, including 25 grasses.

Two woody species of the characteristic serpentine grassland flora are worth special mention—blackjack oak and Bush's oak, a blackjack oak-black oak hybrid—because of lingering uncertainty about their status. Trees at the Unionville Barrens that look like blackjack oak have the typical branching structure, bark appearance and growth habit of the species, but all those found to date have atypical leaf morphology. The leaves more closely resemble those of black oak than the highly distinctive leaves of blackjack oak seen throughout the species' range, including just 16–30 miles away at the State Line Barrens. It is possible that the entire population at the Unionville Barrens is of an introgressive hybrid, that is, an organism whose genome is mostly of one species (in this case, blackjack oak) but with a smaller part from another (black oak), a condition produced by repeated backcrossing of hybrid individuals with just one of the parent species. Testing this hypothesis will likely require advanced-

(continued on p. 37)

Table 3. **Summary of the vascular plant flora of the Unionville Barrens and adjacent forest.** See Appendix B (pp. 111–143) for sources and details on individual species.

↓ vascular plant categories ↓	species counts →	native	nonnative	total
nonflowering plants	clubmosses	2		2
	ferns	17		17
forbs	annual	22	18	40
	biennial	6	10	16
	perennial	113	16	129
grasses	perennial cool-season	13	8	21
	annual warm-season	6	2	8
	perennial warm-season	12	1	13
graminoids	sedges	22		22
	rushes	6		6
woody plants	shrubs	25	10	35
	trees	31	7	38
	lianas	7	2	9
total		282	74	356

major family	species count	major family	species count
Asteraceae (composites)	46	Fagaceae (oaks, beech)	14
Poaceae (grasses)	42	Polypodiaceae (ferns)	13
Cyperaceae (sedges)	22	Caryophyllaceae (pinks)	8
Rosaceae (rose family)	20	Ericaceae (ericads)	8
Fabaceae (legumes)	15	Lamiaceae (mints)	8

Table 4. **Summary of the characteristic serpentine grassland species present at the Unionville Barrens.** The species tallied on this list are the native vascular plants (also included in Table 3) marked S1E, S1, S2 or S3 in Appendix B (see explanation of those symbols on p. 111).

↓ vascular plant categories ↓		species count
nonflowering plants	ferns	1
forbs	annual	5
	biennial	2
	perennial	28
grasses	perennial cool-season	11
	annual warm-season	5
	perennial warm-season	9
graminoids	sedges	9
	rushes	3
woody plants	shrubs	5
	trees	4
	lianas	2
total		84

major family	species count
Poaceae (grasses)	25
Asteraceae (composites)	13
Cyperaceae (sedges)	9

Table 5. **Plants of special conservation concern recorded recently at the Unionville Barrens.** Sources: field inventory by J. Ebert and J. Holt (2002–2003) augmented by R. E. Latham (2003–2011) except where footnoted. Species in gray typeface do not qualify as an indigenous population (*Ilex opaca*) or as a population at all (a single individual of *Quercus nigra*), or were misidentified (*Sporobolus heterolepis*).

plant taxon	common name(s)	global rank	state rank*	PABS status*	distribution (& estimated total abundance)
Ageratina aromatica	small-leaf white-snakeroot	G5	S3	PR	Grasslands, edges (> 5,000)
Andropogon gyrans	Elliott's beardgrass, Elliott's bluestem	G5	S3	PR	One small area in grassland (~ 10)
Aristida purpurascens	arrow-feather three-awn	G5	S2	PT	Grasslands (> 5,000)
Bouteloua curtipendula	side-oats grama, tall grama	G5	S2	PT	Grassland patches near east end of barrens (> 5,000)
Carex bicknellii	Bicknell's sedge	G5	S1	PE	One small area in grassland (~ 20)
Carex richardsonii	Richardson's sedge	G4	S1	PE	One small area in grassland (10–100)
Ceanothus americanus	New Jersey tea	G5	SNR	SP	Grasslands (50–100)

(Table continues on next page.)

* Global and state rarity ranks and Pennsylvania Biological Survey (PABS) status are explained in Appendix A, pp. 109–110.

plant taxon	common name(s)	global rank	state rank*	PABS status*	distribution (& estimated total abundance)
Cerastium velutinum var. *velutinum*	barrens chickweed	G5T4?	S3	SP	Grasslands, edges (> 5,000)
Deschampsia cespitosa	tufted hairgrass	G5	S3	PT	Moist patches in grasslands (1,000–5,000)
Dichanthelium oligosanthes	Heller's rosette grass, Heller's witch grass	G5	S3	PT	Grasslands (100–1,000)
Dichanthelium villosissimum	long-haired panic-grass, whitehair rosette grass	G5T5	SH	PE	Grasslands (100–1,000)
Fimbristylis annua	annual fimbry	G5	S2	PT	Moist patches in grasslands; present only as dormant seeds in most years (1,000–5,000)
Helianthemum bicknellii	Bicknell's hoary rockrose, hoary frostweed	G5	S2	PE	One small area in grassland (~ 10)
Ilex opaca	American holly	G5	S2	PT	Woods; most likely escaped from cultivation and not an indigenous population (50–500)
Minuartia michauxii	rock sandwort, Michaux's stitchwort	G5	SNR	SP	Grasslands (> 5,000)
Packera anonyma	Small's ragwort, Appalachian groundsel	G5	S2	PR	Grasslands, edges (> 5,000)
Phemeranthus teretifolius	round-leaf fameflower, quill fameflower	G4	S2	PT	Grasslands (50–500)
Quercus nigra	water oak	G5	†	†	One individual in an old collapsed mine in grassland; most likely not planted but possibly escaped from cultivation
Scleria pauciflora	few-flowered nut-rush	G5	S2	PT	Grasslands (> 5,000)
Sporobolus heterolepis‡	prairie dropseed‡	G5	S1	PE	Misidentification by several investigators, 1990–2000
Symphyotrichum depauperatum	serpentine aster	G2	S2	PT	Grasslands (> 5,000)

* Global and state rarity ranks and Pennsylvania Biological Survey (PABS) status are explained in Appendix A, pp. 109–110.

† At present, this is the only known wild occurrence of *Quercus nigra* in Pennsylvania.

‡ Misidentified in 1990, 1992 and 2000 by botanists reporting to the Pennsylvania Natural Heritage Program; record corrected in 2011 with assistance from Greg Edinger, Larry Klotz and Jeff Walck.

Table 6. **Plants of special conservation concern documented historically but not seen recently at the Unionville Barrens.** Sources: Herbarium records compiled by the Pennsylvania Flora Project of the Morris Arboretum, University of Pennsylvania; Pennell (1910, 1912). Gray typeface: considered by the author to be a probable misidentification of a closely related plant listed in Table 5.

plant taxon	common name(s)	global rank*	state rank*	PABS status*	documentation / other comments
Aletris farinosa	colic-root, white colic-root	G5	S1	PE	Collected 1884 and 1887 by J. L. Seal, 1908 by Francis W. Pennell, 1929 by Hugh E. Stone
Aristida longespica var. *longespica*	slender three-awn, slimspike three-awn	G5T5?	S3S4	TU	Reported in Pennell 1910, 1912; may have been overlooked in recent surveys
Cerastium velutinum var. *villosissimum*	serpentine barrens chickweed	G5T1	S1	PE	Collected 1942 by E. M. Gress; considered by author as probable misidentification of *C. velutinum* var. *velutinum* (see Table 5, pp. 35–36)
Desmodium obtusum	stiff tick-trefoil	G4G5	SU	TU	Reported in Pennell 1910, 1912
Digitaria filiformis	slender crabgrass	G5	S3S4	SP	Reported in Pennell 1910, 1912; may have been overlooked in recent surveys
Juncus dichotomus	forked rush	G5	S1	PE	Reported in Pennell 1910, 1912
Lobelia puberula	downy lobelia	G5	S1	PE	Collected 1935 by John M. Fogg, Jr.
Prenanthes serpentaria	lion's-foot, cankerweed	G5	S3	PT	Collected 1908 by Francis W. Pennell
Scleria triglomerata	whip-grass, nut-rush	G5	SH	PE	Reported in Pennell 1910, 1912
Symphyotrichum ericoides ssp. *ericoides*	white heath aster	G5	S3	PT	Reported in Pennell 1910, 1912

* Global and state rarity ranks and Pennsylvania Biological Survey (PABS) status are explained in Appendix A, pp. 109–110.

technology laboratory analysis by a molecular geneticist. Introgressive hybrids have special significance in evolutionary biology because they are regarded as one of several means by which new species can emerge. Whatever its status turns out to be, the blackjack/Bush's oak at the Unionville Barrens should be treated as a population of special conservation concern.

2.3.5 Vascular plant species of special conservation concern

Eighteen vascular plant species of special conservation concern have been documented recently as living in the Unionville Barrens (Table 3, p. 34), and another nine were documented historically at the site but have not been found in recent surveys (Table 4, p. 35). Those nine are apparently extirpated.

Serpentine aster is the only serpentine barrens endemic living in the barrens. It is globally rare, with less than 15 known populations. The rest of the plants of special conservation concern are edge-of-range or disjunct occurrences of species that live mainly in the Midwest, South or Atlantic Coastal Plain, some ranging as far away as the desert Southwest and Mexico.

Ten of the plants of special conservation concern have population sizes at the Unionville Barrens large enough to be considered secure (see last column of Table 5, pp. 35–36). The rest have been squeezed to perilously low numbers by habitat loss over the past century. Thriving populations of these species are the best indicators of a healthy, functioning ecosystem. They are central to identifying desired conditions and establishing the metrics that will be used to evaluate restoration and management progress and pinpoint needs for fine-tuning management methods.

2.3.6 Animal species of special conservation concern and their habitat needs

There is no doubt that animal species now classified as endangered, threatened, rare or declining were present when the serpentine grassland area was much larger, and little doubt that at least a few of those species are still present, although any serpentine grassland habitat specialists remaining are likely at or near critically low population numbers. Only one such species has been confirmed—in 1987 Dr. Al Wheeler, Jr. discovered a population there of the prairie leaf beetle[1], which lives mainly in the Midwest and West. To date no one has done a systematic survey of any major animal group at the site. Relatively little effort has been put into animal surveys at any Pennsylvania serpentine barrens except to search for butterflies and moths at a few sites.

A concept in ecology and population biology often invoked to help illuminate the relationship between animals dependent on "island" habitats such as serpentine barrens is that of sources and sinks. These terms describe specific areas of contiguous habitat for a particular species across a region or landscape. A *source* is an area of high-quality contiguous habitat in which the net population growth rate of the species of interest is positive. A *sink* is an area of low-quality habitat in which the net population growth rate is negative. All of the individuals of a species breeding in all of the habitats within dispersal distance of each other are termed a *metapopulation*. If there were no source in a metapopulation's range, it would eventually die out. Sources are essential but sinks are important, too, because they allow a metapopulation to be larger, patchier and more genetically diverse than it would be if it occupied only its source habitats. Larger, more dispersed and more genetically diverse populations are more resilient against setbacks and less vulnerable to potential catastrophes caused by unusual weather, disease outbreaks and other environmental variability.

The best-known animal group at Northern Piedmont serpentine barrens in general is the Lepidoptera. Of the hundreds of butterfly and moth species found in these habitats in Pennsylvania, at least 48 of those found so far are known to be species of special conservation concern. Three are globally rare—mottled duskywing and broad-lined erastria moth, specialist feeders as larvae on New Jersey tea, and persius duskywing, whose larvae eat wild indigo; both larval host plants are present in very small populations at the Unionville Barrens. Scientists expect to find many more kinds of rare animals as more species

[1] Wheeler (1988)

groups and more serpentine barrens sites are surveyed.

The 11 rare butterfly species and 37 rare moth species so far found living in serpentine barrens in Pennsylvania make up 17% and 32% of the butterfly and moth species, respectively, listed as candidates for endangered or threatened status statewide—fractions vastly disproportionate to the relatively minuscule total area of the serpentine barrens. Most, if not all, are specialist feeders as larvae on plants that are locally abundant in some serpentine grasslands, but the larval host plants of 22 of the 48 rare Lepidoptera that have been captured as adults in Pennsylvania serpentine barrens are still unknown.

Appendix C (pp. 145–148) is a preliminary list of arthropods of special conservation concern (pending further discoveries as more serpentine barrens and more arthropod groups are surveyed) considered as the most likely past, present or future residents of the Unionville Barrens. The list includes 10 butterflies, 32 moths, 1 beetle and 2 hemipterans or "true bugs" that depend in some way on plants presently found at the site. The list is not in any way exhaustive of the endangered, threatened or rare animal species that might inhabit the Unionville Barrens. Its utility is in identifying several plant species as targets of management to enhance or sustain habitat value for serpentine barrens-dependent animal life and as additional indicators of desired conditions to be monitored.

Many hundreds of more-common arthropod species occur in the barrens, including some that are declining in the region and in eastern North America in general as nonnative invasive plants crowd out the native plants they depend on. Examples of butterfly species often seen in Pennsylvania serpentine barrens[1] include monarch, great spangled fritillary, Aphrodite fritillary, question mark, comma, mourning cloak, red admiral, painted lady, American copper, black swallowtail, eastern tiger swallowtail and falcate orange tip.

No bird survey has yet been conducted at the Unionville Barrens. At the State Line Barrens, some birds are consistently found nesting in or near serpentine grasslands or utilizing them for other habitat needs. Examples include prairie warbler, white-eyed vireo, eastern towhee, yellow-breasted chat and American woodcock. Before a recent steep decline in the regional population[2], northern bobwhite also was commonly seen and heard.

Grassland-obligate birds—in the Northern Piedmont including grasshopper sparrow, savannah sparrow, vesper sparrow, eastern meadowlark, bobolink and horned lark—have been a focus of conservation efforts in the region and it is worth mentioning why they are not considered likely residents of the soon-to-be-expanded grasslands at the Unionville Barrens. The term "grassland birds" most often refers to grassland-obligate or grassland-interior species. In order to nest and successfully rear young they need access to large contiguous areas of treeless grassland or meadow or to habitats that supply the same nesting cues and resources. Pennsylvania's breeding bird fauna includes 15 such species; two are classified as endangered and five as threatened or candidates at risk and nearly all have undergone serious declines in recent decades due to the decline in native grasslands and meadows. Even after restoration, the grasslands at the Unionville Barrens may be too small and the savanna landscape too threatening (trees provide perches for birds that prey on other birds) to attract grassland-obligate birds.

As a rule of thumb in the Mid-Atlantic region, grassland or meadow patches of 12

[1] Anderson (1971)

[2] Mulvihill *et al.* (2011)

to 25 acres sometimes support one or a few breeding pairs of a single grassland-obligate bird species, 25 to 50-acre patches do so more consistently, and it takes a minimum of 100 to 250 acres of contiguous open habitat, unbroken by hedgerows and with few or no trees, to support multiple grassland-obligate bird species[1]. When fully restored, the Unionville Barrens' grassland is expected to cover upwards of 50 acres, but much of that area will be savanna, which is usually avoided as nesting habitat by grassland-obligate species. However, as cultivated fields elsewhere in the ChesLen Preserve are converted to grasslands dominated by native plants, the largest areas free of trees within the Unionville Barrens might intermittently become home to one or a few nesting pairs of grassland-obligate birds spilling over from the larger habitat areas nearby.

The Unionville Barrens are fully capable of providing habitat for birds with an affinity for grasslands and other specialized habitats that do not require large, treeless blocks. Pennsylvania's Wildlife Action Plan[2] identifies several species in this category as being of "maintenance concern" statewide, including brown thrasher, common nighthawk, yellow-breasted chat and American woodcock. In addition to those mentioned above as having an affinity for nearby large serpentine barrens (prairie warbler, white-eyed vireo, eastern towhee, yellow-breasted chat and American woodcock), other such species include—but are not limited to—American kestrel, red-tailed hawk, yellow-shafted flicker, barn swallow, tree swallow, northern rough-winged swallow, eastern bluebird, eastern kingbird, purple martin, house wren, cedar waxwing, indigo bunting, American goldfinch, song sparrow, chipping sparrow and field sparrow.

No surveys of amphibians, turtles, snakes or mammals have been conducted at the Unionville Barrens. The probability is low (but not zero) that species in these groups listed as endangered, threatened[3] or otherwise of maintenance concern[4] in Pennsylvania will be found there. Regardless of the species' conservation status, managers of a highly significant natural area should have as comprehensive as possible an understanding of what the resources they are managing consist of, including the vertebrate species present. Amphibians in particular are declining worldwide and many species—perhaps the majority—are now, or are on the verge of becoming, species of special conservation concern. The vernal pools, swamps and streams in and around the Unionville Barrens doubtless support some salamander, frog and toad species. The sooner these populations are surveyed the better, in time for managers to consider actions to prevent or reduce further declines and extirpations. One probable factor in regional declines of terrestrial salamander species is the proliferation of invasive exotic earthworms, especially several newly established East Asian species[5]. Acidic soils such as those typical of dry oak – heath forest may be resistant to earthworm invasions. No mention has been made in the scientific literature of the effects of eastern North American serpentine soils on earthworms[6]. The soil fauna of serpentine barrens is a subject ripe for scientific exploration.

[1] Peterjohn (2006)

[2] Pennsylvania Game Commission and Pennsylvania Fish and Boat Commission (2005)

[3] Pennsylvania Natural Heritage Program (2010)

[4] Pennsylvania Game Commission and Pennsylvania Fish and Boat Commission (2005)

[5] Maerz *et al.* (2009)

[6] Rajakaruna *et al.* (2009)

3 Desired Conditions, Indicators of Management Success, and Threats

3.1 Desired conditions

Desired conditions are attributes considered vital to restoring and maintaining ecosystems to a high standard of ecological integrity. They are based on current understanding of pre-European-settlement conditions, but they also take into account unavoidable constraints on recreating historical conditions such as landscape isolation, invasive species populations, missing (extirpated or extinct) species that are infeasible to restore, and other historical changes at landscape and regional scales beyond management area boundaries.

An essential element is a set of metrics or indicators used to evaluate and communicate ecosystem conditions, with a range of target values for each. Metrics are quantitative attributes of specific ecosystem elements, measured at regular intervals to monitor conditions as they change over time.

The first four subsections give a qualitative description of desired conditions for the Unionville Barrens. The aim is to meet a high standard of ecological integrity, with a particular focus on sensitive habitats of imperiled, rare or declining species.

> An ecological system or species has integrity … when its dominant ecological characteristics (e.g., elements of composition, structure, function and ecological processes) occur within their natural ranges of variation and can withstand and recover from most perturbations imposed by natural environmental dynamics or human disruptions.[1]

A bullet-point summary of the desired conditions comes first, followed by a narrative presenting additional details on desired conditions. The narrative is organized in four broad subject areas: (1) desired species diversity and composition, (2) desired structural, patch and habitat diversity, (3) desired ecosystem processes, and (4) desired landscape context.

Next is a table presenting a set of quantitative and highly specific metrics to serve as the basis for monitoring. Ranges of values for each measured indicator are ranked as excellent, good, fair or poor. Where known, the present status in the Unionville Barrens is given for each metric.

The last part of this section is an assessment of the major threats to achieving and sustaining desired conditions. Stresses and stressors are described and ranked in terms of severity, scope and irreversibility.

3.1.1 Qualitative summary of desired conditions

Desired conditions of serpentine barrens communities and landscape:

- Total area of serpentine grassland (including savanna and serpentine gravel forb community) approaching 80% of documented historical maximum, or approximately 50 acres
- Dominance by native herbaceous plant species characteristic of serpentine grassland in all grassland patches
- High within-patch native serpentine grassland plant species diversity
- High between-patch diversity in native serpentine grassland plant species

[1] Eckert (2009): p. 2

composition, including variation in which species are dominant
- Dominance by a mixture of oak species in canopy and subcanopy of forest and woodland surrounding serpentine grasslands
- Dominance by native woody species in shrub layer of forest and woodland surrounding serpentine grasslands
- High density of native tree seedlings, tree saplings and shrubs in shrub layer in patches totaling at least 50% of area of forest and woodland surrounding serpentine grasslands
- High within-patch and between-patch species diversity of native tree seedlings, tree saplings, shrubs and herbaceous plants in of forest and woodland surrounding serpentine grasslands
- Dominance by native plant species in wetlands
- High within-patch and between-patch species diversity of native herbaceous plants in wetlands

Desired conditions of serpentine barrens plant and animal species of special conservation concern:

- Secure population status of all plant species of special conservation concern present at the Unionville Barrens:
  - small-leaf white-snakeroot (PR)
  - Elliott's bluestem (PR)
  - arrow-feather three-awn (PT)
  - side-oats grama (PT)
  - Bicknell's sedge (PE)
  - Richardson's sedge (PE)
  - New Jersey tea (SP)
  - barrens chickweed (SP)
  - tufted hairgrass (PT)
  - Heller's rosette grass (PT)
  - long-haired panic-grass (PE)
  - annual fimbry (PT)
  - Bicknell's hoary rockrose (PE)
  - rock sandwort (SP)
  - Small's ragwort (PR)
  - round-leaf fameflower (PT)
  - few-flowered nut-rush (PT)
  - serpentine aster (PT; globally rare)
- Recovery to secure population status of at least 50% of the plant species of special conservation concern formerly present in the Unionville Barrens:
  - colic-root (PE)
  - slender three-awn (TU)
  - stiff tick-trefoil (TU)
  - slender crabgrass (SP)
  - forked rush (PE)
  - downy lobelia (PE)
  - lion's-foot (PT)
  - whip-grass (PE)
  - white heath aster (PT)
- Secure population status of animal species of special conservation concern present in the Unionville Barrens

  Survey work is needed to identify what species are present. The initial focus should be on arthropods, birds and amphibians because of the high likelihood of finding rare or declining species in those groups at the site.

Desired conditions of ecosystem resilience:

- Long-term stability across entire range of indicators
- Stability of indicators following severe drought
- Stability of indicators in the event of unforeseen major perturbation

Desired conditions of landscape context:

- 1,000-foot smoke buffer with few houses or other buildings
- 500-foot seed dispersal buffer where bird- and wind-dispersed invasive species are kept in check

3.1.2 Species diversity and composition

Plant species. The most dramatic change from current to desired conditions will be the resurgence of grassland from its current low of 7 acres in widely scattered patches, many very small, to broad expanses totaling 50 acres or more. The expansion of habitat is expected to halt the ongoing decline and extirpation of grassland plant populations due to the twentieth-century steep decline in habitat area. It is also expected to restore the site's long-term ability to support viable populations of declining species and of extirpated species that may recolonize on their own or be targets for reintroduction from local seed sources. All of the plants of special conservation concern will benefit by having more space to proliferate into larger—and therefore more resilient and secure—populations (critically low population numbers are discussed further under *Threats* later in this section).

Another major change will be a sharp reduction in the abundance of invasive nonnative plants, especially autumn-olive and stiltgrass, and a decrease in several native species, principally red maple, eastern red-cedar and common greenbrier, which have invaded the barrens and caused changes to soil and light conditions that are detrimental to serpentine grassland plants.

Forests and woodlands will be restored to mixed oak dominance or a successional trajectory of eventual oak species dominance by the thinning of competitive trees, especially red maple, and by the reduction of the outsized deer population, which is browsing oak seedlings to near-total loss each winter (there is more on deer effects later under *Threats*).

Wetlands that have been increasingly shaded by dense overtopping tree growth will be exposed to more sunlight by tree thinning and prescribed fire, fostering the return of shade-intolerant native wetland species whose populations have been reduced or extirpated.

Animal species. The particular value of the Unionville Barrens to wild animals is in providing habitat for specialists that depend on serpentine grasslands and oak-dominated forests or on small native grasslands and scrubby vegetation in general. Assessing the current condition of wildlife habitat and determining desired conditions will depend partly on the outcomes of future animal surveys.

Indicators of wildlife habitat quality, include (but are not limited to):

- secure populations of host plants for rare animals whose diets are narrowly limited to plant species restricted to a degree to serpentine barrens (examples include wild indigo, New Jersey tea and native warm-season grasses)
- acreage of the serpentine grassland community, where most plant hosts for specialist insect herbivores live
- availability of dead tree snags for cavity-nesting animals (mainly eastern red-cedars killed but left standing)

Monitoring will also include direct observations of the animals themselves. Indicators include all animal species of special conservation concern, which first need to be identified in baseline surveys and then tracked over time in periodic follow-up surveys. Indicators also include species of highly visible animals—birds and butterflies—whose presence is associated with the specialized habitats of the barrens or whose populations are declining in the region. To date, the prairie leaf beetle is the only animal species of special conservation concern confirmed at the Unionville Barrens. Other arthropods of special conservation concern are highly likely to be found through professional surveys conducted by qualified entomologists. Bird species of special conservation concern or whose populations are declining in the region are also most likely present.

3.1.3 Structural, patch and habitat diversity

Clarification of terms. Structural diversity is variety from place to place in community structure, which consists of the vertical layering and horizontal arrangement of plants of different sizes and growth forms, extent of canopy closure or bare ground, and amounts and types of decomposing plant material on the ground. Patch diversity is the variety of patch types within a community or ecosystem; a patch is a relatively discrete area that is different in some significant way from its surroundings, for instance, in plant species composition, age since the last major disturbance, or community structure. Habitat diversity is a measure of the difference in species composition among patches within a community and communities within a landscape. Desired conditions generally maximize these three components of diversity, within the parameters imposed by other desired conditions such as overall dominance by native species and secure population status of species of special conservation concern.

High diversity in community structure and patch type is needed to accommodate a variety of plant and animal species. Such diversity corresponds to some degree with site features, for instance, spring seeps, exposed bedrock, old mine tailings, and varied soil depth, slope steepness and aspect. Patch diversity associated with differences in species dominance and composition also arises from variation in land-use, disturbance and management histories. Another important influence on patch diversity is the priority effect—which species arrived and established first after a disturbance. The desired condition is a diverse mosaic of patch types differing in successional stage, species composition, vegetation density and prevailing vegetation height.

The communities with highest stewardship importance, in rank order by conservation priority, are:

(1) **Serpentine Indian-grass – little bluestem grassland** (including prairie and savanna) and **serpentine gravel forb community** are globally rare ecological communities and have the highest priority for stewardship at the Unionville Barrens. Despite their greatly reduced area from the historical peak, their diversity in structural, patch and habitat attributes remains relatively high. The desired condition is still higher diversity in these factors, including the return of large, open prairie patches, that is, areas of one to several acres with less than 10% tree cover.

Measures of success in achieving high grassland and gravel forb community patch diversity include:

- plant species turnover (different composition) among patches
- frequency of patches with high plant species richness
- relative proportion of grassland (at least 50% cover of native grasses) and serpentine gravel forb community (at least 50% cover of forbs) among patches
- relative proportion of patches dominated by short herbaceous plants and patches dominated by intermediate to tall herbaceous plants
- plant density variation among patches
- relative area of savanna versus prairie

(2) **Serpentine seep**, also globally rare, will expand in total area as tree and invasive shrub cover is removed from spring seeps and swales formerly dominated by its shade-intolerant characteristic species, including tufted hairgrass, swamp thistle, slender spikerush and New York ironweed.

There is a low likelihood that its reflectance signature on satellite imagery can be distinguished from that of the surrounding grassland but GPS-assisted ground surveys in fall or spring may provide a feasible measure of total area. Besides increased area, desired conditions also include scarcity or absence of nonnative species, high within-patch species diversity, and between-patch variation in species composition, all of which can be measured on a representative sample of occurrences.

(3) **Mixed forb marsh** is ranked high in conservation priority at the Unionville Barrens because its occurrences are hotspots for native plant species diversity

and the core habitats for a high proportion of the native plant species once found at the site but now extirpated. Desired conditions are the same as for serpentine seep and can be monitored on a representative sample of occurrences using the same indicators.

(4) **Red maple – oak – greenbrier serpentine forest and woodland**, although globally rare, is lower in priority than other serpentine barrens-restricted communities. Its species diversity and habitat value for species of special conservation concern are far lower than in serpentine grassland, which it has invaded and displaced through forest succession. Desired conditions include substantial *reduction* in the present-day extent and lowered dominance by red maple and other mesic forest species that alter soil conditions and hasten further succession toward ordinary mesic forest. The desired result is higher oak dominance, in particular by the characteristic oaks of serpentine barrens—post oak, blackjack oak and Bush's oak in the canopy and dwarf chinkapin oak in the understory.

3.1.4 Ecosystem processes

Disturbance regime. Regular disturbance is essential to maintain grasslands against forest succession in most of eastern North America, with its year-round moist climate. However, different disturbances can have very different effects on grassland ecosystems. Moreover, nuances of disturbance type, seasonal timing, severity and frequency help to determine whether a grassland becomes a high-dominance near-monoculture (undesired) or a diverse mix of many species (desired), or whether it converges toward structural uniformity (undesired) or diverges into a highly patchy environment that can accommodate the habitat needs of many species (desired). Patchiness at a range of scales is desired, from 100–1,000-square foot gravel forb and serpentine seep communities or localized stands of a rare species to 1–10-acre patches of grassland, woodland or forest differing in the relative abundances of the dominant species.

The measures of success in applying disturbance regimes to achieve and sustain grassland and meadow desired conditions are the indicators relating to grassland acreage and species diversity and composition described elsewhere in this section.

Fire. The halt in regularly recurring fire with the collapse and dispersal of American Indian populations has been identified as the main cause of diminishing native plant species diversity in Midwestern prairie remnants[1] and almost certainly caused the loss of more than 99% of the land area formerly in native grasslands and meadows from within the present-day borders of Pennsylvania soon after European contact[2].

There is little doubt that fires of extreme severity were common through the evolutionary history of temperate eastern North American serpentine barrens even though they almost never occur today. Fire severity is associated with drought severity. There was little reason not to burn during droughts before European settlement; it is even possible that droughts were preferred times for burning because of the boost in ecological impact toward conditions desired by Native Americans. Ever since rural fire suppression started in the mid-twentieth century, fire has been virtually excluded. Prescribed burning is banned during all but the mildest of drought conditions (for good reasons of safety to life and property).

The main distinction of high-severity fire is that it burns downward into the duff layer by extended smoldering, "cooking" the roots of shallow-rooted plants, killing part of the seed bank, and leaving the soil highly vulnerable to erosion in the early post-fire period—all of which are beneficial to the long-term persistence of serpentine

[1] Leach and Givnish (1996)

[2] Latham (2005)

barrens-restricted species and serpentine grassland, gravel forb and seep communities. Lower-severity fires, including typical prescribed burns, are essential for the long-term maintenance of serpentine barrens but they cannot replicate all of the effects of the fires that fostered and sustained those communities throughout most of their history. Prescribed burning crews may be able to achieve high severity in limited areas under controlled conditions where fuel loads are high enough and moisture levels low enough to ignite duff and prolong smoldering overnight, with round-the-clock monitoring to insure any flare-ups do not result in loss of control. Once feasibility is demonstrated, rotating severe fire among selected areas could be a powerful tool for maintaining desired patch diversity.

Soil reduction. The desired effects of severe fire can be simulated in part by mechanical soil organic matter removal with off-site 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. However, 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.

Grazing and browsing. Historically, grazing by cattle has had positive effects in sustaining serpentine grassland through extended periods of fire exclusion at many, if not all sites. This has been observed most recently or is best documented at the New Texas Barrens, Chrome Barrens and Pink Hill. Prescribed browsing and grazing by goats has been employed at a small scale as a serpentine grassland restoration tool in three-year trials at the Nottingham Barrens, with disappointing results. Goats browsed dense thickets of common greenbrier to the point where no aboveground parts were visible but the succeeding vegetation cover, although dominated by herbaceous species, was not serpentine grassland. Surviving greenbrier rhizomes restored the thickets within a year or two after the goats were removed[1]. Although prescribed browsing or grazing should not be ruled out as a management method to be tested in future adaptive management trials, logistical and cost challenges such as the need for fencing and veterinary care make it an unlikely routine management method in the Unionville Barrens' future.

Selective herbivory associated with long-term deer superabundance is unlike disturbances listed in the preceding paragraphs in at least two ways: its source is the target of an active reduction effort—the ChesLen Preserve's deer management program; and herbivory by deer is a threat to desired conditions at high deer population density. Unlike fenced or tethered livestock, deer numbers and intensity of browsing pressure are difficult to regulate, their effects on vegetation cannot be targeted only where desired on the landscape for management purposes, and it is impractical to exclude them except from small areas. Deer herbivory is treated under *Threats* (pp. 61–66)

Soil dynamics. The key desired soil change is a reversal of the accumulation of soil organic matter and associated increases in nutrient availability and moisture-holding capacity over the past century in the areas where tree and shrub cover has replaced grassland. This is equivalent to re-intensifying the serpentine soil syndrome and reducing macronutrient availability.

A short-term increase in the rate of soil erosion from the hilltops and upper slopes (and deposition downslope and on stream floodplains) will be encouraged as the ground surface is exposed to the full force of rain and runoff following restoration burning and soil scarification by machinery

[1] Latham and Thorne (1997); R. E. Latham, unpublished data

used to remove trees and invasive shrubs. These disturbances will increase organic matter decomposition rates as soil surfaces blackened by fires increase soil temperature and the easily decomposed fine roots of cut trees and fire-killed plants feed soil microbes. Accelerated soil organic matter decomposition and erosion will decrease soil thickness.

Erosion rates are likely to level off later, after a switch to the longer fire return intervals associated with maintenance burning and the spread of cover by native perennial warm-season grasses, with their dense, rain-intercepting foliage and deep, fibrous root systems. As restored grasslands mature, the desired trajectory of soil development is a gradual shift of some soil nutrients now in labile forms into living biomass and more-recalcitrant litter (including charcoal), which bind up some of the macronutrient pool for long periods. This makes macronutrients less available to highly nutrient-demanding species, which include most invasive nonnatives.

The forested headwater stream ecosystems will unavoidably undergo some degradation during this rearrangement of soil and organic matter. This trade-off in desired conditions is made necessary by the higher priority placed on the globally rare serpentine barrens communities compared with the more common forested headwater stream community. The streams are expected to rebound to near starting conditions or better as newly expanded grasslands and gravel forb communities mature, becoming increasingly effective at stabilizing soil and filtering runoff. However, because of their lower priority and the high demands of monitoring the highest priority communities and species, no monitoring of stream indicators is suggested at this time.

Metrics relating to plant species diversity and composition will reflect the desired shift to heightened serpentine soil syndrome effects and decreased fertility and soil thickness. In general in terrestrial ecosystems, lower soil fertility is associated with lower dominance (higher species evenness) and lower competition, which at the Unionville Barrens should translate to higher native species richness and increases in serpentine grassland-restricted plant populations.

Ecological resilience. "The ability of a system to absorb disturbance and still retain its basic function and structure" is a general definition of resilience[1]. Ecologists commonly use the term resilience with two more-restricted meanings. One is the speed at which an ecosystem returns to its former state after it has been displaced from that state by a disturbance; the other is the amount of disturbance required to push an ecosystem over a threshold onto a successional pathway leading to different persistent state[2]. The former lends itself to measurement.

Resilience has no separate metrics from those of other desired conditions. Instead, its measure is the speed of recovery among all of those metrics following severe droughts or other major perturbations. It is also the stability of those indicators in the face of ongoing climate change.

Climate change. Changes in species composition and other ecosystem attributes due to climate change hinge on the characteristics of many individual species and therefore are difficult to predict accurately and in detail[3]. The best anyone can do is a set of educated guesses based on the fossil record during past climate changes and knowledge of living species' tolerances and habitat preferences. There is every reason to expect that serpentine barrens' resilience to climate change will be high. Experimental simulations show that resilience depends on the particular set of species present; however, there is evidence

[1] Walker and Salt (2006): p. 1

[2] Eckert (2009)

[3] Graham and Grimm (1990)

that mature, native grasslands are highly resilient and successional or newly reclaimed grasslands considerable less resilient to the likely effects of climate change, which include elevated CO_2 levels, higher temperatures, more-variable precipitation, and longer droughts[1].

Native grasslands and meadows in general are likely to be more resilient than forests to disruption by global climate change. As climate warms and droughts become more severe and frequent, grassland is likely to need less intensive management to resist forest succession. Drought kills tree seedlings and saplings at higher rates than upland grassland plants and in so doing, slows succession. Warming and wider variation in precipitation almost certainly will lead to changes in species composition, depending on localized (patch scale) conditions. More severe rainstorms and less precipitation as snow may increase soil erosion locally. Drought-tolerant species are expected to increase in cover and dominance while moisture-demanding species contract. In the long term, the expectation is of range expansions northward of southern species (additions to the local flora), some with a human assist, and range contractions northward of northern species (local extirpations).

Serpentine barrens have long been famous as collections of disjunct or "island" populations of species whose main ranges are in the hotter Southeast, in the drier Midwest, or on the sandy, low-nutrient, more drought-prone soils of the Atlantic Coastal Plain. Grassland community changes are likely to be less dramatic in the face of expected climate change than those in surrounding Northern Piedmont forests, where some forest types may decline, especially in well-drained soils and on south-facing slopes, possibly with gradual replacement by mixed pine-deciduous forests similar to those currently widespread in the Atlantic Coastal Plain and Piedmont to the east and south. The oak forests of the Unionville Barrens are likely to be among the most resilient of local forest types, because they are already dominated by species with relatively high tolerance for intermittent drought.

3.1.5 Landscape context

Smoke buffer. Prescribed burning can be applied most effectively if there is a large buffer zone around all potential burn units within which there are no houses or other occupied buildings. Smoke and hazard management are critical issues in prescribed burning. The wider and more completely encircling the buffer zone is, the less severe the constraints are on how many days are available for burning due to wind direction, and the lower the likelihood is that a burn already in progress will need to be shut down because of an unexpected wind shift. An adequate buffer also minimizes risk to life and property in case of escape. Ideally, new construction will be restricted by easement or fee purchase so that no more houses may be built within at least 1,000 feet of any management unit boundary (see Map 10). Township zoning is another means of limiting new construction, but it is less reliable in the long term because it is subject to variances and amendments.

Seed dispersal buffer. Most seeds fall close to the parent plant, but for species capable of long-distance dispersal, mainly by birds or wind, a relatively concentrated "seed shadow" may extend several hundred feet (only a very small proportion of seeds are carried farther). Success in managing invasive species in the barrens and adjacent high-quality oak forests will depend in part on eradicating those plants or reducing them as much as possible in the surround-ing area and targeting new colonies as they arise. It is assumed that doing so in a zone 500 feet wide surrounding management

[1] Grime *et al.* (2000); Adler *et al.* (2006); Engel *et al.* (2009)

unit boundaries will substantially reduce the effort needed to manage invasive species in core areas of grassland and high-quality oak forest stands. At present in and around the Unionville Barrens, the most common invasive species in the category of long-distance dispersers are autumn-olive, Japanese barberry, Oriental bittersweet, Japanese honeysuckle, Amur honeysuckle, Morrow's honeysuckle, multiflora rose, wineberry, winged euonymus (burning-bush), border privet, tea viburnum, mile-a-minute and Canada thistle.

3.1.6 Metrics of ecosystem condition—the phytometer approach

The Unionville Barrens are important enough that they merit a higher intensity of monitoring effort than most NLT preserves. NLT's management of the Unionville Barrens will have global consequences because the site harbors several globally rare communities, one globally rare plant and possibly one to several globally rare insect species. It also is home to at least 17 other plant species and possibly a similar number of animal species of special conservation concern in Pennsylvania. The metrics recommended here (Table 7, pp. 50–59) seem complex at first reading, but most of them can be calculated from simple estimates of plant species cover on a set of permanent monitoring quadrats, which need only to be surveyed every 3–5 years. Also, because of the site's importance it is urgent that resources and qualified personnel are deployed soon to conduct baseline arthropod and bird surveys and a system put in place for follow-up surveys at appropriate intervals.

Plants are the dominant organisms in nearly all non-aquatic ecosystems and certain attributes of their performance are effective proxies for many aspects of whole-ecosystem condition. Plants and ecological communities have been used as ecological measuring instruments since nearly a century ago[1]. "Phytometers" remain one of the most effective and efficient ways of tracking the complexities of ecosystem conditions and dynamics.

Using selected attributes of individual plants, populations or entire communities as assessment tools in ecological research and monitoring is based on the idea that plant responses integrate a multitude of physical, chemical and other environmental factors and their complex interactions. When measured or counted at regular intervals they can better reflect ecosystem conditions and be more predictive of trends than direct measurements of abiotic factors, whose interactive effects on ecosystem components are often poorly understood. Measuring phytometers takes the place of guessing which environmental factors are important, how they rank relative to each other, and in what intricate ways they may counteract or intensify each other's effects. Most of the indicators recommended in this report are phytometric (Table 7).

Attributes of animal populations also can be important indicators of ecosystem conditions, but in most cases they are much more difficult, expensive and time-consuming to count or measure. Unlike plants, animals rarely submit docilely to measurement or stay in the same place until the next monitoring occasion. However, unlike the majority of animal species, grassland birds and butterflies are conspicuous and diurnal and some bird-related attributes may be monitored by sound as well as sight. Several animal metrics are recommended for at least occasional monitoring (Table 7).

In some monitoring situations it is essential to include metrics of one or more physical, chemical or other abiotic factors, in particular where such a factor has a

(continued on p. 60)

[1] Clements and Goldsmith (1924)

Table 7. **Desired conditions, metrics, target values and existing conditions of the Unionville Barrens.** See Table A-2, Appendix A (p. 110) for meanings of codes in parentheses after species names. See text (pp. 60–61) for methods used to derive target values.

desired condition	metric (= indicator) & suggested monitoring interval	target values	present condition
ECOLOGICAL COMMUNITIES AND LANDSCAPE			
1. Total area of grassland + gravel forb community + serpentine seep approaching 45 acres	GIS computation of area based on recent high-resolution (1-m/3-foot or better) satellite imagery—every 2–3 years	EXCELLENT ≥ 45 acres GOOD 35–44.9 acres FAIR 25–34.9 acres POOR < 25 acres	POOR 7 acres
2. Ample proportion of serpentine gravel forb community (vs. grassland & wetland) in total herbaceous-dominated area	GIS computation of area based on recent high-resolution (1-m/3-foot or better) satellite imagery, assuming image classification software can be used to reliably separate the communities—every 3–5 years	EXCELLENT ≥ 20% GOOD 15%–19.9% FAIR 10%–14.9% POOR < 10%	unknown; possibly GOOD
3. Intermediate to high (but not too high) proportion of prairie (vs. savanna) in total area of grassland	GIS computation of area based on recent high-resolution (1-m/3-foot or better) satellite imagery, counting only prairie (< 10% tree cover) polygons that can fully enclose a circle ≥ 1 acre (≥ 236-foot diameter)—every 3–5 years	EXCELLENT 50%–80% GOOD 40%–49.9% or 80.1%–85% FAIR 30%–39.9% or 85.1%–90% POOR < 30% or > 90%	POOR < 30%
4. Dominance by native herbaceous serpentine grassland plant species in all grassland patches	Average percent of total plant cover in herbaceous serpentine grassland species per 5-m × 5-m monitoring quadrat (100 × sum of percent cover of those species ÷ sum of all species)—every 3–5 years	EXCELLENT 95%–100% GOOD 90%–94.9% FAIR 85%–89.9% POOR < 85%	probably GOOD to EXCELLENT
5. High within-patch native serpentine grassland plant species diversity	Average richness (α) of native serpentine grassland plant species per 5-m × 5-m monitoring quadrat—every 3–5 years	EXCELLENT ≥ 20 GOOD 15–19.9 FAIR 10–15.9 POOR < 10	unknown; possibly GOOD to EXCELLENT
	Average evenness ($E_{1/D}$) of all plant species per 5-m × 5-m monitoring quadrat—every 3–5 years	EXCELLENT 30–100 GOOD 24–29.9 FAIR 18–23.9 POOR < 18	unknown; possibly GOOD to EXCELLENT
	Upper quartile of evenness of all plant species per 5-m × 5-m monitoring quadrat—every 3–5 years	EXCELLENT 36–100 GOOD 30–35.9 FAIR 24–29.9 POOR < 24	unknown; possibly GOOD to EXCELLENT

desired condition	metric (= indicator) & suggested monitoring interval	target values		present condition
6. High between-patch diversity in native serpentine grassland plant species composition, including dominant species	Herbaceous serpentine grassland plant species turnover (β_H) among 25-m² monitoring quadrats—every 3–5 years	EXCELLENT GOOD FAIR POOR	15–100 12–14.9 9–11.9 < 9	unknown; possibly GOOD to EXCELLENT
	Upper quartile of herbaceous serpentine grassland plant species richness per 25-m² monitoring quadrat—every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 25 20–24.9 15–19.9 < 15	unknown; possibly GOOD to EXCELLENT
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%	not yet measured
	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%	not yet measured
8. Dominance by a mixture of oak species in woods (forest and woodland) canopy and subcanopy	Average percent of total canopy cover in oaks per 25-m² monitoring quadrat (100 × sum of percent cover of those species ÷ sum of all species)—every 3–5 years	EXCELLENT GOOD FAIR POOR	90%–100% 80%–89.9% 70%–79.9% < 70%	unknown; possibly FAIR to GOOD
9. Dominance by native plants in woods (forest and woodland) shrub and ground layer	Average percent of shrub and ground layer (< 2 m height) plant cover in native species per 25-m² monitoring quadrat (100 × sum of percent cover of native species ÷ sum of all species)—every 3–5 years	EXCELLENT GOOD FAIR POOR	90%–100% 80%–89.9% 70%–79.9% < 70%	unknown; possibly POOR
10. High density of native tree seedlings and saplings in patches totaling at least 50% of area of woods	Average aggregate percent cover of native tree seedlings & saplings per 25-m² monitoring quadrat, counting only the 50% of quadrats with the highest aggregate percent cover—every 3–5 years	EXCELLENT GOOD FAIR POOR	> 90% 80%–89.9% 70%–79.9% < 70%	unknown; possibly POOR
11. High density of native shrubs in patches totaling at least 50% of area of woods	Average aggregate percent cover of native shrubs per 25-m² monitoring quadrat, counting only the 50% of quadrats with the highest aggregate percent cover—every 3–5 years	EXCELLENT GOOD FAIR POOR	> 90% 80%–89.9% 70%–79.9% < 70%	unknown; possibly POOR

(Table continues on next page.)

desired condition	metric (= indicator) & suggested monitoring interval	target values		present condition
12. High within-patch species diversity of native tree seedlings, saplings, shrubs and herbaceous plants in woods	Average richness (α) of native tree seedlings, saplings, shrubs and herbaceous plant species per 25-m² monitoring quadrat—every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 20 15–19.9 10–15.9 < 10	unknown; possibly POOR to FAIR
	Average evenness ($E_{1/D}$) of all tree seedlings, saplings, shrubs and herbaceous plant species per 25-m² monitoring quadrat—every 3–5 years	EXCELLENT GOOD FAIR POOR	30–100 24–29.9 18–23.9 < 18	unknown; possibly POOR to FAIR
	Upper quartile of evenness of all tree seedlings, saplings, shrubs and herbaceous plant species per 25-m² monitoring quadrat—every 3–5 years	EXCELLENT GOOD FAIR POOR	36–100 30–35.9 24–29.9 < 24	unknown; possibly POOR to FAIR
13. High between-patch species diversity of native tree seedlings, saplings, shrubs and herbaceous plants in woods	Native plant species turnover (β_H) among 25-m² monitoring quadrats—every 3–5 years	EXCELLENT GOOD FAIR POOR	15–100 12–14.9 9–11.9 < 9	unknown; possibly FAIR to GOOD
	Upper quartile of native plant species richness per 25-m² monitoring quadrat—every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 25 20–24.9 15–19.9 < 15	unknown; possibly FAIR to GOOD
14. Dominance by native herbaceous plant species in wetlands	Average percent of total herbaceous plant cover in native herbaceous species per 25-m² monitoring quadrat (100 × sum of percent cover of those species ÷ sum of all species)—every 3–5 years	EXCELLENT GOOD FAIR POOR	90%–100% 80%–89.9% 70%–79.9% < 70%	unknown; possibly POOR to FAIR
15. High within-patch species diversity of native herbaceous plants in wetlands	Average richness (α) of native herbaceous plants per wetland patch—every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 20 15–19.9 10–15.9 < 10	unknown; possibly POOR to FAIR
	Average evenness ($E_{1/D}$) of all plant species per wetland patch—every 3–5 years	EXCELLENT GOOD FAIR POOR	30–100 24–29.9 18–23.9 < 18	unknown; possibly POOR to FAIR

desired condition	metric (= indicator) & suggested monitoring interval	target values		present condition
Within-patch diversity in wetlands (continued)	Upper quartile of evenness of all plant species per wetland patch—every 3–5 years	EXCELLENT GOOD FAIR POOR	36–100 30–35.9 24–29.9 < 24	unknown; possibly POOR to FAIR
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 years	EXCELLENT GOOD FAIR POOR	15–100 12–14.9 9–11.9 < 9	unknown; possibly FAIR to GOOD
PLANTS OF SPECIAL CONSERVATION CONCERN				
17. Secure population status of Bicknell's sedge (PE)	Discrete clusters at least 500 apart—every 2–3 years until GOOD, then every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 4 3 2 1	POOR 1 known
	Estimated total number of tufts—every 2–3 years until GOOD, then every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 10,000 1,000–9,999 100–999 < 100	POOR ~ 25 known
18. Secure population status of Richardson's sedge (PE)	Discrete clusters at least 500 apart—every 2–3 years until GOOD, then every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 4 3 2 1	POOR 1 known
	Estimated total number of tufts—every 2–3 years until GOOD, then every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 10,000 1,000–9,999 100–999 < 100	POOR est. 10–100
19. Secure population status of long-haired panic-grass (PE)	Discrete clusters at least 500 apart—every 2–3 years until GOOD, then every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 4 3 2 1	unknown
	Estimated total number of tufts—every 2–3 years until GOOD, then every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 10,000 1,000–9,999 100–999 < 100	probably FAIR est. 100–1,000

(Table continues on next page.)

desired condition	metric (= indicator) & suggested monitoring interval	target values		present condition
20. Secure population status of Bicknell's hoary rockrose (PE)	Discrete clusters at least 500 apart—every 2–3 years until GOOD, then every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 4 3 2 1	POOR 1
	Estimated total number of stems—every 2–3 years until GOOD, then every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 1,000 100–999 10–99 < 10	POOR to FAIR est. ~ 10
21. Secure population status of arrow-feather three-awn (PT)	Discrete clusters at least 500 apart—every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 4 3 2 1	probably GOOD
	Estimated total number of tufts—every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 100,000 10,000–99,999 1,000–9,999 < 1,000	probably FAIR to GOOD est. > 5,000
22. Secure population status of side-oats grama (PT)	Discrete clusters at least 500 apart—every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 4 3 2 1	probably FAIR
	Estimated total number of tufts—every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 100,000 10,000–99,999 1,000–9,999 < 1,000	probably FAIR est. > 5,000
23. Secure population status of tufted hairgrass (PT)	Discrete clusters at least 500 apart—every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 4 3 2 1	EXCELLENT >4
	Estimated total number of tufts—every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 10,000 1,000–9,999 100–999 < 100	GOOD est. 1,000–5,000

desired condition	metric (= indicator) & suggested monitoring interval	target values		present condition
24. Secure population status of Heller's rosette grass (PT)	Discrete clusters at least 500 apart—every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 4 3 2 1	probably EXCELLENT
	Estimated total number of tufts—every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 10,000 1,000–9,999 100–999 < 100	probably FAIR est. 100–1,000
25. Secure population status of annual fimbry (PT)	Discrete clusters at least 500 apart—yearly	EXCELLENT GOOD FAIR POOR	≥ 4 3 2 1	probably EXCELLENT
	Estimated total number of individuals—yearly	EXCELLENT GOOD FAIR POOR	≥ 10,000 1,000–9,999 100–999 < 100	probably GOOD est. 1,000–5,000
26. Secure population status of round-leaf fameflower (PT)	Discrete clusters at least 500 apart—every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 4 3 2 1	probably GOOD to EXCELLENT
	Estimated total number of stems—every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 1,000 100–999 10–99 < 10	FAIR to GOOD est. 50–500
27. Secure population status of few-flowered nut-rush (PT)	Discrete clusters at least 500 apart—every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 4 3 2 1	EXCELLENT >4
	Estimated total number of tufts—every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 10,000 1,000–9,999 100–999 < 100	GOOD to EXCELLENT est. > 5,000

(Table continues on next page.)

desired condition	metric (= indicator) & suggested monitoring interval	target values		present condition
28. Secure population status of serpentine aster (PT; globally rare)	Discrete clusters at least 500 apart—every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 4 3 2 1	EXCELLENT >4
	Estimated total number of stems—every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 10,000 1,000–9,999 100–999 < 100	GOOD to EXCELLENT est. > 5,000
29. Secure population status of small-leaf white-snakeroot (PR)	Discrete clusters at least 500 apart—every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 4 3 2 1	EXCELLENT >4
	Estimated total number of stems—every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 10,000 1,000–9,999 100–999 < 100	GOOD to EXCELLENT est. > 5,000
30. Secure population status of Elliott's beardgrass (PR)	Discrete clusters at least 500 apart—every 2–3 years until GOOD, then every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 4 3 2 1	POOR 1
	Estimated total number of tufts—every 2–3 years until GOOD, then every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 10,000 1,000–9,999 100–999 < 100	POOR est. ~ 10
31. Secure population status of Small's ragwort (PR)	Discrete clusters at least 500 apart—every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 4 3 2 1	EXCELLENT >4
	Estimated total number of stems—every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 10,000 1,000–9,999 100–999 < 100	GOOD to EXCELLENT est. > 5,000

desired condition	metric (= indicator) & suggested monitoring interval	target values		present condition
32. Secure population status of New Jersey tea (SP)	Discrete clusters at least 500 apart—every 2–3 years until GOOD, then every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 4 3 2 1	unknown
	Estimated total number of stems—every 2–3 years until GOOD, then every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 2,500 500–2,499 100–499 < 100	POOR to FAIR est. 50–100
33. Secure population status of barrens chickweed (SP)	Discrete clusters at least 500 apart—every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 4 3 2 1	EXCELLENT >4
	Estimated total number of stems—every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 10,000 1,000–9,999 100–999 < 100	GOOD to EXCELLENT est. > 5,000
34. Secure population status of rock sandwort (SP)	Discrete clusters at least 500 apart—every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 4 3 2 1	EXCELLENT >4
	Estimated total number of individuals—every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 10,000 1,000–9,999 100–999 < 100	GOOD est. > 5,000
35. Secure population status of each other plant species of special 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	unknown
	Each species: estimated total number of stems	EXCELLENT GOOD FAIR POOR	contingent on species	unknown

(Table continues on next page.)

desired condition	metric (= indicator) & suggested monitoring interval	target values		present condition
LARVAL HOST PLANTS FOR LEPIDOPTERA OF SPECIAL CONSERVATION CONCERN				
36. Secure population status of moss-phlox	Discrete clusters at least 500 apart	EXCELLENT GOOD FAIR POOR	≥ 4 3 2 1	GOOD to EXCELLENT
	Estimated total number of plants	EXCELLENT GOOD FAIR POOR	≥ 10,000 1,000–9,999 100–999 < 100	FAIR to GOOD est. 500–5,000
Secure population status of New Jersey tea (same as 32, above)	Discrete clusters at least 500 apart—every 2–3 years until GOOD, then every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 4 3 2 1	unknown
	Estimated total number of stems—every 2–3 years until GOOD, then every 3–5 years	EXCELLENT GOOD FAIR POOR	≥ 2,500 500–2,499 100–499 < 100	POOR to FAIR est. 50–100
Secure population status of all native warm-season grasses in aggregate (same as 1, above)	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 7 acres
ARTHROPOD SPECIES OF SPECIAL CONSERVATION CONCERN				
37. Presence and detection frequency of individual arthropod species of special conservation concern	Each species: number of individuals captured by standardized methods—every 3–5 years	EXCELLENT GOOD FAIR POOR	contingent on species	unknown
	Each species: variation from previous surveys in number of individuals captured by standardized methods (population increase, decrease or stability)	EXCELLENT GOOD FAIR POOR	contingent on species	unknown

desired condition	metric (= indicator) & suggested monitoring interval	target values	present condition
BIRD SPECIES OF SPECIAL CONSERVATION CONCERN			
38. Secure breeding status of individual bird species of special conservation concern (e.g., brown thrasher, common nighthawk, yellow-breasted chat) 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	unknown
	Each species: variation in number of verified nesting pairs from average over previous 3 years (short-term population increase, decrease or stability)	EXCELLENT < 10% decline GOOD 10%–14.9% decline FAIR 15%–19.9% decline POOR ≥ 20% decline	unknown
	Each species: variation in number of verified nesting pairs from average over previous 15 years (long-term population increase, decrease or stability)	EXCELLENT ≤ 0% decline GOOD 0.1%–5% decline FAIR 5.1%–10% decline POOR > 10% decline	unknown
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
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	unknown
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	unknown

strong effect and is likely to undergo rapid change. That is more often true of aquatic ecosystems than those on land; for instance, in streams and lakes certain water chemistry attributes can change quickly and such change can bring about massive changes in species composition and other ecosystem conditions. At present no abiotic metric is considered to be essential for effective monitoring of ecosystem conditions in the Unionville Barrens, but unforeseen circumstances could change that state of affairs at some future time.

Ecological indicators. According to a seminal paper, indicators of ecological integrity and management success

> need to capture the complexities of the ecosystem yet remain simple enough to be easily and routinely monitored. Ecological indicators should meet the following criteria: be easily measured, be sensitive to stresses on the system, respond to stress in a predictable manner, be anticipatory, predict changes that can be averted by management actions, be integrative, have a known response to disturbances, anthropogenic stresses, and changes over time, and have low variability in response.[1]

The most effective metrics for learning whether management methods need to be modified or new methods tried are quick-response indicators—those that respond rapidly to any escalation or decline in stresses and to management actions taken to remedy those stresses.

Instead of defining a single threshold value separating "acceptable" from "unacceptable" for each metric, we describe potential values of indicators in terms of *ranges of variation* and split the ranges into segments ranked excellent, good, fair or poor. One reason for bringing ranges of variation into play is that fluctuation over time in most of the key ecological attributes is natural and expected and not inconsistent with high ecosystem integrity. Equally importantly, judging success in restoring and maintaining ecosystem integrity is not an either/or proposition; success is better viewed as something that is achieved by gradual progress from less-desired to more-desired conditions. Part of the reward and satisfaction in natural land stewardship is achieving milestones along that path. Systematically measuring indicators is a way of cataloging and honoring those milestones.

Most indicators of desired conditions at the scale of ecological communities and landscapes (Table 7, items 4–16) and populations of plants of special conservation concern that occur in high abundance at the site (items 21–29, 31–34, 36 and 39) can be calculated from the results of a single periodic monitoring task, namely, surveying plant species cover in scattered, permanently marked quadrats. A few sparsely distributed plants of special conservation concern (items 17–20, 30 and 39) will not be picked up by quadrats and will require special surveys targeting known clusters of individuals. Some landscape-scale indicators are measured by GIS analysis of satellite imagery (items 1–3). Skilled amateur volunteers can be pressed into service to monitor bird indicators (item 38). Professional entomologists must be employed to track arthropod indicators (item 37). Details are presented in the next section under *Monitoring* (pp. 80–84) and in Appendix D (pp. 149–153).

Methods for setting target values. Desired condition metrics and target values involving plant species diversity, combined cover of species functional groups, community structure, patchiness and habitat for animals of special conservation concern were developed based on quantitative analyses of plant species cover data from the few relevant reference sites for which such data are available. Nottingham Barrens contain the only serpentine grassland with available pertinent data; data from two other major

[1] Dale and Beyeler (2001), p. 3

grassland areas in southeastern Pennsyl–vania were also included in the analyses[1].

Because so little pertinent data exist, much professional judgment is involved; therefore ranking of target values into ranges identified as poor, fair, good and excellent are not definitive, but are properly viewed as hypotheses subject to further testing and upgrading. How well the ranges of target values reflect relative quality under real-world conditions may be tested using data gathered in future years at the Unionville Barrens and at other serpentine barrens across the Northern Piedmont as grassland restoration and maintenance move forward. Hypothesis testing in this case will be somewhat subjective and future adjustments to target values based on monitoring data will likewise rely to a large degree upon professional judgment and consensus among experts.

Metrics and target values at the level of whole landscapes, such as total serpentine grassland area and proportions of grassland in prairie, savanna and gravel forb community, were developed from historical descriptions of Northern Piedmont serpentine barrens together with consideration of the specific resource potentials and constraints at the Unionville Barrens.

Metrics for populations of plant species of special conservation concern require rough estimates of abundance and distribution of each extant species within the barrens. Target values are based on crude estimation of the levels of abundance and patterns of distribution required for long-term population viability, given what is known about each species' life history and other characteristics.

3.2 Threats

A *threat* is a stress affecting a desired condition and the source or sources of that stress. A *stress* is a process or event with direct negative consequences on the desired condition, such as forest succession at the grassland edge or invasive species proliferation. A *stressor* (source) is the action or entity that produces a stress, such as fire exclusion or soil organic matter accumulation. Threat analysis involves identifying and ranking stresses and stressors for each of the desired conditions. In ranking threats, several factors are taken into account:

- Severity of damage—What level of damage can reasonably be expected within 10 years under current circumstances if they do not change?
- Scope of damage—What is the geographic scope of impact on the desired condition within the project area that can reasonably be expected within10 years under current circumstances if they do not change?
- Irreversibility of damage—How responsive is the ecological attribute described by the desired condition likely to be to corrective action after the damage is done?

The principal threats to the desired conditions identified in the previous section, in rank order of severity, scope and irreversibility of the consequences, are:

(1) Critically low population numbers associated with habitat area decline

(2) Fire exclusion and forest succession

(3) Invasive nonnative species

(4) Artificially elevated white-tailed deer population

[1] Analysis methods and results are detailed in Latham (2011).

3.2.1 Critically low population numbers associated with habitat area decline

Nearly 90% of the 1937 grassland area has been lost to forest succession (see Figure 2, p. 23). As the area of each grassland patch declines, the population numbers of all of the native plant and animal species that depend on grassland habitat also fall off. Wild plants and animals lack the option of responding to decreasing living space by crowding together. The minimum amount of territory, food and other land-based resources each individual needs is a characteristic of its species. As numbers drop, any population becomes more vulnerable to local extinction. Wild populations fluctuate as a matter of course with year-to-year differences in weather, predator abundance, disease outbreaks, and other factors. When populations are small, their chances of dipping to zero during normal fluctuation greatly increase.

Small, isolated populations are especially vulnerable to disaster from causes such as disease, prolonged drought, or a management error based on inadequate knowledge. An example is the heath hen (*Tympanuchus cupido cupido*), a wild cousin of the prairie chicken that once lived in Pennsylvania's serpentine barrens. Soon after European settlement of the Northeast the species dwindled catastrophically due to hunting pressure. By the early twentieth century, it survived only on Martha's Vineyard, Massachusetts, where it was protected and considered to be secure. But, ironically, the decision by wildlife managers to protect its habitat from fire most likely sealed its fate. The dwindling of grasslands and heathlands on Martha's Vineyard due to an absence of the fires that had sustained them for centuries aggravated the population's decline. When the last individual on Martha's Vineyard died, heath hens became extinct.

Extirpation—local extinction—of native species has already happened over the last 50 to 100 years at the Unionville Barrens. Of the 27 plant species classified as endangered, threatened or rare that have been documented since around 1900 at the Unionville Barrens, 9 were not found in 2004–2011 surveys and are probably gone (see Tables 1 and 6, pp. 22–23 and 37). It is safe to assume that grassland-dependent invertebrate species, which have never been comprehensively surveyed at the site, have declined at even higher rates, because animal populations are generally more sensitive and quicker to respond to habitat loss than plants.

As local habitat area declines for a species, there is often an extended lag time before extirpation, particularly for plants. Plants may persist for years at less than the minimum viable population—what some ecologists have termed the "walking dead," that is, too few to have any significant ecological role, depleted in genetic diversity from inbreeding and thus increasingly vulnerable to disease, and so highly localized that the last individuals are at risk of eradication by a chance mishap. With the steep loss of habitat area at the Unionville Barrens since 1937, several species are likely living on borrowed time. Of the 18 rare plant species known to survive at the site, at least 5 are represented by a precariously small number of individuals (Table 5, pp. 35–36).

3.2.2 Fire exclusion and forest succession

With the major exception of salt marshes along the Atlantic coast, most long-persisting (dating from before European settlement) native grasslands in the Mid-Atlantic region owe their existence and long-term maintenance to fire[1]. This principle has been recognized for a long time with respect to some grassland ecosystems, but apparently it was first connected to serpentine grasslands in particular less than 30 years ago[2]. The

[1] Day (1953); Thompson and Smith (1970); Denevan (1992); Latham and Thorne (2007)

[2] Miller (1981); Sladky (1981); Latham (1993)

peculiar qualities of serpentine soil were thought to be enough to explain the unusual vegetation until some botanists and ecologists in the mid-twentieth century began to notice that the serpentine grasslands were shrinking and disappearing. The losses were not all due to conversion to housing developments and golf courses; in many cases the culprit was simple forest succession, starting at the edges of the grasslands.

The reasons why succession seemed to abruptly begin taking its course in the mid-twentieth century after years of suspension are twofold. First, increasing human population density in the area, together with advancing technology, led to effective fire control in rural areas for the first time. For the 2½ centuries before then, fires in remote areas were allowed to burn themselves out—rural residents had no choice in the matter. Secondly, increasing human population density was accompanied by the abandonment of farms and the end of livestock grazing.

Also critical to the connection between fire and the persistence of serpentine grasslands over long time periods are two effects of severe soil conditions and harsh summertime heat in the barrens—slowed plant growth and increased plant mortality. The inhospitable conditions kill many trees at the seed or seedling stage and cause the few survivors to grow quite slowly, with the exception of root-suckering species such as black locust and sassafras (water and mineral-nutrient needs of new shoots originating as root sprouts are subsidized via rhizomes, or underground runners, connected to their full-grown "parents" at the woods edge). The result is that grasses and forbs, which are more tolerant of thin serpentine soils and hot conditions, can maintain their dominance longer between tree-killing disturbances in serpentine barrens than in other kinds of grasslands, meadows and abandoned farm fields. This is why burning maintains serpentine grassland even if fires occur seldom and sporadically. Most grasslands and meadows in the region would need to burn much more often and on a more regular schedule to prevent forest succession.

The chief forest trees invading the grassland edges are red maple, black-gum sassafras and black cherry. Black locust and ailanthus are nonnative weedy trees invading small areas of the Unionville Barrens. Black locust is native to parts of eastern North America but did not occur east of the Appalachians before European contact; ailanthus is from northern and eastern China. Common greenbrier is a native woody vine that prefers wet habitats or shade, but a greenbrier living in partial shade and organic-matter-rich soils at the forest edge or under an isolated tree can send rhizomes into the open grassland and grow a thicket there to harvest light rays, secondarily shading out the grasses and forbs. Trees and greenbriers that successfully invade grassland drop large quantities of organic matter in dead leaves, bark and branches. The buildup of soil organic matter eventually buffers plant life in the vicinity against the effects of serpentine mineral soil, gradually converting barrens into species-poor forest, which exterminates grassland species by shading them[1].

3.2.3 Invasive and aggressive plant species

Invasive nonnative species. The invasive plant posing the greatest risk to serpentine grasslands at the Unionville Barrens is autumn-olive (not to be confused with the closely related Russian-olive, which is very scarce at the Unionville Barrens, or with any member of the unrelated true olive family, represented at the site only by white ash and border privet). In forest and woodland and along forest edges, the greatest threat is posed by autumn-olive and stiltgrass.

[1] Barton and Wallenstein (1997); McCandless (1998)

Most of the nonnative species living in serpentine grassland occur there sparsely and are not considered a threat to the grasslands' integrity. Examples in the Unionville Barrens include common yarrow, field garlic, sweet vernalgrass, nodding thistle, Queen Anne's-lace, Deptford pink, sheep sorrel and meadow fescue. To be considered as severely invasive, a plant species must usurp large amounts of space from native species and cause changes in soil conditions that result in degradation of habitat for native species. So far only autumn-olive meets these criteria in the grassland. The list of invasive species in the wooded parts of the barrens is much longer. Besides stiltgrass and autumn-olive, which cover more area than all other invasive species put together, the most severe infestations are of garlic mustard, Japanese barberry, Oriental bittersweet, Japanese honeysuckle, Amur honeysuckle, multiflora rose and wineberry. Others present in small numbers but posing a risk of increasing impact include Norway maple, ailanthus, black locust, winged euonymus (burningbush), border privet, Morrow's honeysuckle and tea viburnum.

Of all invasive plants, autumn-olive is the most severe threat to the ecological integrity of the Unionville Barrens and to the imperiled species that live there. It has root nodules that house nitrogen-fixing actinomycetes[1]. As a byproduct of gaining nitrogen for themselves, autumn-olives increase its availability to other plants. Where abundant, autumn-olive can change entire habitats by enabling nitrogen-demanding plants to be highly competitive, replacing plants that are tolerant of soils with low available nitrogen (including all native serpentine grassland species), which tend to be poor competitors.

Autumn-olive produces a large amount of seed. A single individual can produce 2–8 pounds of seed per year and the number of seeds per pound ranges from 20,000 to 54,000[2], totaling 40,000–400,000 seeds per plant per year. The seeds are distributed widely by birds and have a high rate of germination. Because seeds are bird-dispersed, commonly traveling hundreds of feet from the parent plant and occasionally over much longer distances, it is helpful wherever possible to eradicate autumn-olive populations in larger areas surrounding the threatened area.

Aggressive native species. The most aggressive invaders of serpentine barrens among native tree species are red maple and eastern red-cedar. Atypically, the Unionville barrens lack the most prevalent aggressive native tree species at more than half of the Northern Piedmont serpentine barrens—Virginia pine.

Common greenbrier cover is moderate at the Unionville Barrens relative to many other serpentine barrens. Greenbriers are most abundant in oak – red maple – greenbrier serpentine forest and woodland and in the ecotone along the edge between that community and serpentine grassland. It is both fire-tolerant and fire-facilitating, as are the warm-season perennial grasses that dominate the savannas. Its highly flammable stems and leaves spread fire rapidly along the ground and, where there is a high density of climbing individuals, upward into tree crowns. It recovers quickly post-fire from reserves stored in thick rhizomes. Greenbrier outcompetes herbaceous serpentine grassland plants in situations of moderate shade, advancing as a phalanx from the forest or woodland edge or from beneath scattered savanna trees.

Fortunately, in experiments at the Nottingham Barrens, prescribed burning across the grassland-woodland edge has been found to result in the incremental

[1] Sather and Eckardt (1987)

[2] Sather and Eckardt (1987) citing Holtz (1981) but without listing the source

retreat of greenbrier advancing fronts[1]. Greenbrier can also be effectively curtailed by mechanical removal and off-site disposal of the top few inches of soil, including the greenbrier rhizomes.

3.2.4 Artificially elevated white-tailed deer population

White-tailed deer are a natural part of the region's ecosystems, but a convergence of events has caused them to proliferate to unprecedented population densities. For the first two centuries after Europeans arrived the human population grew exponentially and unlimited hunting eroded the balance between predators and deer that had prevailed for eons. By 1900 deer were nearly extinct in Pennsylvania and other eastern states because of over-harvesting. By then the native predators of deer had been exterminated. State agencies instituted game laws in an effort to rebuild the deer population. These hunting rules, which have persisted to the present with few major changes, focused on providing a maximum sustained yield of game for recreational hunters. Deer reproduce rapidly and the deer population soared to unprecedented levels in just a few decades.

Deer populations are no longer kept at ecologically innocuous levels as they were for more than 99% of their existence—for over two million years by large predators and for most of the last 13,000–15,000 years or longer also by Native Americans, for whom venison was a major source of food. A diverse array of predators regulated deer populations for millions of years before humans arrived in what is now southeastern Pennsylvania, including the gray wolf, dire wolf, grizzly bear, giant short-faced bear, mountain lion, American cheetah and jaguar. When human hunters arrived they displaced all but a handful of the other major predators, but American Indians, gray wolves and mountain lions continued to regulate deer populations until Europeans arrived and expelled all three.

Recreational hunting as it is practiced today under strict game laws and for only a short interval in the fall and winter has traditionally had relatively little impact on deer population numbers, although NLT's deer management program has achieved some success by recruiting and supervising hunters and focusing their efforts on doe removal. Success in limiting deer populations to levels compatible with restoring and sustaining ecosystem integrity also hinges on cooperation by neighboring landowners. Deer pass freely across land ownership boundaries except where predator (hunting) pressure is different on one side of the line from the other. Areas where hunting effort is low or nonexistent serve as refuges and can sabotage even the best deer management program on adjacent lands.

Deer thrive best in the forest-edge habitat that timbering, farming and suburbanization have created over most of our region. The unprecedented high numbers that exist in much of the region today consume the tree seedlings and saplings, shrubs and wildflowers that in more favorable circumstances make native forest and grassland ecosystems healthy, beneficial to other wildlife and self-sustaining. Much of the forest in and around the Unionville Barrens has been stripped of native understory vegetation. The dense layer of native shrubs, young trees, ferns and wildflowers that are the hallmark of a healthy forest is sparse or, in some parts, almost completely missing. The understory now is typically either largely devoid of plant life or choked with invasive nonnative species, especially autumn-olive, stiltgrass, Oriental bittersweet, multiflora rose and garlic mustard. Deer and other plant-eating wildlife generally avoid invasive nonnative plants, which is one of the reasons they can proliferate unchecked.

[1] Latham and Thorne (1997); R. E. Latham, unpublished data

The effects of deer on grassland are much more subtle than in the forest. The dominant grassland plants are adapted to disturbance, including grazing and browsing. The few pertinent scientific studies have shown a positive influence on Midwestern prairie forb diversity at very low deer density and negative effects at densities similar to those prevailing today in southeastern Pennsylvania[1]. Species that are highly preferred by deer have little chance against the onslaught of the current deer population, which may be 20 times higher than before European settlement. Plants known to be vulnerable include many current residents of the Unionville Barrens whose regeneration has been halted or nearly so, including the seedlings and small saplings of the eight oak species found at the site. Oaks may appear secure to the casual observer but when the current adult trees die through natural decline, disease or windfall, the populations will decline or disappear if high rates of deer browsing persist. Several other vulnerable plant species have already been extirpated from the Unionville Barrens, including colic-root and downy lobelia (both endangered in Pennsylvania) and lion's-foot and white heath aster (both threatened in the state), but it is only a guess whether and to what degree the outsized deer population was a factor in their demise.

Sustaining or restoring any of these species must start with the goal of reducing and maintaining deer density at an appropriate level. Unless that goal is achieved, management of other stressors and attempts at reintroduction will be a lesson in futility that ultimately will end with the loss of more vulnerable species.

Monitoring well-chosen indicators is the only sure way to track success in ongoing management of the deer population, verify whether observed ecosystem trends are due to deer or to other factors, and determine when adjustments to deer management methods are needed to achieve or sustain desired conditions. However, devising an effective set of metrics is complicated by the need to separate deer effects from the multitude of other influences on vegetation and by the fact that deer feeding preferences are notoriously variable from place to place and at different times.

> Food preferences depend partly on what is available to eat. Food variety and availability in turn depend on current local deer density, recent trends in local deer density, availability of alternative forage, human land-use patterns, forest disturbance history, snow cover, and various other factors. Thus, preferred species frequently differ between regions in the same forest type, within regions over long periods of time, at different times during a growing season, and at different deer densities in the same forest type.[2]

Separating deer effects from other influences requires that indicators be measured using exactly the same methods inside and outside of fenced deer exclosures (see *Monitoring deer effects*, p. 83, and *Experimental control*, pp. 149–150). The unpredictability of feeding preferences is sidestepped as a potential confounding factor in the same way, by comparing vegetation change over time between adjacent fenced and unfenced monitoring quadrats. Indicators related to deer herbivory include:

- relative frequencies and abundances of plants preferred and avoided by deer as food
- survival and fecundity of plant species known to be exceptionally highly preferred

[1] Anderson *et al.* (2001, 2005)

[2] Latham *et al.* (2005): p. 51

4 Management Recommendations

4.1 Adaptive management

Adaptive management, in simplest terms, consists of carrying out a set of actions, periodically monitoring the results, reconsidering the methods in light of those results, and adjusting the next round of implementation accordingly. This approach is a way of reducing uncertainty without high-cost research. Trials of promising alternative methods for achieving objectives are carried out and results compared quantitatively as a part of routine management. This subsection outlines stewardship tools and methods needed to achieve and sustain desired conditions. Monitoring, an indispensible part of adaptive management, is covered in subsection 4.2 (pp. 80–84). The concluding subsection (pp. 84–91) prioritizes tasks and outlines a timetable. The fundamentals of effective design of management trials are given in Appendix D (pp. 149–153).

Skepticism about adaptive management arises from fears that it will be too time-consuming or add costs, burdening stewardship budgets already stretched thin. However, part of the motivation to adopt adaptive management is to save time and money in the long run. It is more powerfully self-correcting than traditional management approaches, discarding methods with second-rate performance more quickly (saving time that would otherwise be wasted) and improving methods faster toward greater effectiveness and efficiency. Appendix D, if read in conjunction with this section, attempts to answer a skeptic's questions: When confronted with a management problem, why not just try something and see if it works? What is the point of comparing the results of alternative methods with each other or with areas where no management is applied? Why is it necessary to conduct trials in more than one area at the same time? And why go to the trouble of actually measuring and quantifying the results? Isn't it enough to just look at what happens in order to judge whether a method works well enough to keep on using it?

Throughout this section, a distinction is made between *restoration* and *maintenance* phases of management. Restoration is aimed at changing ecosystem attributes now considered "poor" or "fair" toward their desired condition, preferably in a short span of years. Maintenance is aimed at keeping those ecosystem attributes within the "good" to "excellent" range over the long term—in fact, indefinitely. Restoration work is generally more time- and energy-intensive and more costly on an annual basis than maintenance work.

For convenience in planning and communication, the barrens are divided into seven numbered management units or M.U.s (Map 10). Each M.U., in turn, is divided into grassland management areas (shown in yellow on Map 10 and labeled as the *grassland restoration target area*) and forest management areas (untinted on Map 10). Besides grassland and forest, a third category of vegetation is *woodland*, defined as having 25%–60% tree cover across minimum mapping units of 1 acre. Woodlands will—as restoration progresses—lie mostly along the edges where grassland and forest management areas meet. Woodlands may fall either in the grassland or forest management areas on the map but they can be differentiated from forest, which is defined as having 60%–100% tree cover, by visual appraisal on the ground.

The grassland management areas are further divided into two zones—present-day grassland (yellow area on Map 4) and forest and woodland to be restored to grassland (overlap between the two shades of green on Map 4 and yellow on Map 10). Future (post-restoration) grasslands will be a mosaic of *savanna*, defined as having 10%–25% tree cover, and *prairie*, with 0%–10% tree cover in a contiguous area (single GIS polygon) that can fully enclose a circle of at least 1 acre (≥ 236 feet in diameter).

The seven M.U.s cover all the barrens area regardless of present ownership. M.U.s 1–5 lie mostly within present ChesLen Preserve boundaries. M.U.s 1, 2 and 5 will grow larger (see interim boundaries, Map 10) and M.U.s 6 and 7 will be added if NLT gains management rights on the two neighboring parcels.

4.1.1 Selective tree removal and replacement

Restoration of grassland on over 50 acres of forest and woodland that had grassland cover within the last 75 years starts with substantial, but still somewhat selective, tree removal. In the grassland restoration target area, the main objectives of tree removal are greatly increasing sunlight at ground level and eliminating the main source of soil organic matter accumulation. A moderate level of more highly selective tree removal is desirable in the forest management areas. The objective there is to counter the successional trajectory toward replacement of the oak canopy by red maple and other mesic forest trees that began with fire exclusion in the mid-twentieth century and accelerated with the onset of seedling overbrowsing by the outsized deer population.

The most cost-effective and least environmentally damaging method of tree removal is cutting flush to the ground and hauling away the entire tree to be used for a purpose that prevents the carbon bound in the wood from being released as CO_2 for a significant period of time. Certain species must be removed by other means.

Tree removal in grassland management areas (shaded in yellow on Map 10) will target most trees, but some species are excluded from cutting.

Trees off-limits to cutting in grassland management areas include oaks of species that are part of the characteristic flora of Northern Piedmont serpentine barrens, open-grown oaks with branches almost down to ground level (emblematic of the savanna landscape), and very large oaks. They are:

- any post oak, blackjack oak, Bush's oak (blackjack oak-black oak hybrid), water oak or dwarf chinkapin oak
- isolated open-grown trees in existing grassland of black oak, scarlet oak, northern red oak, pin oak, white oak or chestnut oak
- large specimen trees ≥ 20 inches dbh (diameter at 4½ feet above the ground) of any oak species

Eastern red-cedars also should be left standing for the most part to serve as long-lasting snags providing habitat for cavity-nesters (see *Treatment of eastern red-cedar*, next page. If workers cutting other trees would have to go to unusual lengths to avoid felling a particular red-cedar, it may be cut.

The reasons to preserve very large oak trees are as much esthetic as biological. They are major sources of food and complex tree-canopy habitat for wildlife and of acorns endowed with good survival genes to perpetuate oak regeneration. But they also have historical significance and are a source of awe and inspiration. It is inappropriate to take down monumental oaks in a nature preserve. The threshold size of 20 inches dbh is high enough that a relatively small number of the largest trees will be preserved.

Tree thinning in forest management areas (areas within management units but not shaded in yellow on Map 10) will be more limited, with a broader range of trees excluded from cutting. The objectives of thinning are to

- enhance tree size variation and structural diversity in even-age stands
- open up the canopy to increase sunlight at the forest floor and favor tree seedling and sapling growth, especially of oaks and hickories

The objective of tree thinning in forest management areas is to redirect forest succession back into a pathway toward mixed oak dominance and away from its current trajectory toward red maple dominance. Oaks are poorly represented in the < 6 inches dbh cohort of trees to be left behind in a wood products harvest, which will take most trees 6–20 inches dbh. In two approximately 25-m × 25-m quadrats in M.U.s 1 and 2 surveyed informally in 2011, oaks and hickories made up

- 12% of trees < 6 inches dbh
- 19% of trees 6–20 inches dbh
- 100% of trees > 20 inches dbh

Those percentages for red maple and black-gum were

- 68% of trees < 6 inches dbh
- 74% of trees 6–20 inches dbh
- 0% of trees > 20 inches dbh

Sustaining or restoring oak dominance in these stands requires that stewardship staff (and volunteers) go into those areas after the intermediate-sized trees are cut to thin the smaller trees. Any sapling oaks and hickories should be left intact. Red maple, black-gum, tuliptree and other native mesic forest species should be drastically thinned. Nonnative species should be eradicated. Thinning will improve the prospects for oak regeneration over what they are now in every way except one—there are still too many deer to allow regeneration from seed. After at least one post-thinning burn to reduce invasive species abundance, oaks and hickories will need to be planted in tree tubes in the larger canopy gaps. The species to be planted are black oak, scarlet oak, white oak, pignut hickory, northern red oak (on lower slopes only) and chestnut oak (on upper slopes and the ridgetop only).

Since the barrens are an important natural area, introduction of non-local genotypes should be avoided. Ideally the planting stock should be raised from acorns and hickory nuts collected at the site. But if the stock is needed earlier, container stock from Pennsylvania Northern Piedmont genotypes can be bought from a reputable native plant wholesale nursery. It is best if they come from seed collected in Chester County or its neighboring counties.

Large seed trees of oaks and hickories should be left intact at a high enough density for mice and squirrels to spread seed throughout the area, in anticipation of the time when deer density is brought down to a level that allows natural oak regeneration and is maintained at that level long-term.

Tree species to be generally excluded from cutting in forest management areas:

- sapling (< 6 inches dbh) and large (> 20 inches dbh) oaks, pignut hickory (and other hickory species, if found) and black walnut
- a few intermediate-size (6–20 inches dbh) oaks and hickories per acre of any species not represented in the large size class, to serve as additional seed sources
- eastern red-cedar (to be converted to dead snags and, where stands are very dense, thinned; see next page)
- ailanthus (removed by other means)
- black locust (removed or converted to dead snags by other means)

The latter three species are singled out for special treatment other than cutting. Ailanthus and black locust should not be cut or girdled because such actions typically result in massive proliferation of root suckers. These two species are discussed below under *Invasive and aggressive species control* (pp. 74–78).

Tree species targeted for cutting in forest management areas:

- natives (objective is drastic thinning but not eradication):
  - red maple
  - black-gum
  - tuliptree (yellow-poplar)
  - white ash
  - black cherry
  - American beech
  - bigtooth aspen
  - sassafras
- nonnatives (objective is eradication):
  - white mulberry
  - crabapple
  - sweet cherry
  - common pear
  - Norway maple
  - sycamore maple

Preventing stump-sprouting. Herbicide may be applied to the freshly cut stumps of nonnative stump-sprouting species, in particular Norway maple, sycamore maple and white mulberry. Such treatment is not necessary for native species because for them the objective is not eradication; for oaks in particular, stump-sprouting is a desired condition. Glyphosate without an added surfactant (trade names Rodeo, Accord) is the least environmentally damaging choice for treating freshly cut stumps of nonnatives (other than ailanthus and black locust; see p. 76). It is effective when applied to the outer 2–3 inches of a stump's rim within a few minutes of cutting.

No cutting in wetlands. Black-gum and red maple dominance is a desired condition in the swamps along Corundum Run (see Map 8). Cutting, skidding and equipment transport should be kept out of any wet ground and a reasonable buffer (at least 50 feet) around it.

Treatment of eastern red-cedars. Eastern red-cedar is a characteristic species of the serpentine barrens but can displace grasslands if allowed to proliferate in the absence of fire. Live red-cedars cast dense shade and continually shed old leaves, which loads decomposing organic matter onto the soil. Both effects foster invasion by non-barrens species, especially invasive nonnatives such as stiltgrass, Japanese honeysuckle, Oriental bittersweet and garlic mustard. As dead snags, they are exemplary habitats for cavity-nesters and other snag-utilizing wildlife because their wood is rot-resistant and they can provide many years of service. Local cavity-nesters include flying squirrel, wood duck, screech owl, barred owl, barn owl, American kestrel, downy woodpecker, hairy woodpecker, red-bellied woodpecker, northern flicker, pileated woodpecker, red-headed woodpecker, tree swallow, eastern phoebe, great crested flycatcher, purple martin, white-breasted nuthatch, gray catbird, Carolina wren, house wren, eastern bluebird, black-capped chickadee, Carolina chickadee, tufted titmouse and prothonotary warbler. Hawks and owls use dead snags as perches. After trees or snags fall, the logs and branches provide essential habitat for a wide variety of amphibians, snakes, mammals and arthropods.

Conversion of red-cedars to dead snags. Most of the eastern red-cedars at the Unionville Barrens should be left standing but converted to dead snags. Some will be killed (but not destroyed) the first time they are exposed to prescribed fire, either by torching—fire igniting the resinous, highly flammable foliage of a red-cedar's crown—or by injury to the bark's inner cambium at the base of the tree if the ground fire is exceptionally hot. Torching is possible if ground fuels support flame lengths higher than the lowest foliage, likely only where dense grasses or shrubs surround a red-cedar with intact low branches or where there are ladder fuels—dense vines such as greenbriers climbing into the crown. During a prescribed burn, isolated red-cedars in grassland that escape burning can be ignited by applying a drip torch or a flamethrower designed for use in prescribed burning (trade name Terra

Torch) to individual trees. After an area has been burned once or twice, most of the red-cedars that remain alive may be converted into dead snags by basal bark application of triclopyr (trade name Garlon 4) mixed with a penetrant or in a ready-mixed formulation (Pathfinder II). Waiting to see how many trees are killed by fire cuts down time and material costs for herbiciding and reduces herbicide collateral damage to nearby plants, including rare species.

Thinning of dense stands of red-cedar. In the densest red-cedar stands, which occur in M.U. 3 and the northwestern corner of M.U. 2, the density may be reduced by thinning—flush-cutting selected trees to ground level or pulling them out of the ground whole with a backhoe. Sawn trees should be removed from the site but pulled trees, because they resemble natural treefalls and are similarly beneficial to wildlife, may be left on the ground in small numbers. In general, larger trees should be left standing for conversion to snags because they can support more cavity-nesting wildlife. Trees selected for felling should be mainly in the small to intermediate size range. Very large red-cedars, 18 inches trunk diameter or larger, may be left intact and alive as specimen trees.

Selected red-cedar trees to remain alive. A few smaller red-cedars should be left intact and alive. A reasonable target density for live trees is 1–10 per acre, which can be achieved by killing 90%–95% of the red-cedar population living in the barrens in 2010 (shown in red on Map 4). The very largest trees have special esthetic and historical value and should be allowed to reach the end of their lifespan by natural causes.

Expected outcomes of tree removal. In terms of staff time, logistics and funding, the most practical approach to tree removal is contracting with a wood products business to harvest trees over large areas all at once. There is a high risk that large-scale tree removal will result in massive proliferation of undesired species. The response of invasive species will vary from one area to another within the barrens. It is expected to be most severe where forest stands are thinned to a very open-canopy state and least severe where the trees that are removed have warm-season grasses growing beneath them before removal. It is worth looking ahead to the various likely outcomes of taking the trees out all at one time over a large area to ensure that stewardship staff is prepared to deal with them. Funding, equipment, supplies and personnel time should be secure for any and all probable outcomes. Likely scenarios include, but are not limited to:

- Best case—a mixture of invasives and barrens natives develops and there is enough fuel for a hot burn the following spring or summer, which greatly reduces the invasive cover relative to the native cover.
- Worst case—mostly invasives develop and it rains too much for any burning the following year, allowing them to become fully established and produce a large seed crop in the first season.
- Intermediate case 1—the fuel still is not dense enough in the first 1–2 years to carry a fire across the entire timber cut, which allows the invasives to become fully established and set seed, but prescribed burns starting in year 2 or 3 post-fire gradually reduce their cover.
- Intermediate case 2—a drought precludes burning the year after cutting, but the drought itself reduces the invasive cover relative to the native cover.

Control of invasive and aggressive species is the subject of subsection 4.1.3 (pp. 74–78).

4.1.2 Prescribed burning

Frequency and severity of prescribed burning.

Prescribed burning in grassland is to be applied as often as needed to halt the spread of woody plants, especially common greenbrier, that overrun and displace herbaceous plants. Fire return intervals can be as short as 2–3 years early on in the restoration phase and later, 10–15 years or longer for maintenance. No attempt should be made to standardize return interval. Decisions about what year to burn should be triggered by local conditions, for instance, by an established grassland area having passed a threshold level of tree or greenbrier invasion. The desired condition of high grassland patch diversity can be fostered by varying the fire return interval among and within patches over long periods of time, much as it would have varied throughout the ecological history of the temperate eastern North American serpentine barrens throughout their range.

Grassland burns are typically low-severity, but high-severity (overnight smoldering) fire is desirable in certain circumstances, including where cover of common greenbrier is higher than 20% or where high soil organic matter accumulation persistently supports the proliferation of nonnative plants or rapid growth of native or nonnative woody vines. Mitigating the increased risk of escape associated with high-severity fire involves applying it in a small area at any one time—small enough for one person to be able to see the entire burn unit post-fire from one vantage point—and maintaining round-the-clock monitoring until the fire is extinguished.

Prescribed burning in forest needs to be applied less frequently than in grassland. Forest areas may be burned concurrently with adjacent grasslands as large, combined units. Early on, in the restoration phase, the main objective is to reduce or eliminate invasive woody species such as Oriental bittersweet, Japanese honeysuckle, Japanese barberry, winged euonymus, Amur honeysuckle, wineberry and multiflora rose (but not autumn-olive) and to reduce seed production and survival by invasive annuals and biennials such as stiltgrass, Canada thistle, garlic mustard and mile-a-minute. Later, in the maintenance phase, the objective is to restore oak regeneration by releasing oak seedlings and stump sprouts from suppression by faster-growing but less fire-tolerant tree seedlings, saplings and stump sprouts such as those of red maple, black-gum, tuliptree, white ash and black cherry. The trigger for maintenance burning is a dense growth of tree seedlings and saplings, including oaks. This in turn depends critically on light availability (canopy openness) and intensity of winter deer browsing.

Low-severity fires will achieve the forest management objectives of helping to restore oak and hickory regeneration, redirecting forest succession back toward mixed oak dominance and away from red maple dominance in the canopy, and discouraging understory dominance by nonnative invasive species. High-severity fires would pose a risk of killing the native trees and understory plants that define the forest ecosystem and giving advantage to nonnative invasive species that thrive in the typically deep forest soils with increased light.

Prescribed burning in open woodland between grassland and forest may need to be more frequent, more severe, or both to achieve desired conditions than in either open grassland or closed-canopy forest. The rationale for this hypothesis:

(1) Soils are thicker there than in open grassland, supporting invasion by non-barrens species.

(2) Partial shade at ground level allows growth of non-grassland species that are intolerant of extreme summer heat in open grasslands.

(3) Common greenbrier reaches its densest growth in the ecotone and experimental ecotonal burning has decreased its cover there.

The desired condition of open woodland is an understory dominated, at least in patches, by native warm- and cool-season grasses. Whether this condition can be achieved by burning only at the same time as adjacent grassland or if it will require additional, smaller burns focused specifically on woodland is unknown. The adaptive management approach provides the framework for resolving such questions—conducting trials of alternative methods in several replicate plots, in this case, varying fire frequency and severity, then measuring and comparing the effects of high and low frequency and high and low severity on key indicators.

Scale of prescribed burning. No more than one-third of the existing grassland habitat should ever be burned in one year at any site where species of special conservation concern are present[1]. This is because some of the rare species are insects, many of which are killed outright by fire. Furthermore, recolonization of burned areas by insects is not instantaneous. It can take 1–5 years for insect populations to recover following a burn[2], even if the burned area is adjacent to occupied habitat that is not burned that year.

Burn units correspond roughly but not fully to the seven management units (M.U.s). Some prescribed burns will comprise an entire management unit (or more than one), covering forest, woodland and grassland in the same fire. However, it is not necessary or desirable to burn oak forest areas as often as the adjacent woodland and grassland areas, so some burns will be confined to just the grassland and woodland parts of a management unit. Furthermore, varying fire footprints over years and decades to achieve desired patch diversity and diversity of habitats requires that prescribed burns should sometimes target partial or multiple M.U.s.

Season of prescribed burning. Almost all burning to date to manage serpentine grasslands has been in spring before most plants have leafed out. Growing-season (late summer) burns should be subject to repeated trials in different areas to assess their effectiveness in meeting desired condition objectives. In all likelihood, there was considerable variation in seasonality of fire through the evolutionary history of serpentine grasslands. It is reasonable to expect that spring burns will work best to meet some objectives, growing-season burns will work best to meet others, and conducting both kinds of burns in different parts of the barrens in different years will result in higher patch diversity and native species diversity across the entire landscape. Spring burns generally favor warm-season grasses and late-flowering forbs over cool-season grasses, graminoids and early-flowering forbs, whereas late-summer burns are likely to have the opposite effect.

After tree cutting, parts of the grassland restoration area with deep soils, especially on mid- to lower slopes, are expected first to support a rapid growth of woody plants and nonnative invasive plants and eventually, with repeated or severe fire, to develop dense, relatively uniform stands of tall warm-season grasses. Such stands often exhibit high dominance (low species evenness) and low species richness. Occasional late-summer burns in such situations may enhance both components of species diversity. Adaptive management trials are the most powerful tool for testing this prediction.

4.1.3 Invasive and aggressive species control

On thin serpentine soils with little shade from trees, invasive plants pose little threat to native serpentine barrens biodiversity. Typically an initial flush of undesired species appears after disturbances such as tree-cutting or mechanical removal of the upper layer of soil, but most disappear in 1–3 years, or more quickly if the disturbance is followed by prescribed

[1] Schultz and Crone (1998)

[2] Swengel (1996); Panzer (2002)

burning as soon as growth produces enough fuel to carry a fire. However, the thicker the soil, the more buffered from the serpentine soil syndrome newly germinated plants will be, and the faster and more closely packed the undesired species are likely to grow. Moderate shade in woodland and savanna, in contrast with full sun in treeless areas, also is likely to facilitate invasion by undesired species.

Ranked in terms of severity of infestation and urgency of treatment, the most important invasive nonnative species are autumn-olive[1] and stiltgrass[2]. Other woody species degrading ecosystem integrity are ailanthus[3], Japanese barberry[4], Oriental bittersweet[5], winged euonymus[6], Japanese honeysuckle[7], Amur honeysuckle[8], multiflora rose[9], black locust[10] and wineberry[11]. Other herbaceous species posing major threats are garlic mustard[12], Canada thistle[13], lesser celandine[14] and mile-a-minute[15] (for online information sources on these species see Appendix E, pp. 154–157).

Invasive species infestation is expected to undergo a temporary upsurge in areas where trees are removed. Soil scarification by equipment and dragged trees will cause seeds in the soil seed bank to break dormancy. The increased sunlight at ground level after canopy thinning or removal will enable rapid growth. A burst of plant-available nutrients released by increased decomposition of organic matter residues by soil microbes will give invasive nonnative species a strong advantage over native barrens species.

In newly restored grassland, prescribed burning within a year after tree clearing and repeated at least once or twice within the following 2–4 years is expected to be effective in controlling invasive species. Desired conditions may be achieved sooner by supplementing burning with spot-herbiciding localized outbreaks of prolific seed-dispersers such as Canada thistle, if stands are not too large or numerous. Persistent problem spots are also likely where soils are thick or high in organic matter, for instance, in depressions where dead leaves collect or on concave slopes where soil builds up with sheet erosion. In such cases, consideration should be given to physically removing the invasive plants, including their roots, together with a few inches of the organic-matter rich upper soil layer using a front-end loader or backhoe and disposing of the material off-site.

Removing autumn-olive. The highest urgency is placed on autumn-olive removal. Initially, this will consist of trials of two methods on four trial plots (Figure 5): (1) mechanical removal of entire plants using the tines of a backhoe bucket, with off-site disposal; (2) basal bark application of triclopyr (trade name Garlon 4) mixed with a penetrant or in a ready-mixed formulation (Pathfinder II), with later burning of dead aboveground parts in the course of prescribed burning. Use of foliar herbicide is not recommended in the Unionville Barrens for autumn-olive control because damage to nearby nontarget species is unavoidable when spraying the foliage of large shrubs and because of the large scope of the infestation.

[1] Sather and Eckardt. (1987); Munger (2003)
[2] Barden (1991); Tu (2000); Swearingen and Sheherezade (2008); Flory and Lewis (2009); Fryer (2011b)
[3] Hoshovsky (1988); Swearingen and Pannill (2009); Fryer (2010)
[4] Swearingen (2005); Zouhar (2008)
[5] Dreyer (1994); Swearingen (2006); Fryer (2011a)
[6] Martin (2000); Fryer (2009)
[7] Nuzzo (1997b); Munger (2002a); Bravo (2005)
[8] Batcher and Stiles (2000); Munger (2005); Williams (2005)
[9] Eckardt (1987); Munger (2002b); Bergmann and Swearingen (2005); Bowles *et al.* (2007)
[10] Converse (1984); Wieseler (2005); Stone (2009)
[11] Spencer (2005); Innes (2009)
[12] Nuzzo (2000); Munger (2001); Rowe and Swearingen (2005); Bowles *et al.* (2007)
[13] Nuzzo (1997a); Zouhar (2001); Thunhorst and Swearingen (2005)
[14] Swearingen (2010)
[15] Gerlach *et al.* (2010); Stone (2010)

These trials are an example of adaptive management. The result will be achieving a crucial management objective across the entire trial plot area but the added step of comparing quantitative indicators between two methods will allow stewardship staff to learn some valuable lessons that can be applied to other infested areas within the barrens (and elsewhere in NLT's preserve system). The largest areas of autumn-olive infestation at the Unionville Barrens besides M.U. 1 are in large parts of M.U.s 3 and 6, but there are scattered autumn-olive stands in every management unit.

Among the hypotheses or predictions to be tested in the trial plots are:

(1) Mechanical pulling will disturb soil, increasing erosion of upper soil layers (desired) and stimulating germination of invasive plant seeds in large numbers (undesired). It is unknown what the balance will be between these effects.

(2) Mechanical pulling and off-site disposal will remove some of the nitrogen mineralized by symbiotic bacteria in autumn-olive roots (desired) whereas basal bark herbicide application followed by burning or decomposition of dead autumn-olive biomass will return excess nitrogen and other nutrients bound in biomass to the soil where it will favor invasive species (undesired).

(3) Basal bark herbicide application may be cheaper per acre in staff, material and equipment costs.

Figure 5. **Autumn-olive removal trial plots.** Two approaches—mechanical removal and basal-bark herbicide treatment—are recommended to be compared in terms of effectiveness, staff time and material costs in four trial plots in Management Unit 1 (see Maps 4 and 10 for landscape context of trial plot area). The results may show one method as superior overall or they may show both to be useful for removing autumn-olive elsewhere in the barrens, with the better method for a specific area depending on local conditions. This is a model for many more adaptive management trials to come, which will be devised by stewardship staff and their scientific advisers based on future management challenges, future changes in conditions, or new management methods and technologies.

Metrics for evaluating these hypotheses include some of the ecosystem response and desired condition metrics given in the first three pages of Table 7 (pp. 50–52), namely trends in the cover of nonnative plant species, autumn-olive survival rates, and trends in the cover of characteristic serpentine grassland plant species. An additional set of indicators is estimated staff time, material and equipment costs per acre for each of the four trial plots. One 25-m × 25-m quadrat may be used to assess the autumn-olive survival rate near the center of each trial plot and four smaller quadrats, each 2 m × 2 m, randomly located within each larger quadrat to track changes in nonnative and characteristic serpentine grassland species cover (see details on methods under *Monitoring*, pp. 80–84, and *Randomization*, pp. 148–149). Quadrats for these trials can be regarded as temporary and monitored for just a few years. It is likely that one or more of the recommended 5-m × 5-m permanent monitoring quadrats will also be placed within the trial area. If a permanent monitoring quadrat should be situated near the center of any of the four trial plots, it can do double-duty and replace two of the smaller species cover quadrats.

Eradicating ailanthus and black locust. Ailanthus (tree-of-heaven), from northern and eastern China, and black locust, with a native range from central Pennsylvania to Oklahoma and Alabama, spread prolifically in grasslands and harm grassland plants by shading them and by changing soil conditions. Ailanthus secretes allelopathic chemicals that deter establishment of other plants[1] and black locust houses symbiotic bacteria in root nodules that convert inert atmospheric nitrogen to forms that enrich the soil in mineralized forms of nitrogen available to plants.

Both species are rhizomatous, that is, they spread by underground runners. (Sassafras is also rhizomatous, but it is locally indigenous and less aggressive in serpentine barrens than the other two.) Burning, cutting, girdling or even injuring the stems of these trees stimulates rapid proliferation of new suckers by breaking the dormancy of underground buds along their rhizomes. Painting herbicide on cut or girdled stumps does not prevent suckering[2]. The most effective and efficient way of eradicating them is to leave the trunks intact and employ a basal bark application of triclopyr (trade name Garlon 4) mixed with a penetrant or in a ready-mixed formulation (trade name 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 is essential.

Reducing common greenbrier density. Common greenbrier is fully fire-tolerant and is not reduced by burning in a woodland or forest edge situation with partial shade. Herbiciding using a foliar spray of glyphosate gave poor results in experimental trials at the Nottingham Barrens; the vines were killed but not replaced by other species and greenbrier cover was restored in just a few years. In other Nottingham Barrens experiments, "ecotonal burning"—driving prescribed fire across the forest-grassland edge—caused greenbrier to retreat and native warm-season grassed to advance. Repeated ecotonal burning can expand grassland and reduce dense greenbrier thickets incrementally over long periods. However, this incremental approach may be effective only in full sun and where soils are thin.

Greenbrier thickets are more tenacious where soils are thicker and in the partial shade of savanna or woodland trees or along the southern edge of a grassland patch, where shade cast by adjoining forest is deepest. In such conditions, a more effective way to reduce greenbrier cover is by partial soil organic matter removal.

Partial soil organic matter removal with off-site disposal. Removing the roots and top few inches of organic-matter-rich soil from areas dominated by undesired woody plants such as autumn-olive, black locust, ailanthus or common greenbrier has proven effective as a way of restoring serpentine grassland and serpentine gravel forb communities. The first experiments were conducted in the mid-1990s at the Nottingham Barrens. The results were so favorable that the method has been applied as a restoration tool at several other serpentine barrens, including Goat Hill, Rock Springs Barrens and Pink Hill. The typical result has been immediate colonization of the treated area by a diverse array of the characteristic species of serpentine

[1] Hoshovsky (1988); Swearingen and Pannill (2009)
[2] Converse (1984); Swearingen and Pannill (2009)

grassland and gravel forb communities. There is often a minor admixture of invasive nonnative plants and other non-barrens plants in the first growing season, but most die within a year or two.

The method works by reducing the blanket of organic matter that buffers many non-barrens plant species from the low calcium-to-magnesium ratio and high nickel content (serpentine soil syndrome) of the underlying mineral soil. Presumably it also exposes a rich seedbank of characteristic serpentine barrens species; however, most of the successful applications of the method have been on ground that was very near an existing area of serpentine grassland and serpentine gravel forb vegetation to serve as an ongoing seed source. Seeding after partial soil removal using seed collected on-site could be used in areas not immediately adjacent to an existing grassland.

Per-acre costs have not been tallied but they are high compared with other restoration methods, in addition to posing unusual logistical challenges such as transporting and appropriately disposing of soil contaminated with invasive or aggressive plant roots and seeds. Areas so treated also must be accessible by heavy machinery, including a backhoe or front-end loader and dump truck, without harming existing stands of plant species of special conservation concern.

In order to be considered as a candidate for this drastic treatment, an area should meet one or both of these criteria:

- Plants of special conservation concern are directly threatened by invasive plant or greenbrier spread.
- Other methods such as herbiciding and prescribed burning have repeatedly failed to transform an area in invasive or aggressive plant cover to one dominated by a variety of characteristic serpentine barrens plant species.

Reducing stiltgrass cover in forest/woodland stands. There is little information available on the effects of prescribed burning on the locally important invasive species of forest and woodland, including stiltgrass[1]. Spring burns are ineffective at controlling stiltgrass because a new cohort of seeds germinates quickly post-fire. There is some evidence that burns in late summer or fall may be useful in controlling the species[2] but annual burning in oak forest actually resulted in increases in garlic mustard[3], a biennial whose response to fire may or may not be similar to that of stiltgrass. Running trials is the only way to determine how stiltgrass and other invasive forest-floor species will respond to fire under the particular conditions of Unionville Barrens forests and woodlands.

In Big Oaks National Wildlife Refuge, Indiana, late summer prescribed fire, spring prescribed fire, hand-pulling, and fall mowing were compared as control treatments for Japanese stiltgrass. Study sites were in second-growth American beech – black walnut – Virginia pine/northern spicebush forest with a history of prescribed fire. Late summer fires were ignited and mowing was conducted in early September after Japanese stiltgrass had set seed. Spring fires were ignited and hand-pulling started in June, when Japanese stiltgrass seedlings were 4 to 8 inches (10–20 cm) tall. 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). Hand-pulling in spring did not significantly change Japanese stiltgrass cover or biomass. Native understory species showed no significant difference in cover or biomass on treated compared to control plots.[4]

[1] Fryer (2011b)
[2] Barden (1991)
[3] Bowles *et al.* (2007)
[4] Flory and Lewis (2009), quoted in Fryer (2011b)

Alternative methods to compare with late summer burning include repeated broadcast application of a pre-emergent herbicide such as imazapic (trade name Journey), pendimethalin (Pendulum Aquacap), diphenamid (Enide) or benefin (Balan) on areas heavily infested with stiltgrass, on the theory that eliminating competition from stiltgrass will give established native perennial forest under-story plants a chance to grow larger and spread. Because stiltgrass is a warm-season annual, it requires repeated pre-emergent applications during the growing season, starting in March, to prevent germination[1].

There is little point in applying a broad-spectrum foliar herbicide such as glyphosate to combat stiltgrass infestations unless followed by seeding or planting plugs of native forest understory plants. With no competition from other species the next cohort of seedlings will quickly restore stiltgrass cover. However, imazameth (tradename Plateau), applied at a rate of 6 ounces per acre, has been used to kill stiltgrass without killing desirable native sedges and forbs, and the grass-specific herbicide sethoxydim (tradenames Poast, Vantage), applied during late summer at a rate of 8 ounces per acre, also provided excellent (more than 95%) control of stiltgrass and released forbs from competition without injuring them[2]. Great care must be taken to keep herbicides well away from any area where plant species of special concern occur. Those that live in the moist, partly shaded habitats most likely to be invaded by stiltgrass include Richard–son's sedge, barrens chickweed, tufted hairgrass and small-leaf white snakeroot.

Limiting regeneration of mesic forest trees in forest/woodlands stands. Prescribed burning can foster oak regeneration in forest and woodland settings by releasing oak seedlings from suppression by faster-growing but less fire-tolerant tree seedlings and saplings such as red maple, black-gum, tuliptree, white ash and black cherry. The trigger for prescribed fire in oak forest stands is a dense growth of tree seedlings and saplings that includes oaks, which can occur only with relatively high light availability (canopy openness) and low intensity of deer browsing in winter, when most tree seedlings and shrubs are consumed.

4.1.4 Deer management

The primary deer management tool is an annual controlled hunt, with hunting supervised by preserve management staff and carried out by authorized hunters who have passed mandatory proficiency tests. Hunters must agree to devote at minimum some reasonable number of hours per season to hunting on the site and to remove at least one doe before they are allowed to harvest a buck.

If recreational hunting should fail to deliver on desired conditions, as measured in replicate paired quadrats inside and outside deer exclosures (see *Monitoring deer effects*, p. 83), then sharpshooter culling should be considered as a means of bringing the deer population down to a level that can then be sustained by annual recreational hunts. A special deer control permit related to forest depredation can be obtained from the Pennsylvania Game Commission by demonstrating that hunting is insufficient to meet a landowner's goals for tree regeneration or other desired conditions that are prevented by excessive deer browsing. Permit conditions require the landowner to provide a reasonable level of hunting opportunity to licensed hunters in the hunting season prior to any cull. Culling usually consists of sharpshooters using high-powered rifles killing groups of deer from high ground over baiting stations established several weeks prior to the cull. The work is done over a period of days or weeks, often at night using infrared scopes. Venison is dressed and often distributed to

[1] Tu (2000); Swearingen and Sheherezade (2008)
[2] Tu (2000)

local food banks, soup kitchens and needy families through the state's Hunters Sharing the Harvest program. Culls are typically conducted for 1–3 consecutive years. Quantitative data on ecosystem indicators from replicate paired quadrats inside and outside deer exclosures is the basis for judging how long culling is necessary to meet the objectives.

4.1.5 Species reintroduction and augmentation

Reintroduction. Reintroducing species to the Unionville Barrens that were once present but are now gone mimics nature's island population "rescue effect" but on a shorter time-scale. Species selected for reintroduction may be planted as seeds or as nursery-reared plugs or potted plants. In all cases, only wild-collected seeds from one (or preferably more than one) of the nearest serpentine barrens sites in eastern and central Chester County are eligible to serve as reintroduction growing stock.

The highest priority species for reintroduction are grassland species believed extirpated from the Unionville Barrens that are either species of special conservation concern (Table 6, p. 37) or have strong fidelity to the communities with high conservation priority (pp. 30–32). For instance, extirpated species native to wetlands (Table 1, pp. 22–23) may be reintroduced to restored mixed forb marsh communities.

Augmentation. Remnant populations that have dwindled to such small size or have such low recruitment rates that they are in danger of being extirpated if not "rescued" are the primary candidates for augmentation planting. Mass plantings in restoration areas of the characteristic native grass species of the serpentine grasslands also come under the rubric of augmentation.

Grassland restoration areas, not existing grasslands, are the appropriate sites for augmentation plantings. Only seed collected in the Unionville Barrens or plugs or potted plants grown from them should be used. Long-term, if this stratagem should fail for any species, the next step would be using seed collected at the nearest serpentine barrens where the species is still thriving.

The highest-priority species for augmentation from seed collected on-site are:

- species of special conservation concern whose populations are so small that their viability is in question; examples include Bicknell's sedge, Richardson's sedge, Bicknell's hoary rockrose, New Jersey tea and Elliott's beardgrass
- additional species of special conservation concern found in further survey work; most-likely candidates are species documented historically at the site that have eluded detection in recent years (Table 6, p. 37)
- plants whose populations are similarly low that are host plants for animals of special conservation concern, for instance, wild indigo
- post oak, blackjack or Bush's oak and dwarf chinkapin oak, which are no longer regenerating; planted stock will need to be protected from deer browsing
- mixtures of the characteristic native grass species of serpentine grasslands for broadcast seeding in grassland restoration areas

4.1.6 Maintaining esthetic and historical preservation standards

A significant part of the value of a natural area is esthetic. Although no quantitative metrics are suggested, "natural" appearance is a desired condition. The Unionville Barrens' high ecological, geological, historical and conservation importance makes the site an exceptional attraction to a wide range of visitors with both casual and professional interest in the site and how it is managed. It will serve as a model and showpiece for best management practices and successful restoration results, furthering NLT's reputation for high-quality land management.

All management operations should be done with esthetic consequences in mind. For instance, tree-cutting should leave few or no artificial traces. Trunks should be flush-cut to the ground surface and all wood, slash and trimmed brush taken off-site or chipped for use on trails. Firebreaks and equipment access paths should be curvilinear with no long straight-line views. Deer exclosures erected to monitor browsing effects on desired conditions should be well engineered and durable but inconspicuous, as much as possible not easily discernible from a distance.

Conserving historical and archaeological resources provides a sense of the land-use history of the site for visitors and protects useful information for future historians to unearth. Heavy equipment should be kept away from quarries, mining pits and other sites where archaeological evidence of historical land use may persist at or just under the ground surface.

4.2 Monitoring

Monitoring is an indispensible part of adaptive management, generating practical new knowledge that is promptly put to use. It brings consistency, rigor and efficiency to the process of tracking changes in conditions resulting from management actions and external causes. The key to monitoring is to choose an appropriate set of indicators to reflect progress in achieving and sustaining the desired conditions. Indicators, also called metrics, are quanti–tative attributes of specific ecosystem components used to characterize, evaluate and communicate the condition of an ecosystem at a specific time or across a sequence of intervals. Indicators must be measurable at a reasonable cost and within a feasible timeframe. Monitoring is in essence an audit—a systematic, disciplined approach to evaluate and improve the effectiveness of management.

4.2.1 Quadrat monitoring of vascular plant species cover

Quadrat locations and data collection methods. A *quadrat* is a small area of land, often square, rectangular or circular, on which ecological data are collected. It is distinguished from a *plot*, a term better reserved, to head off confusion, for a unit of land on which a treatment or combination of treatments is applied (trial plot) or not applied, for comparison (control plot); a plot is the fundamental unit of replication (see Appendix D, pp. 149–153, for the meanings of *control* and *replication* in adaptive management). Quadrats are subsamples, not replicates. Each plot may contain one to several quadrats.

Suggested procedures for quadrat surveys are summed up in these steps:

(1) Allocate quadrats among high-priority vegetation types (pp. 30–32) and management units (Map 10) by stratified random sampling using GIS data layers, random numbers and a set of acceptance/rejection criteria such as distance from the edge of a management unit (for more details on stratified random sampling, including guidance on randomizing monitoring locations, see Appendix D, p. 149–153).

(2) Stratify quadrats in these location categories:
- seven management units (M.U.s)
- three vegetation categories:
    - grassland (including gravel forb community)
    - forest/woodland
    - wetland

(3) Distribute quadrats in proportion to area in each land type in each M.U.:
- 1–3 in each M.U. in existing grassland
- 1–3 in each M.U. in forest/woodland within grassland management area

- 1–3 in each M.U. in forest/woodland outside grassland management area
- at least 6 total in wetlands

(4) Employ predetermined acceptance/rejection criteria to decide which GIS-randomized quadrat locations to accept when examined in the field; example: a quadrat in existing grassland must have at least 20% cover but no more than 80% cover of gravel forb community.

(5) Lay out quadrats 25 m² (270 square feet) in area, as squares 5 m (~ 16½ feet) on a side or rectangles (1 m × 25 m, 2 m × 7.5 m, etc.) with corners marked by steel rebar driven into the ground, identified by fire-resistant steel tags with engraved numbers attached to rebar with fire-resistant wire, and georeferenced using GPS.

(6) In each monitoring year (every third to fifth year), employ a botanist to estimate and record percent cover of every species in three layers (0–1 m, 1–2 m and > 2 m above the ground surface) and at two times during the season (May–early June and late August–September) to capture species with different phenologies.

(7) Record data in computer spreadsheets, organized as specified by a qualified biostatistician employed to conduct the analyses.

Additional stratified random sampling locations will be needed to assess the effects of future management trials if they are conducted in areas without enough permanent monitoring quadrats to provide replication and control. They can be permanent or short-term, depending on the nature of the management trial and how long indicators need to be measured to assess the results. A mixture of permanent and temporary monitoring quadrats may be used for a management trial. Any monitoring quadrat intended for temporary use should be installed in the same way as a permanent quadrat so that credible comparisons can be made. Corner markers and tags should be left in place after the monitoring period is over in case the quadrat might someday be needed again to evaluate some future management trial or to extend the assessment of long-term trends into areas not covered by permanent quadrats.

Data analysis. Using appropriate statistical methods[1], two components of vascular plant species diversity (*richness* and *evenness*) are analyzed separately[2] at three scales (alpha, beta and gamma). Alpha (α) is the richness within habitats, expressed as the average number of species in the 25-m² (270-square foot) vegetation monitoring quadrats. Gamma (γ) is the overall richness across the entire Unionville Barrens landscape, expressed as the total number of species across all quadrats within a vegetation category. Beta (β) is the species turnover among habitats within the landscape, a measure of habitat diversity. Harrison's modification of Whittaker's beta:

$$\beta_H = 100 \times (((\gamma/\alpha_{max}) - 1)/(N - 1))$$

(where α_{max} = highest number of species in any quadrat and N = number of quadrats) is an index of β diversity among multiple quadrats (N) surveyed across a landscape. It is used to compare different landscapes or surveys conducted in different years in the same landscape. It can range from 0 (no turnover among samples) to 100 (every sample has a unique set of species).

Evenness (the inverse of dominance) among species in each quadrat is calculated using a variation of Simpson's index:

$$E_{1/D} = 100 \times (1/\sum((n_i\,(n_i - 1))/(N\,(N - 1)))/\alpha$$

where n_i = abundance of the ith species, N = total abundance, and α = number of species in the quadrat (to transform fractional percent cover quantities to integer values, abundance = estimated percent cover ×

[1] Reviewed in Magurran (2004)

[2] The widely used index derived from information theory by Shannon and Wiener, commonly called the Shannon index, is not used because it confounds richness and evenness. Different values give no indication whether the disparities reflect different richness, different evenness, or both (Magurran 2004).

100). $E_{1/D}$ is independent of species richness. It can range from near 0 (one species is highly dominant) to 100 (all species are equally abundant).

Some indicators consist of groups of species with key traits in common, with no need to distinguish individual species. Evaluating such species categories, called *functional groups*, requires the percent cover of multiple species to be summed together. Functional groups used as indicators are as follows (see Tables 3 and 4, pp. 34, 35; individual species are listed in Appendix B, pp. 111–143):

- native trees (31 species marked in Appendix B as native and TD or TE)
- native shrubs (25 species marked as native and SD)
- native herbaceous plants (219 marked as native and HA, VA, HB, HP or VP)
- native perennial warm-season grasses (12 species marked as native and C_4)
- native serpentine grassland plants (83 species marked as S1E, S1, S2 or S3)
- native herbaceous serpentine grassland plants (72 species marked as HA, VA, HB, HP or VP and S1E, S1, S2 or S3)
- native woody serpentine grassland plants (11 species marked as SD, TD, TE or VW and S1, S2 or S3)
- oaks (10 species in the genus *Quercus*)
- nonnative plants (74 species marked as nonnative)
- nonnative herbaceous plants (55 species marked as nonnative)

4.2.2 Monitoring sparsely distributed plant species of special conservation concern

Some plants of special conservation concern and host plants of animals of special conservation concern occur as small populations that would not be adequately represented in a stratified random sample of quadrats. They are monitored by locating clusters of individuals and periodically mapping them or counting stems in representative 2-m × 2-m quadrats and extrapolating to the entire area of coverage to estimate total population numbers.

4.2.3 GIS metrics

Some indicators (first three items in Table 7, p. 50) are evaluated periodically using digital mapping software and recent high-resolution satellite imagery. Changes over time in the areas covered by particular vegetation types are computed using GIS image classification software.

4.2.4 Monitoring bird populations

Key bird indicators are the numbers of confirmed nesting pairs of bird species of special conservation concern that are expected to benefit from grassland restoration such as brown thrasher, common nighthawk and yellow-breasted chat. Annual breeding bird counts, often conducted by skilled volunteer amateurs with supervision and quality control by staff naturalists, are used to track short-term and long-term trends in these species.

4.2.5 Monitoring arthropod populations

Most insects and other arthropods of special conservation concern can be captured and identified and their populations evaluated only through professional surveys conducted by qualified entomologists. However, in the case of butterflies, it is sometimes possible to rely on help from skilled volunteer amateurs, depending on their availability and reliability.

It is not practical to estimate arthropod populations as is sometimes done for breeding bird species by counting nesting pairs. This is not only because arthropods are far more numerous, but also because different species have different detection probabilities and the species-specific relationships between detection rates and population numbers are unknown. Furthermore, detection probability varies among methods, investigators, weather before and during surveys and other factors that change from one survey to another. However, variation in detection frequency over several survey years can be used by an experienced entomologist as a rough *index* of population trends in a species of special conservation concern.

4.2.6 Monitoring deer effects

Monitoring indicators of deer browsing effects requires multiple permanent deer exclosures. There is no other way to separate the effects of deer from myriad other effects on plant relative abundance, survival and fecundity. The only practical way of monitoring deer effects on highly vulnerable (preferred) plant species is to plant them as nursery-reared plugs in identical phytometer arrays positioned in pairs—an array inside each deer exclosure and a matching one in like conditions just outside each exclosure[1]. Such trials should be considered for plant species of special conservation concern whose populations at the Unionville Barrens are so small that their viability is in question (Table 5, pp. 35–36) and for species targeted for reintroduction (p. 79).

Care will need to be taken that all routine management is the same inside each exclosure as in its adjacent unfenced comparison area. Exclosure fences that are easily disassembled and reassembled and whose permanent corner posts will not be damaged by prescribed fire are ideal for this reason. The area within each exclosure should be at least 100 m^2 (1,100 sq. ft.) to enable the fence to contain an entire 25-m^2 (270-square foot) monitoring quadrat with an adequate buffer zone (2.5 m/8 feet wide) to minimize edge effects. To account for expected high spatial variation in deer effects, a minimum of three and preferably six 5-m × 5-m grassland monitoring quadrats need to be paired with an adjacent monitoring quadrat of the same size surrounded by a deer exclosure fence.

[1] Latham *et al.* (2009)

Deer-effects monitoring is also desirable in the forest stands to be managed to promote oak regeneration, since a deer population elevated far above the historical norm is one of the most serious risk factors throughout the Northeast to the persistence and integrity of forests dominated by oaks. In a forest setting it is essential that both exclosed and non-exclosed comparison plots be located where shade is not too dense. To ensure a reasonably fast response time of the plant indicators, the tree canopy must be open enough to admit sunlight to the forest floor adequate to support robust and relatively fast plant growth. Furthermore, the spaces between trees must be large enough that this condition is likely to persist for 10–15 years or more. Where necessary, trees should be thinned above exclosed and non-exclosed comparison plots in forest stands to decrease the amount of shade uniformly across all monitoring quadrats and postpone the time when lateral growth of the remaining trees' limbs fills in the canopy gaps again.

4.2.7 Baseline surveys focusing on ecosystem components of special conservation concern

A survey of invertebrate species, especially butterflies and moths, is needed to establish whether any of the rare species known to inhabit serpentine barrens in the region are present at the Unionville Barrens. The Pennsylvania Natural Heritage Program (Western Pennsylvania Conservancy, Pittsburgh and Middletown), the Carnegie Museum of Natural History's Section of Invertebrate Zoology (Pittsburgh) and the Academy of Natural Sciences (Philadelphia) work together on similar surveys statewide and are best positioned and qualified to collect the data and interpret the results.

Surveys of birds, amphibians, turtles and snakes are also a priority, although less urgent than invertebrate surveys, which are more likely to find imperiled species. A well-supervised volunteer program is likely to produce useful data on bird species breeding at the site. Herpetological survey work must be done by professionals.

An urgent priority is to undertake a thorough search for plant species of special conservation concern that are known to exist at the site only as small, highly localized populations and those documented as having been present historically but not seen in recent years. It is probable that there are additional remnant populations so small as to have escaped observation so far. Accurate documentation of the population size and distribution of each such species is needed as a baseline for developing recovery strategies and for measuring progress toward long-term viability.

The wetlands at the Unionville Barrens—serpentine seep, mixed forb marsh, sparsely vegetated vernal pool and red maple – black-gum palustrine forest (pp. 31–32)—are not visible in aerial photos and thus were mapped only approximately and incompletely for this plan (Map 8). No attempt was made to map serpentine seeps (see cover photo), which, together with serpentine grasslands and gravel forb communities, are ranked highest in conservation priority of all communities at the site. All of the wetlands are important out of proportion to their small total area because a diverse array of plant and animal species, including some of special conservation concern, are absolutely dependent on them to supply their habitat needs. Effective stewardship of these small and exceptionally sensitive communities requires that all occurrences be found and their locations and boundaries be accurately mapped.

4.3 Stewardship task priorities and timeframe

The main criteria for prioritizing restoration and management tasks are:

- priority of the specific resource(s) that the task is intended to safeguard
- severity, scope, irreversibility and time-sensitivity of the risk(s) that the task is intended to avert

The purpose here is not to provide a specific calendar, which would soon be obsolete in any case because the farther into the future one plans, even as soon as next year, the more unpredictable key events or their timing become. Such events may include, for example, drought or prolonged wet weather, NLT's acquisition of more of the barrens area, and unforeseen responses of invasive species to tree clearing. On the other hand, it is urgent to begin some tasks as soon as resources can be mustered (and then repeat them at regular intervals thereafter), no matter what unexpected events may occur, for instance, prescribed burning, long-term monitoring of vegetation quadrats, and surveys of rare arthropod species.

Task priorities are outlined here in three ways:

(1) Brief bullet-point description of each management unit as it stood in 2011 before management began, with its specific task priorities

(2) List of barrens-wide management tasks with each one's triggering event, earliest start time and relative priority (Table 9, pp. 86–89)

(3) Summary of most-urgent stewardship tasks recommended for implementation in 2012–2013 (Table 10, p. 91)

4.3.1 Management units

The acreage of each management unit (M.U.) broken down by 2011 ownership parcel, existing grassland, grassland restoration area and forest management area, is given on Table 8 (opposite).

Management unit 1

- Mostly mesic forest with a small area of existing grassland (0.7 acre) rapidly succeeding to woodland and forest.
- Both grassland and forest are heavily invaded by autumn-olive.
- Highest priorities are to remove autumn-olive, clear non-barrens tree species from the grassland management area and begin prescribed burning.
- Only known stand of a species of special conservation concern, Bicknell's hoary rockrose, is localized around the Heckert-NLT parcel boundary near the gate along Cannery Road (Map 8)—an area to be avoided as an access route for vehicles or heavy machinery.

Management unit 2

- Includes one of the two highest-quality and largest blocks of existing grassland (1.9 acres) and a large area of oak-dominated forest (14.3 acres).
- Although small in area, the now-wooded portion of the grassland management area (4.6 acres) is high in priority for clearing non-barrens tree species and starting to apply prescribed fire.

Management unit 3

- Area of existing grassland has dwindled to 0.2 acre but wooded grassland management area is large, 14.3 acres.
- Invasion by mesic forest species and soil data (Map 6) indicate deep soils in the eastern half, which also includes a major high-quality wetland area (Map 8).
- Entire barrens area's largest wetland is in the southwestern corner of M.U. 3.

(continued on p. 90)

Table 8. **Sizes of management units and their component grassland and forest management areas**, broken down by ownership in 2011. All quantities are in acres.

management unit		existing (2010) grassland	area targeted for grassland restoration	grassland management area total	forest management area	management unit total
M.U. 1	NLT parcel	0.5	4.6	5.1	15.5	
	Heckert parcel	0.2	0.8	1.0	1.3	
	total	**0.7**	**5.5**	**6.1**	**16.8**	**22.9**
M.U. 2	NLT parcel	1.7	4.0	5.7	8.2	
	Heckert parcel	0.2	0.6	0.7	6.1	
	total	**1.9**	**4.6**	**6.4**	**14.3**	**20.7**
M.U. 3	(all in NLT parcel)	**0.2**	**4.2**	**4.4**	**9.0**	**13.3**
M.U. 4	(all in NLT parcel)	**0.2**	**0.9**	**1.1**	**3.5**	**4.6**
M.U. 5	NLT parcel	1.7	4.0	5.7	8.2	
	Heckert parcel	0.1	1.0	1.1	9.8	
	total	**1.8**	**5.0**	**6.8**	**18.0**	**24.8**
M.U. 6	Kramkowski parcel	1.7	16.9	18.6	3.1	
	Heckert parcel	0.3	0.4	0.8	1.8	
	total	**2.0**	**17.4**	**19.4**	**4.9**	**24.2**
M.U. 7	(all in Heckert parcel)	**0.2**	**3.2**	**3.4**	**3.0**	**6.4**
	grand total	7.0	40.6	47.6	69.3	117.0

Table 9. **Prioritization of major recommendations for restoration and management of the Unionville Barrens.** Priority ranks: **1** = highest (urgent to sustain globally rare communities and imperiled species); **2** = high (urgent to sustain regionally rare communities and local genotypes of key species); **3** = intermediate (required to achieve or sustain desired conditions but less time-sensitive); **4** = low (required to achieve or sustain desired conditions but can be delayed for a period of years).

stewardship task	trigger	earliest start time	priority
TREE CLEARING, THINNING & REPLACEMENT			
Clear firebreaks and equipment access paths (Map 9)	NLT acquisition of land/management rights	2012	1
Selectively remove trees in wooded portions of grassland management areas (Map 10)	Total area of grassland + gravel forb community + serpentine seep less than 45 acres	2012	1
Begin propagating savanna oaks (post oak, blackjack/Bush's oak, dwarf chinkapin oak) from seed gathered on-site for replanting in cleared areas	As soon as feasible	2012	1
Selectively thin trees in forest management areas (Map 10)	Little or no survival of oak seedlings into sapling stage	2012	2
Convert red-cedars to dead snags by where possible by torching in prescribed burns	Most red-cedars alive	2012	2
Plant savanna oak seedlings (propagated from seed gathered on-site) in tree tubes widely spaced across grassland management areas cleared of trees	Trees cleared and propagated seedlings large enough to plant	2014	2
Begin propagating forest oaks (black oak, scarlet oak, northern red oak, white oak, chestnut oak) and pignut hickory from seed gathered on-site for replanting in thinned areas	As soon as feasible	2012	3
Plant forest oak and pignut hickory seedlings (of local provenance) in tree tubes under canopy gaps in forest management areas	Trees thinned and propagated seedlings large enough to plant	2014	3
Convert red-cedars that survive fires to dead snags by basal bark herbiciding	Most red-cedars alive in areas where two prescribed burns have been conducted	After a given area has been burned twice	3
Thin of dense stands of red-cedar	Monospecific stands of red-cedar have closed canopy	2012	3
PRESCRIBED BURNING			
Conduct prescribed burns in tree removal areas	Trees removed recently and fuels sufficient to achieve near-total ground coverage by fire	2012	1

stewardship task	trigger	earliest start time	priority
Conduct prescribed burns in open woodland and adjoining savanna	Abundant nonnative invasive species in understory	2012	1
Conduct late summer prescribed burns in forest management areas (Map 10) for invasive species control	Relatively dense cover of stiltgrass and low or no cover of autumn-olive	2012	1
Conduct spring prescribed burns in forest management areas (Map 10) for invasive species control	Relatively dense cover of garlic mustard, Japanese honeysuckle, Amur honeysuckle, Oriental bittersweet, multiflora rose, winged euonymus, Japanese barberry or wineberry and low or no cover of autumn-olive	2012	2
Conduct prescribed burns in forest management areas (Map 10) for oak regeneration	Dense growth of tree seedlings and saplings, including oaks, and relatively open tree canopy	After deer population is reduced to levels that allow dense tree seedling growth	2
Conduct trials of late-summer prescribed burning in restored grassland (tree removal areas) overlying thick soils	Tall warm-season grasses forming dense, continuous cover with little diversity and few forbs	After warm-season grass cover is established	2
Conduct prescribed burns in existing grasslands (Map 4)	Invasion by greenbriers or other woody plants	Concurrent with burning in adjoining tree removal areas	3
INVASIVE & AGGRESSIVE SPECIES MANAGEMENT			
Conduct trials of autumn-olive removal by mechanical removal and basal-bark herbiciding (pp. 74–75)	Presence of autumn-olive in grassland, woodland or forest	2012	1
Periodically remove autumn-olive, choosing methods according to site conditions and other constraints as indicated by trial results	Presence of autumn-olive in grassland, woodland or forest	After first removal in a given area	1
Spot-herbicide nonnative invasive plant cover in tree removal areas	Persistence of invasive species after prescribed burning	After a given area has been burned	2
Herbicide stiltgrass cover in forest and woodland stands and plant replacement forest understory forbs	Failure of fall prescribed burning to stiltgrass within a reasonable time	After a given area has been burned twice	2
Eradicate ailanthus	NLT acquisition of land/management rights	2012	3
Eradicate black locust	NLT acquisition of land/management rights	2012	3

(Table continues on next page.)

stewardship task	trigger	earliest start time	priority
Reduce greenbrier density by partial soil organic matter removal with off-site disposal	Failure of repeated prescribed burning to push back greenbrier advancing front	After a given area has been burned twice	3
Reduce woody invasive species cover by partial soil organic matter removal with off-site disposal	Failure of repeated prescribed burning or other methods to establish dominance by characteristic serpentine grassland species	After a given area has been treated by less-costly methods	3
DEER MANAGEMENT			
Organize and supervise annual deer hunt intensively targeting females; encourage doe hunting on adjacent private lands	Every year	Ongoing	2
Obtain special deer control permit and contract professional deer culling services	Little or no survival of oak seedlings into sapling stage and other deer-related indicators in the “poor” to “fair” range	2012	3
REINTRODUCTION & AUGMENTATION OF SPECIES OF SPECIAL CONSERVATION CONCERN			
Augment plant species of special conservation concern and host plants of animals of special conservation concern whose on-site populations are too small for long-term viability	NLT acquisition of land/management rights	2012	2
Reintroduce extirpated plant species of special conservation concern	Year-long baseline survey confirms no population remains	2013	4
INDICATOR DATA ACQUISITION, ANALYSIS & APPLICATION TO MANAGEMENT			
Intensively search for small remnant populations of plant species of special conservation concern	NLT acquisition of land/management rights	2012	1
Install monitoring quadrats at stands of plant species of special conservation concern whose populations are small and localized	NLT acquisition of land/management rights	2012	1
Contract qualified entomologists to conduct baseline survey of Lepidoptera and other arthropods, emphasizing species of special conservation concern	As soon as feasible	2012	1
Install network of permanent quadrats to monitor all vascular plant species’ cover in existing grasslands, forest/woodland in grassland management areas, forest management areas and wetlands	NLT acquisition of land/management rights	2012	1

stewardship task	trigger	earliest start time	priority
Collect baseline data in permanent quadrats	Completion of quadrat installation	2012	1
Contract qualified biostatistician to analyze monitoring data and facilitate staff discussion of results and their consequences for management	As needed	2013	1
Collect periodic data in long-term quadrats	Every 3–5 years	2015	2
Contract qualified entomologists to conduct periodic surveys of Lepidoptera (and other arthropods groups likely to include species of special conservation concern, if practical)	Every 3–5 years	2015	2
Build at least two deer exclosures in existing grasslands, at least two in forest/woodland in grassland management areas and at least two in forest management areas	NLT acquisition of land/management rights	2012	2
Collect baseline data on species cover and other deer-related indicators in paired monitoring quadrats at each exclosure, one inside and one outside	Completion of exclosure construction	2012	2
Collect periodic data on species cover and other deer-related indicators in paired monitoring quadrats at each exclosure	Every 2–3 years	2014	2
Georeference locations and extent of wetlands throughout site, refining rough boundaries on Map 8 and locating occurrences not yet mapped, including serpentine seeps	NLT acquisition of land/management rights; update every 10 years	2014	2
Assess extent of serpentine gravel forb community and proportion of grassland in prairie versus savanna using recent satellite photos	Availability of new high-resolution photos on which image classification software can distinguish communities of interest	2012	3
Establish team of skilled volunteer help and supervise annual count of nesting bird species of special conservation concern	NLT acquisition of land/management rights	2012	3
Supervise collection of baseline breeding bird data focusing on species of special conservation concern	Establishment of reliable birding group	2012	3
Supervise collection of annual breeding bird data focusing on species of special conservation concern	Every year	2013	3

- Tree-clearing and burning to expand and stabilize the small remnant grassland (0.2 acre) before it disappears is a high priority, but grassland restoration of the full area (4.4 acres) has a lower priority than other M.U.s.
- Selective tree-thinning in larger wetland to sunlight herbaceous layer and follow-up control of any invasive species outbreak are intermediate priorities.

Management unit 4

- Narrow area between the abandoned part of Oak School Road and Corundum Run
- Includes one very small but high-quality grassland with the only known stand of a species of special conservation concern, the state-endangered Bicknell's sedge, on a knoll near the center of the M.U.
- Grassland has shrunken (to 0.2 acre) and is near disappearing.
- Wooded perimeter of the knoll is a high-priority site for grassland restoration, with due diligence to avoid harming the rare species stand.

Management unit 5

- NLT parcel portion includes one of the two highest-quality and largest blocks of existing grassland (1.7 acres) and a large area of oak-dominated woodland and forest (8.2 acres).
- Most scenically outstanding area of remaining serpentine grassland, with views of rolling hills across the barrens. This is currently the showpiece of the Unionville Barrens and will be significantly enhanced by restoration of an additional 5 acres of grassland.
- Existing grassland and surrounding woodland and forest have highest priority for prescribed burning of the entire barrens area.

Management unit 6

- Largest M.U. (24.2 acres) and the only one containing side-oats grama (Map 8), a threatened species in Pennsylvania.
- Includes nearly half of the grassland management area of the entire Unionville Barrens (17.4 of 40.6 acres) and 29% (2 acres) of the total existing grassland.
- Contains the largest and best examples of serpentine seep in the Unionville Barrens.
- Outstanding potential for restoration but rapidly being invaded by forest trees and a severe infestation of autumn-olive.
- Highest priority for additional land protection at the Unionville Barrens; because of rapid forest succession and invasive species proliferation, protection and stewardship are of the highest urgency.

Management unit 7

- Shows signs of having been pastured more recently than anywhere else in the barrens and planted in nonnative cool-season pasture grasses.
- Grassland management area (3.2 acres) currently has few if any characteristic serpentine grassland plants.
- Because of the absence of existing stands of species of special conservation concern, grassland restoration has the lowest priority here of anywhere in the Unionville Barrens; however, when restored, the grassland will contribute significantly to the overall quality and viability of the barrens.

4.3.2 Highest-priority stewardship tasks for 2012–2013

Of the stewardship tasks required to achieve and sustain desired conditions at the Unionville Barrens (Table 9, pp. 86–89), the most urgent to begin implementing in the first two years are those most directly aimed at preventing further deterioration of the globally rare serpentine barrens communities and additional extirpations among the imperiled species remaining at the site. They are summarized in Table 10 (facing page).

Table 10. **Summary of highest-priority stewardship tasks for 2012–2013** (numbered for convenience in cross-referencing, not in order of priority or urgency).

task	location(s)
1. Clear firebreaks and equipment access paths (Map 9)	M.U.s 1, 2, 3, 4, 5
2. Cut most trees in grassland management areas, leaving certain trees intact (pp. 68–71)	M.U.s 1, 2
3. Thin trees in upland forest management areas and cut all saplings of mesic forest tree species, leaving all oak and hickory saplings intact (pp. 68–71)	M.U.s 1, 2
4. Propagate savanna oak species from seed collected on-site, possibly in cooperation with a local wholesale native plant nursery (p. 79)	Off-site
5. Collect seed of native serpentine grasses in existing grassland and plant in grassland restoration areas after tree clearing (p. 79)	M.U.s 1, 2
6. Conduct spring prescribed burns in tree removal areas, open woodland and adjoining grassland, leaving at least ½ of each of the larger existing grassland areas (in M.U.s 2 and 5) unburned in any one year (pp. 71–73)	M.U.s 1, 2, 3, 4, 5
7. Conduct adaptive management trials of late-summer prescribed burns in selected plots within forest management areas to control stiltgrass and invasive woody plants other than autumn-olive (p. 73)	M.U.s 1, 2
8. Remove autumn-olive using a combination of mechanical removal and basal-bark herbiciding (p. 74–75)	M.U.s 1, 2, 3, 4, 5
9. Spot-herbicide localized outbreaks of nonnative invasive plant cover (p. 74)	M.U.s 1, 2, 3, 4, 5
10. Continue annual deer hunt intensively targeting females; encourage doe hunting on adjacent private lands (p. 78)	Entire area
11. Conduct baseline survey of plant species of special concern and host plant species for animals of special conservation concern that are present in very low numbers at the site and have poor prospects for long-term population viability without intervention (p. 82)	Known stands: M.U.s 1, 2, 3, 4
12. Conduct searches for small remnant populations of plant species of special conservation concern (p. 83–84)	Entire area
13. Install monitoring quadrats at stands of plant species of special conservation concern whose populations are small and localized (p. 82)	Known stands: M.U.s 1, 2, 3, 4
14. Contract qualified entomologists to conduct baseline survey of Lepidoptera and other arthropod groups likely to include species of special conservation concern (pp. 82, 83)	At minimum, M.U.s 2, 5
15. Begin installing network of permanent quadrats to monitor species cover in existing grasslands, forest/woodland in grassland management areas, forest management areas and wetlands (pp. 80–81)	M.U.s 1, 2, 3, 5
16. Collect baseline data in long-term quadrats (pp. 80–81)	M.U.s 1, 2, 3, 5
17. Begin building deer exclosures in existing grasslands, forest/woodland in grassland management areas and forest management areas (p. 83)	M.U.s 1, 2
18. Collect baseline data on species cover in paired monitoring quadrats at each deer exclosure—one inside and one outside (pp. 80–81)	M.U.s 1, 2
19. Contract biostatistician to analyze monitoring data and facilitate staff discussion of results and their consequences for management (p. 80–82)	Off-site

References Cited

Adler, P. B., J. HilleRisLambers, P. C. Kyriakidis, Q. Guan and J. M. Levine. 2006. Climate variability has a stabilizing effect on the coexistence of prairie grasses. *Proceedings of the National Academy of Sciences* **103**: 12793–12798.

Anderson, R. C., E. A. Corbett, M. R. Anderson, G. A. Corbett and T. M. Kelley. 2001. High white-tailed deer density has negative impact on tallgrass prairie forbs. *Journal of the Torrey Botanical Society* **128**: 381-392.

Anderson, R. C., D. Nelson, M. R. Anderson and M. A. Rickey. 2005. White-tailed deer (*Odocoileus virginianus* Zimmerman) browsing effects on tallgrass prairie forbs: diversity and species abundances. *Natural Areas Journal* **25**: 19-25.

Anderson, R. S. 1971. Butterflies of the serpentine barrens of Pennsylvania. *Entomology News* **81**: 5-12.

Barden, L. S. 1987. Invasion of *Microstegium vimineum* (Poaceae), an exotic, annual, shade-tolerant, C_4 grass, into a North Carolina floodplain. *American Midland Naturalist* **118**: 40-45.

Barton, A. M. and M. D. Wallenstein. 1997. Effects of invasion of *Pinus virginiana* on soil properties in serpentine barrens in southeastern Pennsylvania. *Journal of the Torrey Botanical Society* **124**: 297-305.

Batcher, M. S. and S. A. Stiles. 2000. Element stewardship abstract for *Lonicera maackii* (Rupr.) Maxim (Amur honeysuckle), *Lonicera morrowii* A. Gray (Morrow's honeysuckle), *Lonicera tatarica* L. (Tatarian honeysuckle), *Lonicera* × *bella* Zabel (Bell's honeysuckle), the bush honeysuckles. The Nature Conservancy, Arlington, Virginia. 12 pp.

Bergmann, C. and J. M. Swearingen. 2005. Fact sheet: multiflora rose. Alien Plant Working Group, Plant Conservation Alliance, Bureau of Land Management, Washington, D.C. 3 pp. (www.nps.gov/plants/alien/fact/romu1.htm)

Berkeley, E. and D. S. Berkeley (eds.). 1992. *The Correspondence of John Bartram 1734-1777.* University Press of Florida, Gainesville. 808 pp.

Bowles, M. L., K. A. Jacobs and J. L. Mengler. 2007. Long-term changes in an oak forest's woody understory and herb layer with repeated burning. *Journal of the Torrey Botanical Society* **134**: 223-237.

Bravo, M. A. 2005. Fact sheet: Japanese honeysuckle. Alien Plant Working Group, Plant Conservation Alliance, Bureau of Land Management, Washington, D.C. 3 pp. (www.nps.gov/plants/alien/fact/loja1.htm)

Brooks, R. R. 1987. *Serpentine and Its Vegetation: a Multidisciplinary Approach*. Dioscorides Press, Portland, Oregon. 454 pp.

Cleaves, E. T., J. Edwards, Jr. and J. D. Glaser. 1968. Geologic Map of Maryland. Maryland Geological Survey, Baltimore. (ArcGIS format at pubs.usgs.gov/of/2005/1325/; accessed 2011-08-24)

Clements, F. E. and G. W. Goldsmith. 1924. *The Phytometer Method in Ecology: the Plant and Community as Instruments*. Carnegie Institution of Washington, Washington, D.C. 512 pp.

Commission for Environmental Cooperation. 2006. Ecological Regions of North America: Level I-III [map]. Commission for Environmental Cooperation (Montreal, Quebec, Canada), The Atlas of Canada (Ottawa, Ontario, Canada), National Atlas of the United States (Reston, Virginia, U.S.A.), Instituto Nacional de Estadística, Geografía y Informatica (Aguascalientes, Aguascalientes, Mexico).

Conestoga-Rovers & Associates. 2010. Serpentine barrens restoration and management plan: Jerrehian estate—Fern Hill eastern serpentine barren, West Goshen Township, Chester County, Pennsylvania. Unpublished report prepared for Jerrehian Partners, Conshohocken, Pennsylvania. 51 pp.

Converse, C. K. 1984. Element stewardship abstract for *Robinia pseudoacacia*, black locust. The Nature Conservancy, Arlington, Virginia. 14 pp.

Cotterell, M. 2004. *The Terracotta Warriors: the Secret Codes of the Emperor's Army*. Bear and Company, Rochester, New York. 336 pp.

Custer, J. F. 1996. *Prehistoric Cultures of Eastern Pennsylvania*. Pennsylvania Historical and Museum Commission, Harrisburg. 383 pp.

Dale, V. H. and S. C. Beyeler. 2001. Challenges in the development and use of ecological indicators. *Ecological Indicators* **1**: 3-10.

Darlington, W. 1826. *Florula Cestrica: an Essay Towards a Catalogue of the Phaenogamous Plants, Native and Naturalized, Growing in the Vicinity of the Borough of West-Chester, in Chester County, Pennsylvania ...* Simeon Siegfried, West Chester, Pennsylvania. 152 pp.

Darlington, W. 1837. *Flora Cestrica: an Attempt to Enumerate and Describe the Flowering and Filicoid Plants of Chester County ...* Simeon Siegfried, West Chester, Pennsylvania. 640 pp.

Day, G. M. 1953. The Indian as an ecological factor in the northeastern forest. *Ecology* **34**: 329-346.

Denevan, W. M. 1992. The pristine myth: the landscape of the Americas in 1492. *Annals of the American Association of Geographers* **82**: 369-385.

Dreyer, G. D. 1994. Element stewardship abstract for *Celastrus orbiculatus*, Asiatic bittersweet. The Nature Conservancy, Arlington, Virginia. 12 pp.

Dubinsky, E. 1995. The interdependence of vegetation type and soil depth in eastern temperate serpentine barrens. Unpublished undergraduate thesis, University of Pennsylvania, Philadelphia. 12 pp.

Dublin, H. T., A. R. E. Sinclair and J. McGlade. 1990. Elephants and fire as causes of multiple stable states in the Serengeti-Mara woodlands. *Journal of Animal Ecology* **59**: 1147-1164.

Eckardt, N. 1987. Element stewardship abstract for *Rosa multiflora*, rambler rose, multiflowered rose. The Nature Conservancy, Arlington, Virginia. 8 pp.

Eckert, G. E. (ed.). 2009. Interim technical guidance on defining meaningful desired conditions for natural resources, version 1.0. National Park Service, Biological Resources Management Division, Fort Collins, Colorado. 145 pp.

Engel, E. C., J. F. Weltzin,, R. J. Norby and A. T. Classen. 2009. Responses of an old-field plant community to interacting factors of elevated [CO_2], warming, and soil moisture. *Journal of Plant Ecology* **2**: 1-11.

Erdman, K. 1977. National Natural Landmarks evaluation report: Unionville Serpentine Barrens. Unpublished, National Park Service, Philadelphia. 11 pp.

Fike, J. 1999. *Terrestrial and Palustrine Plant Communities of Pennsylvania*. Pennsylvania Department of Conservation and Natural Resources, Harrisburg, The Nature Conservancy, Middletown, PA, and Western Pennsylvania Conservancy, Pittsburgh. 86 pp.

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

Folke, C., S. Carpenter, B. Walker, M. Scheffer, T. Elmqvist, L. Gunderson and C. S. Holling. 2005. Regime shifts, resilience and biodiversity in ecosystem management. *Annual Review of Ecology, Evolution, and Systematics* **35**: 557-581.

Fryer, J. L. 2009. *Euonymus alatus*. 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/shrub/euoala/introductory.html)

Fryer, J. L. 2010. *Ailanthus altissima*. 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/tree/ailalt/introductory.html)

Fryer, J. L. 2011a. *Celastrus orbiculatus*. 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/vine/celorb/introductory.html)

Fryer, J. L. 2011b. *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/introductory.html)

Futhey, J. S. and G. Cope. 1881. *The History of Chester County, Pennsylvania, with Genealogical and Biographical Sketches*. Louis H. Everts, Philadelphia. 826 pp.

Gabrielli, R. and T. Pandolfini. 1984. Effect of Mg^{2+} and Ca^{2+} on the response to nickel toxicity in a serpentine endemic and nickel-accumulating species. *Physiologia Plantarum* **62**: 540-544.

Gerlach, J. A., J. Hough-Goldstein and J. Swearingen. 2010. Fact sheet: mile-a-minute weed. Alien Plant Working Group, Plant Conservation Alliance, Bureau of Land Management, Washington, D.C. 4 pp. (www.nps.gov/plants/alien/fact/pepe1.htm)

Gigliotti, J. V., Jr. 2010. Carborundum: a diamond in the rough. Student paper, Pennsylvania State University, University Park. 7 pp. (www.personal.psu.edu/jvg5162/blogs/JameyGigliotti/Documents/Carborundum A Diamond in the Rough.pdf)

Graham, R. W. and E. C. Grimm. 1990. Effects of global climate change on the patterns of terrestrial biological communities. *Trends in Ecology and Evolution* **5**: 289-292.

Grime, J. P., V. K. Brown, K. Thompson, G. J. Masters, S. H. Hillier, I. P. Clarke, A. P. Askew, D. Corker and J. P. Kielty. 2000. The response of two contrasting limestone grasslands to simulated climate change. *Science* **289**: 762-765.

Guilday, J. E. 1971. The Pleistocene history of the Appalachian mammal fauna. *Research Division Monographs, Virginia Polytechnic Institute State University* **4**: 233-262.

Haegele, E. 2011. Unionville serpentine barrens: analyzing the relationship between soil profiles and forest succession rate. Unpublished Master of Environmental Studies capstone report, University of Pennsylvania, Philadelphia. 75 pp.

Hoekstra, J. M., T. M. Boucher, T. H. Ricketts and C. Roberts. 2004. Confronting a biome crisis: global disparities of habitat loss and protection. *Ecology Letters* **8**: 23-29.

Hoshovsky, M. C. 1988. Element stewardship abstract for *Ailanthus altissima*, tree-of-heaven. The Nature Conservancy, Arlington, Virginia. 13 pp.

Huenneke, L. F., S. P. Hamburg and R. Koide. 1990. Effects of soil resources on plant invasion and community structure in Californian serpentine grassland. *Ecology* **71**: 478-491.

Hull, J. C. and S. G. Wood. 1984. Water relations of oak species on and adjacent to a Maryland serpentine soil. *American Midland Naturalist* **112**: 224-234.

Innes, R. 2009. *Rubus phoenicolasius*. 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/shrub/rubpho/introductory.html)

Jenny, H. 1980. *The Soil Resource: Origin and Behavior*. Springer-Verlag, New York. 377 pp.

Kirk, W. H. and Company. 1883. *Breou's Official Series of Farm Maps, Chester County, Pennsylvania: Compiled, Drawn and Published from Personal Examinations and Surveys.* W. H. Kirk and Company, Philadelphia. 261 pp.

Kruckeberg, A. R. 1984. *California Serpentines: Flora, Vegetation, Geology, Soils, and Management Problems.* University of California Press, Berkeley. 180 pp.

Kunkle, W. M. 1963. *Soil survey of Chester and Delaware Counties, Pennsylvania*. U. S. Department of Agriculture, Soil Conservation Service, Washington, D.C. 124 pages + 80 maps.

Kurtén, B. and E. Anderson. 1980. *Pleistocene Mammals of North America*. Columbia University Press, New York. 443 pp.

Latham, R. E. 1984. National Natural Landmarks review form: Unionville Serpentine Barrens, Chester County, Pennsylvania. Unpublished, National Park Service, Philadelphia. 8 pp.

Latham, R. E. 1993. The serpentine barrens of temperate eastern North America: critical issues in the management of rare species and communities. *Bartonia* **57** Suppl.: 61-74 (*Proceedings of the Symposium on Rare Plants of Pennsylvania and Adjacent States*, 28 March 1991, Philadelphia).

Latham, R. 2005. Native grasslands and meadows in Pennsylvania: their history and current condition. Unpublished report for Natural Lands Trust, Media, Pennsylvania, and Pennsylvania Department of Conservation and Natural Resources, Wild Resource Conservation Program, Harrisburg. 106 pp.

Latham, R. E. 2011. *Desired Condition of Grasslands and Meadows in Valley Forge National Historical Park*. Natural Resource Report NPS/NER/VAFO/NRTR—2011. National Park Service, Philadelphia, Pennsylvania. 270 pp.

Latham, R. E. and J. F. Thorne. 1997. Understanding successional trajectories to conserve serpentine grasslands [abstract]. Ecological Society of America and the Nature Conservancy Joint Annual Meeting, Albuquerque, New Mexico.

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/deer_report.html)

Latham, R. and J. F. Thorne. 2007. *Keystone Grasslands: Restoration and Reclamation of Native Grasslands, Meadows, and Savannas in Pennsylvania State Parks and State Game Lands*. For the Wild Resource Conservation Program, Pennsylvania Department of Conservation and Natural Resources, Harrisburg. 100 pp.

Latham, R. E. (ed.), M. D. Grund, S. B. Horsley, B. C. Jones, W. H. McWilliams, C. K. Nielsen, C. S. Rosenberry, R. S. Seymour, B. P. Shissler and D. M. Waller. 2009. *Monitoring Deer Effects on Forest Ecosystems in Pennsylvania State Forests.* Pennsylvania Department of Conservation and Natural Resources, Bureau of Forestry, Harrisburg. 49 pp.

Leach, M. K. and T. J. Givnish. 1996. Ecological determinants of species loss in remnant prairies. *Science* **273**: 1555-1558.

Lindeström, P. M. with A. Johnson (ed.). 1925. *Geographia Americae: with an Account of the Delaware Indians: Based on Surveys and Notes Made in 1654–1656*; *Translated from the Original Manuscript with Notes, Introduction and an Appendix of Indian Geographical Names with their Meanings by Amandus Johnson*. Swedish Colonial Society, Philadelphia. 418 pp.

Maerz, J. C., V. A. Nuzzo and B. Blossey. 2009. Declines in woodland salamander abundance associated with non-native earthworm and plant invasions. *Conservation Biology* **23**: 975-981.

Magurran, A. E. 2004. *Measuring Biological Diversity*. Blackwell Publishing, Malden, Massachusetts. 256 pp.

Martin, T. 2000. Weed alert! *Euonymus alatus* (Thunb.) Siebold (burning bush, winged euonymus, winged wahoo, winged spindle-tree, Japanese spindle-tree). Center for Invasive Species and Ecosystem Health. (www.invasive.org/gist/alert/alrteuon.html)

McCandless, S. 1998. Invasive *Smilax rotundifolia* associated with changes in serpentine soil syndrome. Unpublished undergraduate Honors thesis, Swarthmore College, Swarthmore, Pennsylvania. 32 pp.

Milchunas, D. G., O. E. Sala and W. K. Lauenroth. 1988. A generalized model of the effects of grazing by large herbivores on grassland community structure. *American Naturalist* **132**: 87-106.

Miller, G. L. 1981. Secondary succession following fire on a serpentine barren. *Proceedings of the Pennsylvania Academy of Science* **55**: 62-64.

Mulvihill, R. S. (coordinator) *et al.* 2011. 2nd Pennsylvania Breeding Bird Atlas [online]. Carnegie Museum of Natural History, Pittsburgh, Powdermill Nature Center, Rector, Pennsylvania, and Pennsylvania Game Commission, Harrisburg. (www.carnegiemnh.org/atlas)

Munger, G. T. 2001. *Alliaria petiolata*. 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/forb/allpet/introductory.html)

Munger, G. T. 2002a. *Lonicera japonica*. 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/shrub/lonjap/introductory.html)

Munger, G. T. 2002b. *Rosa multiflora*. 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/shrub/rosmul/introductory.html)

Munger, G. T. 2003. *Elaeagnus umbellata*. 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/shrub/elaumb/introductory.htm)

Munger, G. T. 2005. *Lonicera* spp. 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/shrub/lonspp/introductory.html)

Müntener, O. 2010. Serpentine and serpentinization: a link between planet formation and life. *Geology* **38**: 959-960.

Myers, W., J. Bishop, R. Brooks, T. O'Connell, D. Argent, G. Storm, J. Stauffer and R. Carline. 2000. *A Gap Analysis of Pennsylvania—2001 Final Report: a Geographic Approach to Planning for Biological Diversity*. U. S. Department of the Interior, U. S. Geological Survey and Cooperative Fish & Wildlife Research Unit, Pennsylvania State University, University Park. 790 pp.

Nagy, L. and J. Proctor. 1997. Soil Mg and Ni as causal factors of plant occurrence and distribution at the Meikle Kilrannoch ultramafic site in Scotland. *New Phytologist* **135**: 561-566.

National Cooperative Soil Survey. Undated. National cooperative soil characterization database. (ssldata.nrcs.usda.gov; accessed 2011-09-05)

National Health and Environmental Effects Research Laboratory. 2011. Level III ecoregions of the continental United States. U. S. Environmental Protection Agency. Refinement of J. M. Omernik, 1987, Ecoregions of the conterminous United States [map (scale 1:7,500,000)], *Annals of the Association of American Geographers* **77**: 118-125. (ftp.epa.gov/wed/ecoregions/us/Eco_Level_III_US.pdf; accessed 2011-07-21)

Natural Resources Conservation Service. 1999. *Soil Taxonomy: a Basic System of Soil Classification for Making and Interpreting Soil Surveys* (second edition). Agriculture Handbook No. 436. U. S. Department of Agriculture, Washington, D.C. 871 pp.

Natural Resources Conservation Service. 2008. Chrome series [official soil series description]. U. S. Department of Agriculture, Washington, D.C. (soils.usda.gov/technical/classification/osd/index.html; accessed 2011-07-29)

Nuzzo, V. 1997a. Element stewardship abstract for *Cirsium arvense*, Canada thistle, creeping thistle, Californian thistle. The Nature Conservancy, Arlington, Virginia. 32 pp.

Nuzzo, V. 1997b. Element stewardship abstract for *Lonicera japonica*, Japanese honeysuckle. The Nature Conservancy, Arlington, Virginia. 22 pp.

Nuzzo, V. 2000. Element stewardship abstract for *Alliaria petiolata (Alliaria officinalis)*, garlic mustard. The Nature Conservancy, Arlington, Virginia. 19 pp.

Panzer, R. 2002. Compatibility of prescribed burning with the conservation of insects in small, isolated prairie reserves. *Conservation Biology* **16**: 1296-1307.

Pearre, N. C. and A. V. Heyl, Jr. 1960. *Chromite and Other Mineral Deposits in Serpentine Rocks of the Piedmont Upland, Maryland, Pennsylvania and Delaware*. Geological Survey

Bulletin 1082-K. U. S. Government Printing Office, Washington, D.C.

Pennell, F. W. 1910. Flora of the Conowingo barrens of southeastern Pennsylvania. *Proceedings of the Academy of Natural Sciences of Philadelphia* **62**: 541-584.

Pennell, F. W. 1912. Further notes on the flora of the Conowingo or serpentine barrens of southeastern Pennsylvania. *Proceedings of the Academy of Natural Sciences of Philadelphia* **64**: 520-539.

Pennsylvania Bureau of Topographic and Geologic Survey. 2001. Bedrock geology of Pennsylvania [map]. Pennsylvania Department of Conservation and Natural Resources, Harrisburg. (www.dcnr.state.pa.us/topogeo/map1/bedmap.aspx)

Pennsylvania Game Commission and Pennsylvania Fish and Boat Commission. 2005. Pennsylvania Comprehensive Wildlife Conservation Strategy. Harrisburg. 762 pp. (www.pgc.state.pa.us/pgc/lib/pgc/SWG/PAWAP.pdf)

Pennsylvania Natural Heritage Program. 2010. Invertebrate Species List [online]. Plant Species List [online]. Vertebrate Species List [online]. Western Pennsylvania Conservancy, Pennsylvania Department of Conservation and Natural Resources, Pennsylvania Fish and Boat Commission, Pennsylvania Game Commission. (www.naturalheritage.state.pa.us; accessed 2010-07-13).

Peterjohn, B. 2006. Conceptual ecological model for management of breeding grassland birds in the Mid-Atlantic region. Natural Resources Report NPS/NER/NRR—2006/005. U.S. Department of the Interior, National Park Service, Northeast Region, Philadelphia. 43 pp.

Plank, M. O., W. S. Schenck and L. Srogi. 2000. *Bedrock Geology of the Piedmont of Delaware and Adjacent Pennsylvania*, Delaware Geological Survey Reports of Investigations No. 59. University of Delaware, Newark, for the Delaware Geological Survey. 52 pp.

Proctor, J. 1970. Magnesium as a toxic element. *Nature* **227**: 742-743.

Proctor, J. and I. D. McGowan. 1976. Influence of magnesium on nickel toxicity. *Nature* **260**: 134-135.

Proctor, J. and S. R. J. Woodell. 1971. The plant ecology of serpentine. I. Serpentine vegetation of England and Scotland. *Journal of Ecology* **59:** 375-395.

Radford, A. E. and D. L. Martin. 1975. *Potential Ecological Natural Landmarks, Piedmont Region, Eastern United States*. Report to the National Park Service, Washington, D.C. University of North Carolina, Chapel Hill. 249 pp.

Rajakaruna, N., T. B. Harris and E. B. Alexander. 2009. Serpentine geoecology of eastern North America: a review. *Rhodora* **111**: 21-108.

Rawlins, J. E. 2007. *Pennsylvania's Comprehensive Wildlife Conservation Strategy: Invertebrates*. Carnegie Museum of Natural History, Pittsburgh, for Pennsylvania Game Commission and Pennsylvania Fish and Boat Commission, Harrisburg. 227 pp.

Rhoads, A. F. and T. A. Block. 2007. *The Plants of Pennsylvania*, 2nd edition. University of Pennsylvania Press, Philadelphia. 1,042 pp.

Robinson, G. S., L. P. Burney and D. A. Burney. 2005. Landscape paleoecology and megafaunal extinction in southeastern New York State. *Ecological Monographs* **75**: 295-315.

Rowe, P. and J. M. Swearingen. 2005. Fact sheet: garlic mustard. Alien Plant Working Group, Plant Conservation Alliance, Bureau of Land Management, Washington, D.C. 3 pp. (www.nps.gov/plants/alien/fact/alpe1.htm)

Sather, N. and N. Eckardt. 1987. Element stewardship abstract for *Elaeagnus umbellata*. The Nature Conservancy, Arlington, Virginia. 4 pp.

Schultz, C. B. and E. E. Crone. 1998. Burning prairie to restore butterfly habitat: a modeling approach to management tradeoffs for the Fender's blue. *Restoration Ecology* **6**: 244-252.

Sladky, R. J. 1981. The interpretation and management of Pink Hill—a serpentine barren. Master's thesis, University of Delaware, Newark. 58 pp.

Sloto, R. A. 2009. *The Mines and Minerals of Chester County, Pennsylvania.* Published by author. 469 pp.

Spencer, N. R. 2005. Fact sheet: wineberry. Alien Plant Working Group, Plant Conservation Alliance, Bureau of Land Management, Washington, D.C. 2 pp. (www.nps.gov/plants/alien/fact/ruph1.htm)

Stone, K. R. 2009. *Robinia pseudoacacia*. 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/tree/robpse/introductory.html)

Stone, K. R. 2010. *Polygonum perfoliatum*. 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/vine/polpef/all.html)

Swearingen, J. M. 2005. Fact sheet: Japanese barberry. Alien Plant Working Group, Plant Conservation Alliance, Bureau of Land Management, Washington, D.C. 3 pp. (www.nps.gov/plants/alien/fact/beth1.htm)

Swearingen, J. M. 2006. Fact sheet: Oriental bittersweet. Alien Plant Working Group, Plant Conservation Alliance, Bureau of Land Management, Washington, D.C. 4 pp. (www.nps.gov/plants/alien/fact/ceor1.htm)

Swearingen, J. M. 2010. Fact sheet: Fig buttercup. Alien Plant Working Group, Plant Conservation Alliance, Bureau of Land Management, Washington, D.C. 3 pp. (www.nps.gov/plants/alien/fact/rafi1.htm)

Swearingen, J. M. and A. Sheherezade. 2008. Fact sheet: Japanese stiltgrass. Alien Plant Working Group, Plant Conservation Alliance, Bureau of Land Management, Washington, D.C. 4 pp. (www.nps.gov/plants/alien/fact/mivi1.htm)

Swearingen, J. M. and P. D. Pannill. 2009. Fact sheet: Tree of heaven. Alien Plant Working Group, Plant Conservation Alliance, Bureau of Land Management, Washington, D.C. 5 pp. (www.nps.gov/plants/alien/fact/aial1.htm)

Swengel, A. B. 1996. Effects of fire and hay management on abundance of prairie butterflies. *Biological Conservation* **76**: 73-85.

Thompson, D. Q. and R. M. Smith. 1970. The forest primeval in the Northeast: a great myth? *Proceedings of the Annual Tall Timbers Fire Ecology Conference* **10**: 255-265.

Thunhorst, G. and J. M. Swearingen. 2005. Fact sheet: Canada thistle. Alien Plant Working Group, Plant Conservation Alliance, Bureau of Land Management, Washington, D.C. 3 pp. (www.nps.gov/plants/alien/fact/ciar1.htm)

Tu, M. 2000. Element stewardship abstract for *Microstegium vimineum*, Japanese stilt grass, Nepalese browntop, Chinese packing grass. The Nature Conservancy, Arlington, Virginia. 8 pp.

Walker, B. and D. Salt. 2006. *Resilience Thinking: Sustaining Ecosystems and People in a Changing World*. Island Press, Washington, D.C. 174 pp.

Walsh, M. C., J. Deeds and B. Nightingale. 2007. *User's Manual and Data Guide to the Pennsylvania Aquatic Community Classification*. Pennsylvania Natural Heritage Program, Western Pennsylvania Conservancy, Middletown and Pittsburgh. 167 pp.

Wheeler, A. G., Jr. 1988. *Diabrotica cristata*, a chrysomelid (Coleoptera) of relict Midwestern prairies discovered in eastern serpentine barrens. *Entomological News* **99**: 134-142.

Wheeler, A. G., Jr. 1995. Plant bugs (Heteroptera: Miridae) of *Phlox subulata* and other narrowleaved phloxes of the eastern United States. *Proceedings of the Entomological Society of Washington* **97**: 435-451.

Wieseler, S. 2005. Fact sheet: black locust. Alien Plant Working Group, Plant Conservation Alliance, Bureau of Land Management, Washington, D.C. 3 pp. (www.nps.gov/plants/alien/fact/rops1.htm)

Williams, C. E. 2005. Fact sheet: exotic bush honeysuckles. Alien Plant Working Group, Plant Conservation Alliance, Bureau of Land Management, Washington, D.C. 3 pp. (www.nps.gov/plants/alien/fact/loni1.htm)

Williams, S. L., S. B. McLaren and M. A. Burgwin. 1985. Paleo-archaeological and historical records of selected Pennsylvania mammals. *Annals of the Carnegie Museum* **54**: 77-188.

Woods, A. J., J. M. Omernik and D. D. Brown. 1999. Level III and IV Ecoregions of Delaware, Maryland, Pennsylvania, Virginia, and West Virginia. U. S. Environmental Protection Agency, National Health and Environmental Effects Research Laboratory, Corvallis, Oregon. 56 pp. (ftp.epa.gov/wed/ecoregions/reg3/reg3_eco_desc.doc; accessed 2008-10-21)

Zimov, S. A., V. I. Chuprynin, A. P. Oreshko, F. S. Chapin, III, J. F. Reynolds and M. C. Chapin. 1995. Steppe-tundra transition: a herbivore-driven biome shift at the end of the Pleist–ocene. *American Naturalist* **146**: 765-794.

Zouhar, K. 2001. *Cirsium arvense*. 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/shrub/cirarv/introductory.html)

Zouhar, K. 2008. *Berberis thunbergii*. 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/shrub/berthu/introductory.html)

Acknowledgments

We owe our sincere appreciation to those who contributed in substantial ways to the information and ideas contained in this document:

Gary Gimbert, Darin Groff, Roger Nichols, Dr. Jim Thorne, Scott Wendle (Natural Lands Trust)

Tony Davis (Senior Ecologist, Pennsylvania Natural Heritage Program)

Janet Ebert and Jack Holt (botanical inventory consultants)

Greg Edinger (Chief Ecologist, New York Natural Heritage Program; formerly Ecology Research Assistant, Pennsylvania Natural Heritage Program)

Liz Haegele (Urban Forestry Manager, Pennsylvania Horticultural Society; formerly master's student in Environmental Studies, University of Pennsylvania)

Dr. Larry Klotz (botanist, Professor Emeritus, Shippensburg University)

Betsy Leppo (Invertebrate Zoologist, Pennsylvania Natural Heritage Program)

Dr. José-Luis Machado (ecologist, Associate Professor, Swarthmore College)

Caron O'Neil (Senior Geologic Scientist, Pennsylvania Geological Survey)

Dr. Ann Rhoads (Senior Botanist, Pennsylvania Flora Project)

Dr. Dale Schweitzer (Terrestrial Invertebrate Zoologist, NatureServe)

Dr. Jeff Walck (botanist, Professor, Middle Tennessee State University)

Dr. Al Wheeler (entomologist, Adjunct Professor, Clemson University)

Glossary

Note: Terms in *italics* are defined elsewhere in the glossary.

adaptive management: Carrying out a set of land or wildlife management actions including alternative methods, periodically monitoring the results by collecting quantitative data, reconsidering the methods and comparing alternatives in light of those results, and adjusting the next round of implementation accordingly. Alternative methods are compared with each other or with unmanaged *controls* using principles of the *scientific method* but as a routine part of management, with less cost (and less stringent standards) than scientific experiments.

adsorption: Attraction of ions or compounds to the surface of a solid. The soil particles on which adsorption (and release) of essential plant nutrients and other ions occurs (the adsorption complex) are mainly clays and decomposed organic matter.

angular flag: See *flag.*

annual (plant): Usually completes its entire life cycle, seed to seed, in one year.

argillic horizon (of soil): Mineral soil layer characterized by the illuvial accumulation of clay particles of layered crystalline silicon oxides with negative electrical charge. Illuvial refers to the process of material being washed from an overlying horizon, precipitating from solution and accumulating in a distinct layer. The presence or absence of an argillic horizon is used as a diagnostic characteristic in classifying soils.

arthropod: Animal in the phylum Arthropoda, which includes insects, arachnids (spiders, mites, ticks, daddy-longlegs), myriapods (millipedes, centipedes) and crustaceans (pillbugs, woodlice, crayfish, water-fleas, fishlice, copepods). Arthropods, mainly insects on land and crustaceans in freshwater, typically account for the great majority of animal species and animal biomass in a given area of land, stream or lake.

base saturation (of soil): Extent to which the *adsorption* complex of a soil is saturated with exchangeable cations (positively charged ions) other than H^+ and Al^{3+}. (See also *cation exchange activity*.)

biennial (plant): Usually completes its entire life cycle, seed to seed, in two years.

biological diversity (or **biodiversity)**: Variety of life forms at all scales—genomes and locally adapted populations within species; species within patches, communities, landscapes and regions; habitat structure within patches and communities; patch types within communities and landscapes; community types within landscapes and regions, and ecoregions within the biosphere. (See also *habitat diversity*, *patch diversity*, *species diversity*, *structural diversity*.)

browser: *Herbivore* that subsists mainly by *browsing*.

browsing: Eating woody plants.

cation exchange activity (of soil): *Adsorption* and release of cations (positively charged ions), including acidity cations (H^+, Al^{3+}) and base cations, some of which are essential nutrients for plants (including Ca^{2+}, Mg^{2+}, K^+). (See also *base saturation*.)

channer: Thin, flat rock fragment up to 6 inches in length. A subangular channer is one with a shape characterized by neither sharp angles nor smooth rounding but something in between.

channery (of soil): Stony with *channers.*

community: **1.** Group of interacting plants, animals, fungi and other organisms that is fairly consistent in species composition and relative abundance in similar environments throughout a region; also called community type. **2.** Specific occurrence of such a group occupying an area within a *landscape*. (See also *ecosystem*.)

community structure: See *structure.*

control (in research or *adaptive management*): **1.** Separating the effects of a *treatment* under investigation from the effects of everything else. **2.** Untreated group of subjects or *plots* on which the same data are collected as on subjects or plots that receive a treatment, in order to separate the effects of the treatment from the effects of everything else.

cool-season grass: Grass species that has photosynthetic machinery like most plants, a system called C_3 for short after the three-carbon molecule that is the first product of photosynthesis. Cool-season grasses usually flower and fruit in spring or early summer and grow best during spring and fall. (See also *warm-season grass*.)

dbh: Diameter (of a tree trunk) at breast height (standardized in the U.S. as 1.4 m or 4 feet 7 inches).

disturbance: Relatively discrete event in time that changes resources or the physical environment and typically reduces one or more populations in the affected area, opening up space for colonization by the same or different species. The spatial scale of disturbances is highly variable, from a small *patch* to a region.

disturbance frequency: Mean number of disturbance per time period for a particular area of land. The inverse of *disturbance return interval.*

disturbance intensity: Cumulative energy of a disturbance event (e.g., heat released by a fire). (Compare *disturbance severity*.)

disturbance return interval: Mean time between disturbances for a particular area of land. The inverse of *disturbance frequency.*

disturbance severity: Impact of a disturbance on an ecosystem and its constituents, including organisms, resources and the physical environment. Often expressed in terms of amount of mortality or species turnover. (Compare *disturbance intensity*.)

diversity: See *biological diversity, habitat diversity*, *patch diversity*, *species diversity*, *structural diversity.*

dominance: Extent to which one or a few species dominate a community, i.e., have a majority share of total ecosystem biomass or cover. The inverse of *evenness*.

duff: The organic (O) *soil horizons* considered as a unit. Not a soil science term but often used in reference to fire behavior (e.g., proportions or quantities of duff consumed by fires burning under different soil moisture conditions).

ecological community: See *community*.

ecological integrity: Ability of an *ecosystem* to support and maintain a *community* of organisms with species composition, *diversity* and functional organization comparable to those with the smallest degree of post-European-settlement human influence. "An ecological system or species has integrity … when its dominant ecological characteristics (e.g., elements of composition, structure, function and ecological processes) occur within their natural ranges of variation and can withstand and recover from most perturbations imposed by natural environmental dynamics or human disruptions."[1] Sometimes called ecosystem "health" or the quality of being "natural."

ecological resilience: **1**. "Ability of a[n eco]system to absorb disturbance and still retain its basic function and structure."[2] **2**. The speed at which an ecosystem returns to its former state after it has been displaced from that state by a disturbance. **3**. The amount of disturbance required to push an ecosystem over a threshold onto a successional pathway leading to different persistent state.

ecoregion: A geographically defined area in which ecosystems show a consistent pattern of common traits in terms of their geology, physiography, vegetation, climate, hydrology, terrestrial and aquatic fauna, and soils. Classification is hierarchical (e.g., the Piedmont Uplands are part of the Northern Piedmont, which lies within the Southeastern U.S.A. Plains, which are part of the Eastern Temperate Forests[3]).

ecosystem: A *community* and its physical environment.

ecotonal: Pertaining to or located in an *ecotone*.

ecotone: Transition zone between two dissimilar ecological communities. Often applied to a forest-grassland edge, including the area of forest subject to strong grassland influences (more light at ground level, higher heat, lower humidity) and the adjacent area of

[1] Eckert (2009): p. 2

[2] Walker and Salt (2006): p. 1

[3] Commission for Environmental Cooperation (2006)

grassland subject to strong forest influences (more shade, more seed deposition by perching birds, larger organic matter accumulation on the ground and in soil from shed leaves and branches of trees, shrubs and lianas).

endemic: Exhibiting *endemism*

endemism (of a species): Restricted in range to a specific region or a geographically limited ecosystem.

evenness: Measure of how similar in abundance co-occurring species are within a patch or community. The inverse of *dominance*. One component of *species diversity*. (Compare *richness*; see also *biological diversity*.)

fire frequency: See *disturbance frequency.*

fire intensity: See *disturbance intensity*.

fire return interval: See *disturbance return interval.*

fire severity: See *disturbance severity*.

flag: Thin, flat rock fragment 6–15 inches in length. An angular flag is one with a shape characterized by sharp angles.

forb: Herbaceous *vascular plant* that is not a grass or a grass-like plant such as a sedge or a rush. Most forbs are wildflowers, although herbaceous plants that have no flowers such as ferns are often included. (See also *graminoid.*)

forest: Area with 60% to 100% tree cover. (See also *woodland* and *savanna.*)

frequency (of fire or other disturbance): See *disturbance frequency.*

friable (of soil): Easily crumbled.

functional group: Subset of species in a community whose members are similar by one or more meaningful criteria (e.g., morphology, environmental response, role in ecosystem function, trophic level or taxonomic relatedness). Examples in serpentine barrens include perennial *warm-season grasses*, *nonnative* plants, oaks, butterflies or birds.

gradient: **1.** Slope (i.e., change in elevation across an area of land). **2.** Gradual change across an area of land in an environmental factor that affects organisms (e.g., temperature, sunlight, soil moisture, soil depth, soil nutrient availability).

graminoid: Grass or grass-like plant such as a sedge or a rush. (See also *forb.*)

grassland: Area dominated by herbaceous plants with more than 50% cover by grasses that is uncultivated and has soils that are not saturated year-round. Includes prairie and grass-dominated savanna. (See also *meadow.*)

grazer: *Herbivore* that subsists mainly by *grazing*. Some grazers (e.g., bison) eat mainly grasses; others (e.g., white-tailed deer, which are also *browsers*) eat mainly *forbs*.

grazing: Eating herbaceous plants. (See also *browsing*.)

growth form: Classification of plants by size, shape, longevity and mode of overwintering. The main distinction is herbaceous (dies back to the ground in winter) versus woody (bears overwintering buds above the ground). Woody plants are grouped into trees, shrubs, woody vines (lianas) or creepers; they may be deciduous or evergreen. Herbaceous plants are grouped by longevity into *annuals*, *biennials*, short-lived *perennials* or long-lived perennials; by shape into *forbs* or *graminoids*; and by posture into self-standing, prostrate or climbing (herbaceous vines).

habitat: Place where a plant, animal or other organism lives. Defined relative to an individual species or a group of similar species.

habitat diversity: Measure of the difference in species composition, or turnover, among places—usually patches within a community or communities within a landscape. (See also *biological diversity* and *patch diversity*.)

herbaceous (plant): Having no woody parts aboveground. The stems of herbaceous plants in the temperate zone die back to the ground surface in winter. (See *growth form*.)

herbivore: Animal species that subsists on plant foods.

herbivory: Eating plant parts. (See *browsing* and *grazing*.)

horizon (of soil): See *soil horizon*.

humus: Dark-colored organic particles in soil that are among the end-products of microbial decomposition of plant and animal residues.

index (in research or monitoring): A relative measurement substituting for an absolute quantity that is infeasible to measure, used to estimate trends over time (e.g., year-to-year trends in the number of individuals of an animal species captured by a particular method in a standard length of time at a fixed location, taken to indicate actual population trends of that species).

indicator: See *metric*.

integrity: See *ecological integrity*.

intensity (of fire or other disturbance): See *disturbance intensity.*

introgressive hybrid: Organism whose genome is mostly of one species but with a smaller part from another, a condition produced by repeated backcrossing of hybrid individuals with just one of the parent species.

invasive: Describes a *nonnative* plant, animal or other organism that undergoes extreme proliferation, partly resulting from a lack of coevolved parasites, predators, diseases and other checks on population growth outside its native range. Invasive organisms typically disrupt ecosystems by killing off or crowding out native populations, changing key environmental attributes such as resource availability, soil conditions and fire regimes, or starting a cascade effect by disrupting multispecies interactions.

labile (of minerals in soil or soil organic matter): Readily made available to plants by microbial transformation or decomposition.

landscape: Heterogeneous land area composed of multiple interacting *ecosystems* in *patches* or blending together across *gradients*, each usually repeated in similar form throughout.

liana: Woody vine (e.g., summer grape and common greenbrier, both native to the Northern Piedmont; Japanese honeysuckle and Oriental bittersweet, both nonnative in North America).

litter: Layer of undecomposed and little-decomposed fallen leaves, bark, wood and other organic debris on the soil surface; also called the soil Oa *soil horizon*. (See also *duff*.)

macronutrient: Chemical element required in relatively large quantities for plant growth; usually refers to nitrogen, phosphorus and potassium ("NPK").

mapping unit: A polygon on a map or digital map layer identified as belonging to a category of land (e.g., grassland), usually within a set of related categories (e.g., vegetation type). (See also *minimum mapping unit*.)

meadow: Area dominated by herbaceous plants with more than 50% cover by *forbs* that is uncultivated and has soils that are not saturated year-round. (See also *grassland.*)

mesic: **1.** (of plants or plant communities) Intermediate in habitat affinity between hydric (wetland) and xeric (dry upland). **2.** (of soils) Formed in a temperate-zone climate with seasonally strongly fluctuating temperature averaging over the entire year between 8°C/47°F and 15°C/59°F.

metapopulation: Geographically clustered group of localized populations that are genetically and dynamically connected by occasional intermigration of individuals. Often consists of multiple *sources* and *sinks*.

metric: Measurable, quantitative attribute of specific ecosystem components (e.g., plants, animals, water, soil, people) used to characterize, evaluate and communicate the condition of an ecosystem at a specific time or across a sequence of intervals. Also called indicator.

minimum mapping unit: The threshold smallest size *mapping unit* chosen for classifying land on a particular map or digital map layer.

native: Describes a plant, animal, fungus or other organism spontaneously inhabiting a given region without having been introduced there deliberately or inadvertently by human activity. In regions in the Americas, often taken to mean species present at the time of first European contact, irrespective of whether they might have been introduced from other regions by human action before then. Synonymous with indigenous.

nonnative: Describes a plant, animal, fungus or other organism inhabiting a given region by virtue of having been introduced, either deliberately or inadvertently, by human activity. Synonymous with exotic and introduced. A minority of nonnative species become *invasive*.

parent material (of soils): The bedrock or other underlying geological formation from which the components of a soil are weathered.

patch: Relatively discrete area within a *community* or *ecosystem* that is different in some significant way from its surroundings, usually consisting of, or reflected in, differences in plant species composition.

patch diversity: Variety of *patch* types within a *community* or *ecosystem*. (See also *biological diversity* and *habitat diversity*.)

ped: A natural unit of soil structure such as a crumb or granule.

perennial (plant): Typically has a lifespan of three to many years. Usually applied to *herbaceous* plants.

phenology: Seasonal timing of events in the life cycle of a plant, animal or other organism.

phylogenetic: Pertaining to the evolutionary history of a group of organisms, i.e., the relationships of groups of organisms to one another by descent from common ancestors. (See also *taxon*.)

phytometer: Living plant or group of plants on which selected attributes are measured as *metrics* of ecosystem condition or dynamics. Their use in research and monitoring is based on the idea that responses of plants integrate a multitude of physical, chemical and other environmental factors and their complex interactions; thus, when measured at regular intervals they better reflect ecosystem condition and are more predictive of trends—often with less effort—than direct measurements of abiotic factors, whose interactive effects on ecosystem components are poorly understood.

plot (in research or *adaptive management*): The fundamental unit of *replication*; unit of land on which a *treatment* or combination of treatments is applied (trial plot) or not applied, for comparison (*control* plot). (See also *quadrat*.)

prairie: Expansive *grassland* with less than 10% tree cover. (See also *savanna*.)

quadrat: Small area of land, often square, rectangular or circular, on which ecological data are collected; often a subsample within a larger research or adaptive management *plot*.

recalcitrant (of organic matter in or on top of soil): Resistant to decomposition.

refugia: Plural of *refugium*.

refugium: Small, isolated area that has escaped changes undergone by the surrounding area, allowing the survival of plants and animals from an earlier period.

replicates (in research or *adaptive management*): Multiple subjects or environmentally similar *plots* receiving the same *treatment* (or lack of treatment; see *control*).

replication (in research or *adaptive management*): Use of *replicates* in the *scientific method*.

research plot: See *plot*.

resilience: See *ecological resilience.*

return interval (of fire or other disturbance): See *disturbance return interval.*

rhizomatous (of plants): Spreading by rhizomes—underground runners consisting of horizontal roots that send up shoots from tips or nodes. (See also *stoloniferous*.)

richness (of species): Number of species present in a given area (e.g., *quadrat*, research plot, *patch*, *community*, *landscape* or region). One component of *species diversity*. (Compare *evenness*; see also *biological diversity*.)

savanna: *Grassland* with scattered trees or tall shrubs making up between 10% and 25% of the total vegetation cover. May also refer to *meadow* or low *shrubland* with 10% to 25% tree or tall shrub cover. (See also *forest* and *woodland.*)

scientific method: Self-correcting method of research in which a problem is identified, relevant data are gathered, a hypothesis is formulated from the data, the hypothesis is empirically tested by experiment, and the results are used to verify, refute or modify the hypothesis.

serpentine soil syndrome: Unusual soil mineral conditions affecting plants growing in soils weathered from serpentinite, in particular extremely high magnesium and nickel content and extremely low calcium content.

severity (of fire or other disturbance): See *disturbance severity.*

shrubland: Area dominated by shrubs. Usually applied to communities that persist for relatively long periods of time (transient shrub-dominated successional stages are often called thickets).

sink: Localized population (and its habitat) with a consistently negative growth rate, i.e., the death rate is higher than the birth rate and continued existence depends on immigration. May nonetheless be important to help sustain high overall population numbers and genetic diversity in a *metapopulation*. Occurs in smaller or lower-quality habitat areas. (See also *source*.)

soil horizon: A soil layer roughly parallel to the ground surface differentiated from other layers by color, texture, organic matter content, mineral content and other characteristics.

soil profile: Sequence of *soil horizons* in a given place. Profiles of soils in the Piedmont Uplands generally include some subset of the following horizons, listed in order from the uppermost downward:

- O horizons—surface layers of organic matter
  - Oa—mostly undecomposed fallen leaves, bark, wood and other organic debris (also called *litter*)
  - Oi—partly decomposed fibrous matter including small but recognizable fragments of plant parts
  - Oe—more-fully decomposed, finely granular natural compost (rich in *humus*)
- Mineral soil horizons—mainly minerals weathered from *parent material*
  - A—dark-colored mineral layer immediately beneath O horizon with high content of *humus* accumulated from above
  - Ap—plow layer, consisting of a mixture of two or more former soil layers (O, A, E or B horizons) to the depth of plowing
  - E—light-colored mineral layer leached of silicate clays, iron or aluminum, consisting mainly of sand and silt
  - B—layer beneath O, A or E horizon marked by the accumulation of silicate clays, iron or aluminum
  - C—partly weathered *parent material* between B horizon and underlying unweathered parent material

source: Localized population (and its habitat) with a consistently positive growth rate, i.e., the birth rate is higher than the death rate and population stability occurs only if the emigration rate balances the surplus of births over deaths. Occurs in large areas of contiguous, high-quality habitat. (See also *sink* and *metapopulation*.)

species diversity: *Richness* and *evenness* of species in a given area. (See also *biological diversity.*)

species dominance: See *dominance.*

species evenness: See *evenness*.

species of special conservation concern: Its continued existence in all or a part of its native range is known to be imperiled, judged to be at risk of becoming imperiled, or undergoing sustained or rapid decline. In Pennsylvania, vascular plants, mammals, birds, snakes, lizards, turtles, amphibians, freshwater mussels, Lepidoptera (butterflies and moths), Odonata (dragonflies and damselflies) and a few species belonging to other groups of organisms are systematically tracked and an official list of species of special concern is updated yearly by the Pennsylvania Biological Survey, Pennsylvania Natural Heritage Program and state natural resource agencies.

species richness: See *richness*.

stoloniferous (of plants): Spreading by stolons—aboveground runners consisting of horizontal stems that send up shoots from tips or nodes. (See also *rhizomatous*.)

stratified random sampling: Collecting data on research subjects or locations picked using a randomization procedure from a number of subpopulations or categories. "Stratified" refers to the different subpopulations or categories ("strata") from which subjects or locations are chosen. Stratifying insures that roughly equal numbers of subjects or locations are picked as targets of data collection from each subpopulation or category so that valid comparisons can be made.

structural diversity: Variety of community *structure* present within a defined area. (See also *biological diversity*.)

structure (of a community): Vertical layering and horizontal arrangement of plants of different sizes and *growth forms*, the extent of vegetation cover, canopy closure and bare ground, the type and abundance of dead plants or plant parts, and the amounts and types of decomposing plant material.

subangular channer: See *channer.*

succession: Non-seasonal, directional and continuous pattern of colonization, relative dominance and extinction on a site by populations, usually set in motion by *disturbance*.

taxon (plural = taxa): Unit of *phylogenetic* classification of an organism at any level of the classification hierarchy, including (but not limited to) domain, kingdom, phylum, class, order, family, genus, species, subspecies and variety.

treatment (in research or *adaptive management*): Manipulation applied to a set of *replicates* to test scientific hypotheses or alternative methods of management.

vascular plant: Plant in which fluids circulate via conducting vessels—xylem and phloem. All true plants are vascular plants except mosses, liverworts, hornworts and green algae (other algae and lichens are not classified as plants). Includes all trees, shrubs, vines, wildflowers, grasses, rushes, sedges, ferns, clubmosses and spikemosses (the latter are not true mosses).

warm-season grass: Grass species that has a specialized photosynthetic system called C_4 for short, after the four-carbon molecule that is the first product of photosynthesis. It works in a manner similar to a turbocharger in a car engine, delivering carbon dioxide much more efficiently (using far less water) to the sunlight-powered parts of the plants' cells that combine CO_2 with H_2O to produce sugars, fueling growth. Warm-season grasses usually flower and fruit in late summer or fall and grow mainly in the heat of summer. The C_4 system enables warm-season grasses to continue photosynthesizing and growing when most plants are forced by heat or dry soil conditions to shut down. (See also *cool-season grass*.)

woodland: Area with 25% to 60% tree cover. (See also *forest* and *savanna.*)

woods: Informal umbrella term for *woodland* and *forest*.

Appendix A. Interpretation of Rank and Status Codes for Species of Special Conservation Concern

Table A-1. **Explanation of global and state rarity ranks** used in Tables 5 and 6 (pp. 35–37) and Appendix C (pp. 145–148). Adapted from NatureServe and Pennsylvania Natural Heritage Program.

G2	Imperiled globally because of rarity or because of some factor(s) making it very vulnerable to extinction. Typically 6–20 occurrences or few remaining individuals (1,000–3,000).
G3	Vulnerable globally because very rare and local throughout its range, or found only in a restricted range (even if abundant at some locations), or because of other factors making it vulnerable to extinction. Typically 21–100 occurrences or 3,000–10,000 individuals in the species' total range.
G4	Uncommon but not rare globally, and usually widespread. Possibly cause for long-term concern. Typically more than 100 occurrences and more than 10,000 individuals in the species' total range.
G5	Secure globally. Common, typically widespread and abundant, with considerably more than 100 occurrences and 10,000 individuals in the species' total range.
G#G#	Numeric range (e.g., G3G4) used to indicate uncertainty about global status. More information is needed.
T#	Numeric global rank (e.g., T4) reflecting the rarity of a subspecies that differs from that of the species as a whole.
?	Indicates a high level of uncertainty. More information is needed.
S1	Critically imperiled in the state because of extreme rarity or because of some factor(s) making it extremely vulnerable to extirpation from the state. Typically 5 or fewer occurrences or very few remaining individuals or acres within the state.
S2	Imperiled in the state because of rarity or because of some factor(s) making it very vulnerable to extirpation from the state. Typically 6–20 occurrences or few remaining individuals or acres within the state.
S3	Vulnerable in the state because rare, or found only in a restricted range (even if abundant at some locations), or because of other factors making it vulnerable to extirpation. Typically 21–100 occurrences within the state.
S#S#	Numeric range (e.g., S2S3) used to indicate uncertainty about status in the state. More information is needed.
SH	Occurred historically in the state, not verified in the past 20 years, but suspected to be still extant. A rank of SH applies without a 20-year delay after the most recent documented occurrence if the only known occurrences in the state were destroyed or subjected to intensive searching but not found. A rank of SH typically changes to S1 upon verification of an extant occurrence.
SNR	Not yet ranked.
SU	Currently unrankable due to lack of information or due to substantially conflicting information about status or trends.

Table A-2. **Explanation of Pennsylvania Biological Survey (PABS) status codes** used in Tables 5 and 6 (pp. 35–37), subsection 3.1.1 (p. 41-42) and Table 7 (pp. 50–59). Adapted from Pennsylvania Biological Survey.

PE	**Endangered in Pennsylvania.** Native species in imminent danger of extinction or extirpation throughout their range in Pennsylvania if the deleterious factors affecting them continue to operate.
PT	**Threatened in Pennsylvania.** Native species that may become endangered within the foreseeable future throughout their range in Pennsylvania unless the casual factors affecting the organism are abated.
PR	**Rare in Pennsylvania.** Uncommon native species classified as disjunct, limit of range, endemic or restricted that do not qualify for PE or PT status. *Disjunct* = significantly separated from the species' main area of distribution. *Limit of range* = at or near the periphery of the species' natural distribution. *Endemic* = confined throughout its range to a specialized habitat. *Restricted* = in its Pennsylvania range, confined to a specialized habitat or set of habitats occurring infrequently in the state.
SP	**Special population.** Unique occurrence deserving protection that does not fall into any of the other categories. Native species that is relatively scarce and significant for reasons such as ecological importance, recent decline, vulnerability, role as host for imperiled animal species, or occurrence in Pennsylvania comprising a high proportion (~ 10% or more) of the species' entire population.
TU	**Status in Pennsylvania tentatively undetermined.** Native species believed to be in danger of population decline, but which cannot presently be included within another classification due to taxonomic uncertainties, limited evidence in historical records, or insufficient field data. TU is a temporary classification until the needed information can be gathered.

Table A-3. **Explanation of Pennsylvania conservation tier codes** listed in parentheses under *state status* in Appendix C (pp. 145–148). From Rawlins (2007: pp. 16–19).

1	**Immediate concern.** … species that are most at risk and/or are experiencing the most dramatic declines across their range. … include[s] globally rare or imperiled species, nationally rare or imperiled species, as well as those species in Pennsylvania and/or neighboring states that are declining to the point that some may require federal listing in the future.
2	**High-level concern.** … nationally and/or regionally significant species that are vulnerable in Pennsylvania. … include[s] species with localized and vulnerable populations, species with limited dispersal, species with fragmented or isolated populations, and some species in need of additional research to determine status.
4	**Pennsylvania vulnerable.** … species that for reasons of rarity are ranked as being of conservation concern in Pennsylvania, but are not currently at risk globally or in the region. If rarity is known to result from sharp decline in abundance or distribution in the Commonwealth but not elsewhere, then the species in question are certainly of conservation concern, but at a lower priority than those that also are at known risk globally (Tier 1 and to some extent, Tier 2 species).

Appendix B. Vascular Plants of the Unionville Barrens

KEY TO SYMBOLS AND TYPEFACES IN TABLE B-1 (begins on next page)

Nonnative species (most originating in Eurasia) are indicated by small, boldface, sans serif type.

2010 PABS (Pennsylvania Biological Survey) status:

PE	endangered in the state
PT	threatened in the state
PR	rare in the state
SP	special population deserving protection that does not fall into another category
TU	tentatively believed to be declining or imperiled but status undetermined due to insufficient data; under study or needing study

Growth form:

HA	herbaceous annual
VA	herbaceous annual vine
HB	herbaceous biennial
HP	herbaceous perennial
VP	herbaceous perennial vine
SD	deciduous shrub
VW	woody vine
TD/TE	deciduous/evergreen tree

C_3 or C_4 (grasses only):

C_3	cool-season grass
C_4	warm-season grass

Grassland habitat:

S1E	restricted throughout species' range (endemic) to serpentine grasslands
S1	nearly or quite restricted to serpentine grasslands in southeastern Pennsylvania
S2	found more often in serpentine grasslands than in other habitats in southeastern Pennsylvania
S3	characteristic of serpentine grasslands but found no less often in other grassland habitats in southeastern Pennsylvania
O	found mainly in other grassland habitats in southeastern Pennsylvania

Extirpated (?):

X	historically documented in the Unionville Barrens but not seen in recent years; tentatively presumed extirpated, although small numbers might still be present and have eluded detection

Table B-1. **List of the vascular plants of the Unionville Barrens**. Sources: extant species—surveys by Janet Ebert and Jack Holt (2002–2003), Roger Latham (2003–2011), Philadelphia Botanical Club & Muhlenberg Botanical Society field trip (2010); "extirpated (?)" species—Pennell (1910–1912); herbarium records of Pennsylvania Flora Project, Morris Arboretum, University of Pennsylvania & Academy of Natural Sciences of Philadelphia.

HIGHER TAXON **Family** Genus, species (& variety or subspecies)	common name(s)	2010 PABS status	growth form	C_3 / C_4 (grasses)	grass-land specialist	extirpa-ted (?)
FERNS AND LYCOPODS						
Lycopodiaceae						
Diphasiastrum tristachyum (Pursh) Holub	deep-rooted running-pine, deep-root clubmoss		HP			
Lycopodium obscurum L.	flat-branched ground-pine		HP			
Ophioglossaceae						
Botrychium dissectum Spreng.	cut-leaf grape-fern		HP			
Botrychium virginianum (L.) Sw.	rattlesnake fern		HP			
Osmundaceae						
Osmunda claytoniana L.	interrupted fern		HP			
Osmunda regalis L.	royal fern		HP		S2	
Polypodiaceae						
Asplenium platyneuron (L.) Britton, Stearns & Poggenb.	ebony spleenwort		HP			
Athyrium filix-femina (L.) Roth ex Mert.	southern lady-fern		HP			
Dennstaedtia punctilobula (Michx.) T.Moore	hay-scented fern		HP		O	
Deparia acrostichoides (Sw.) M.Kato	silvery glade fern		HP			
Dryopteris carthusiana (Vill.) H.P.Fuchs	spinulose wood-fern		HP			
Dryopteris intermedia (Muhl.) A.Gray	intermediate wood-fern, evergreen wood-fern, fancy fern		HP			
Dryopteris marginalis (L.) A.Gray	marginal wood-fern		HP			
Onoclea sensibilis L.	sensitive fern		HP			

HIGHER TAXON Family Genus, species (& variety or subspecies)	common name(s)	2010 PABS status	growth form	C_3 / C_4 (grasses)	grass-land specialist	extirpa-ted (?)
Polypodium virginianum L.	common polypody, rock polypody, rockcap		HP			
Polystichum acrostichoides (Michx.) Schott	Christmas fern		HP			
Pteridium aquilinum (L.) Kuhn	northern bracken fern		HP		O	
Thelypteris noveboracensis (L.) Nieuwl.	New York fern		HP			
Thelypteris palustris Schott	marsh fern, eastern marsh fern		HP		O	
GYMNOSPERMS						
Cupressaceae						
Juniperus virginiana L.	eastern red-cedar		TE		S3	
MAGNOLIIDS						
Aristolochiaceae						
Aristolochia serpentaria L.	Virginia snakeroot		HP			
Lauraceae						
Lindera benzoin (L.) Blume	spicebush		SD			
Sassafras albidum (Nutt.) Nees	sassafras		TD			
Magnoliaceae						
Liriodendron tulipifera L.	tuliptree, yellow-poplar		TD			
EUDICOTS						
Amaranthaceae						
Chenopodium album L.	lamb's-quarters		HA			
Berberidaceae						
***Berberis thunbergii* DC**	**Japanese barberry**		**SD**			
Podophyllum peltatum L.	mayapple, mandrake		HP			

(Table continues on next page.)

HIGHER TAXON Family Genus, species (& variety or subspecies)	common name(s)	2010 PABS status	growth form	C_3 / C_4 (grasses)	grass-land specialist	extirpa-ted (?)
Caryophyllaceae						
***Arenaria serpyllifolia* L.**	**thyme-leaf sandwort**		**HA**			
Cerastium nutans Raf.	nodding chickweed		HA			
Cerastium velutinum L. var. *velutinum*	barrens chickweed	SP	HP		S1	
***Dianthus armeria* L.**	**Deptford pink**		**HB**			
Minuartia michauxii (Fernald) Farw.	rock sandwort, Michaux's stitchwort	SP	HA HP		S1	
***Myosoton aquaticum* (L.) Moench**	**giant chickweed, water mouse-ear**		**HP**			
Silene stellata (L.) W.T.Aiton	starry campion, widow's-frill		HP		O	
***Stellaria media* (L.) Vill.**	**common chickweed**		**HA**			
Hamamelidaceae						
Hamamelis virginiana L.	witch-hazel		SD			
Papaveraceae						
Sanguinaria canadensis L.	bloodroot, red puccoon		HP			
Phytolaccaceae						
Phytolacca americana L.	pokeweed		HP			
Platanaceae						
Platanus occidentalis L.	American sycamore, buttonwood, American planetree		TD			
Polygonaceae						
***Persicaria longiseta* (Bruijn) Kitagawa**	**low smartweed, Oriental lady's-thumb**		**HA**			
Persicaria virginiana (L.) Gaertn.	jumpseed		HP			
***Polygonum aviculare* L.**	**prostrate knotweed**		**HA**			
Polygonum tenue Michx.	slender knotweed, pleat-leaf knotweed		HA		S2	
***Rumex acetosella* L.**	**sheep sorrel, sourgrass**		**HP**			
***Rumex obtusifolius* L.**	**bitter dock**		**HP**			

HIGHER TAXON **Family** Genus, species (& variety or subspecies)	common name(s)	2010 PABS status	growth form	C_3 / C_4 (grasses)	grass-land specialist	extirpa-ted (?)
Portulacaceae						
Claytonia virginica L.	spring-beauty		HP			
Phemeranthus teretifolius (Pursh) Raf.	round-leaf fameflower, quill fameflower	PT	HP		S1	
Ranunculaceae						
Clematis virginiana L.	virgin's-bower, devil's darning-needles		VP			
***Ranunculus bulbosus* L.**	**bulbous buttercup, St. Anthony's-turnip**		**HP**			
Ranunculus recurvatus Poir.	hooked crowfoot, blisterwort		HP			
Thalictrum pubescens Pursh	tall meadow-rue, king-of-the-meadow		HP			
Saxifragaceae						
Heuchera americana L.	American alum-root		HP			
Saxifraga virginiensis Michx.	early saxifrage		HP			
Vitaceae						
Parthenocissus quinquefolia (L.) Planch.	Virginia-creeper, woodbine		VW			
Vitis aestivalis Michx.	summer grape, pigeon grape		VW			X
Vitis vulpina L.	frost grape		VW			
ROSIDS						
Geraniaceae						
Geranium maculatum L.	wood geranium, spotted geranium		HP			
Onagraceae						
Circaea canadensis (L.) Hill ssp. *canadensis* (L.) Aschers. & Magnus	enchanter's-nightshade		HP			
Oenothera fruticosa L.	sundrops, narrow-leaf evening-primrose		HP		S3	
Oenothera perennis L.	little evening-primrose, sundrops		HP		O	

(Table continues on next page.)

HIGHER TAXON Family Genus, species (& variety or subspecies)	common name(s)	2010 PABS status	growth form	C_3 / C_4 (grasses)	grass-land specialist	extirpa-ted (?)
EUROSIDS						
Anacardiaceae						
Rhus copallina L.	shining sumac, winged sumac, dwarf sumac		SD		S3	
Toxicodendron radicans (L.) Kuntze	poison-ivy, eastern poison-ivy		VW			
Betulaceae						
Carpinus caroliniana Walter	American hornbeam, ironwood		TD			
Corylus americana Walter	American filbert, American hazelnut		SD			
Brassicaceae						
***Alliaria petiolata* (M.Bieb.) Cavara & Grande**	**garlic mustard**		**HB**			
Arabis lyrata L.	lyre-leaf rockcress		HB HP		S2	
***Barbarea vulgaris* R.Br.**	**common wintercress, garden yellow rocket**		**HB**			
***Cardamine hirsuta* L.**	**hairy bittercress**		**HA**			
Cardamine pensylvanica Muhl. ex Willd.	Pennsylvania bittercress		HP			
***Lepidium campestre* (L.) R.Br.**	**fieldcress, field pepperweed**		**HA HB**			
***Lepidium densiflorum* Schrader**	**wild pepper-grass, common pepperweed**		**HA HB**			
Cannabaceae						
Celtis occidentalis L.	common hackberry, sugarberry		TD			
Celastraceae						
***Celastrus orbiculatus* Thunb.**	**Oriental bittersweet**		**VW**			
***Euonymus alatus* (Thunb.) Siebold**	**winged euonymous, burning-bush**		**SD**			
Cistaceae						
Helianthemum bicknellii Fernald	Bicknell's hoary rockrose, hoary frostweed	PE	HP		S2	

HIGHER TAXON Family Genus, species (& variety or subspecies)	common name(s)	2010 PABS status	growth form	C_3 / C_4 (grasses)	grass-land specialist	extirpa-ted (?)
Cucurbitaceae						
Sicyos angulatus L.	bur cucumber, one-seeded bur cucumber		VA			
Elaeagnaceae						
***Elaeagnus angustifolia* L.**	**Russian-olive**		**SD**			
***Elaeagnus umbellata* Thunb.**	**autumn-olive**		**SD**			
Euphorbiaceae						
Acalypha rhomboidea Raf.	common three-seeded mercury		HA			
Fabaceae						
Amphicarpaea bracteata (L.) Fernald	American hog-peanut		VP VA			
Apios americana Medik.	groundnut, wild bean		VP			
Baptisia tinctoria (L.) Vent.	wild indigo, horseflyweed		HP			
Chamaecrista nictitans (L.) Moench	wild sensitive-plant, sensitive partridge pea		HA		O	X
Desmodium ciliare (Muhl. ex Willd.) DC.	hairy small-leaf tick-trefoil, tick-clover		HP			
Desmodium marilandicum (L.) DC	smooth small-leaf tick-trefoil, Maryland tick-clover		HP		S3	
Desmodium obtusum (Muhl. ex Willd.) DC.	stiff tick-trefoil	TU	HP			X
Desmodium paniculatum (L.) DC	panicled-leaf tick-trefoil		HP		O	X
Lespedeza capitata Michx.	round-headed bush-clover, roundhead lespedeza		HP		S2	X
Lespedeza virginica (L.) Britton	slender bush-clover		HP		S2	
***Medicago lupulina* L.**	**black medic**		**HA**			
***Melilotus alba* Medik.**	**white sweet-clover**		**HB HA**			
Robinia pseudoacacia L.	black locust		TD			
***Trifolium campestre* Schreb.**	**low hop-clover, field clover**		**HA**			
***Trifolium pratense* L.**	**red clover**		**HP**			

(Table continues on next page.)

HIGHER TAXON Family Genus, species (& variety or subspecies)	common name(s)	2010 PABS status	growth form	C_3 / C_4 (grasses)	grass-land specialist	extirpa-ted (?)
Fagaceae						
Castanea dentata (Marshall) Borkh.	American chestnut		TD			
Fagus grandifolia Ehrh.	American beech		TD			
Quercus alba L.	white oak		TD			
Quercus ×*bushii* Sarg. (*Q. marilandica* × *velutina*)*	Bush's oak*		TD		S1	
Quercus coccinea Muenchh.	scarlet oak		TD			
Quercus marilandica Muenchh.*	blackjack oak*		TD		S1	
Quercus montana Willd.	chestnut oak		TD			
Quercus nigra L.	water oak		TD			
Quercus palustris Muenchh.	pin oak		TD			
Quercus prinoides Willd.	dwarf chestnut oak		SD		S2	
Quercus prinoides × *alba*	Faxon oak		TD			X
Quercus rubra L.	northern red oak		TD			
Quercus stellata Wangenh.	post oak		TD		S2	
Quercus velutina Lam.	black oak		TD			
Hypericaceae						
Hypericum punctatum Lam.	spotted St. John's-wort		HP			
Juglandaceae						
Carya glabra (P.Mill.) Sweet	pignut hickory		TD			
Juglans nigra L.	black walnut		TD			
Linaceae						
Linum virginianum L.	slender yellow flax		HP		O	X

* It is uncertain which taxon trees at the Unionville Barrens resembling Bush's oak (*Quercus ×bushii*) or blackjack oak (*Q. marilandica*) actually belong to. Branching structure, bark appearance and growth habit are typical of blackjack oak but leaf morphology is atypical, more closely resembling that of black oak (*Q. velutina*), the other parent species of the hybrid Bush's oak (see discussion under *Species surveys*, pp. 33–34).

HIGHER TAXON **Family** Genus, species (& variety or subspecies)	common name(s)	2010 PABS status	growth form	C_3 / C_4 (grasses)	grass-land specialist	extirpa-ted (?)
Moraceae						
***Morus alba* L.**	**white mulberry**		**TD**			
Myricaceae						
Myrica pensylvanica Mirbel	bayberry, northern bayberry		SD			
Oxalidaceae						
Oxalis dillenii Jacq. ssp. *filipes* (Small) G.Eiten	southern yellow wood-sorrel, slender yellow wood-sorrel		HP		O	
Polygalaceae						
Polygala verticillata L.	whorled milkwort		HA		S3	
Rhamnaceae						
Ceanothus americanus L.	New Jersey tea	SP	SD		S3	
Rosaceae						
Agrimonia parviflora Aiton	southern agrimony, harvestlice		HP			
Agrimonia pubescens Wallr.	downy agrimony, soft agrimony		HP			
Amelanchier arborea (Michx.f.) Fernald	common serviceberry, shadbush, juneberry		TD			
***Duchesnea indica* (Andr.) Focke**	**Indian strawberry**		**HP**			
Fragaria virginiana Duchesne	wild strawberry, Virginia strawberry		HP			
Geum canadense Jacq.	white avens		HP			
Malus coronaria (L.) Mill.	sweet crabapple		TD		O	X
Malus sp.	**crabapple**		**TD**			
Potentilla canadensis L.	dwarf cinquefoil		HP		S3	
***Prunus avium* (L.) L.**	**sweet cherry, bird cherry**		**TD**			
Prunus serotina Ehrh.	black cherry, wild black cherry		TD			
***Pyrus communis* L.**	**common pear**		**TD**			
Rosa carolina L.	pasture rose, Carolina rose		SD		S3	
***Rosa multiflora* Thunb. ex Murray**	**multiflora rose**		**SD**			

(Table continues on next page.)

(Key to symbols and typefaces—p. 111. Index to all names—p. 132.)

HIGHER TAXON **Family** Genus, species (& variety or subspecies)	common name(s)	2010 PABS status	growth form	C_3 / C_4 (grasses)	grass-land specialist	extirpa-ted (?)
Rubus allegheniensis Porter	common blackberry, Allegheny blackberry		SD			
Rubus flagellaris Willd.	prickly dewberry, northern dewberry		VW			
Rubus occidentalis L.	black raspberry, black-cap		SD			
Rubus pensilvanicus Poir.	Pennsylvania blackberry		SD		O	X
***Rubus phoenicolasius* Maxim.**	**wineberry, wine raspberry**		**SD**			
Spiraea latifolia (Aiton) Borkh.	white meadowsweet		SD		S2	X
Salicaceae						
Populus grandidentata Michx.	bigtooth aspen		TD			
Salix humilis Marshall var. *humilis*	dwarf upland willow, sage willow, prairie willow		SD		O	X
Sapindaceae						
***Acer platanoides* L.**	**Norway maple**		**TD**			
***Acer pseudoplatanus* L.**	**sycamore maple**		**TD**			
Acer rubrum L.	red maple		TD			
Simaroubaceae						
***Ailanthus altissima* (P.Mill.) Swingle**	**ailanthus, tree-of-heaven**		**TD**			
Urticaceae						
Boehmeria cylindrica (L.) Sw.	false nettle, stingless nettle, smallspike false nettle		HP			
Violaceae						
Viola macloskeyi F.E.Lloyd ssp. *pallens* (Banks ex Ging.) M.S.Baker	sweet white violet, smooth white violet		HP			
Viola sagittata Aiton	arrow-leaf violet		HP		S2	
Viola sororia Willd.	common blue violet		HP		O	

HIGHER TAXON Family Genus, species (& variety or subspecies)	common name(s)	2010 PABS status	growth form	C_3 / C_4 (grasses)	grass-land specialist	extirpa-ted (?)
ASTERIDS						
Balsaminaceae						
Impatiens capensis Meerb.	jewelweed, orange jewelweed, spotted touch-me-not		HA			
Cornaceae						
Cornus florida L.	flowering dogwood		TD			
Ericaceae						
Chimaphila maculata (L.) Pursh	pipsissewa, spotted wintergreen, striped prince's-pine		HP			
Epigaea repens L.	trailing-arbutus		SE			
Gaylussacia baccata (Wangenh) K.Koch	black huckleberry		SD			
Kalmia latifolia L.	mountain-laurel		SE			
Monotropa uniflora L.	Indian-pipe		HP			
Rhododendron periclymenoides (Michx.) Shinners	pinxter-flower, pink azalea		SD			
Vaccinium pallidum Aiton	lowbush blueberry		SD			
Vaccinium stamineum L.	deerberry		SD			
Myrsinaceae						
Lysimachia ciliata L.	fringed loosestrife		HP			
Lysimachia quadrifolia L.	whorled loosestrife, whorled yellow loosestrife		HP			
Nyssaceae						
Nyssa sylvatica Marshall	black-gum, sour-gum, tupelo		TD			
Polemoniaceae						
Phlox subulata L. ssp. *subulata*	moss phlox, moss-pink		HP		S1	

(Table continues on next page.)

HIGHER TAXON Family Genus, species (& variety or subspecies)	common name(s)	2010 PABS status	growth form	C_3 / C_4 (grasses)	grass-land specialist	extirpa-ted (?)
EUASTERIDS						
Adoxaceae						
Sambucus canadensis L.	American elder, American black elderberry		SD			
Viburnum acerifolium L.	maple-leaf viburnum		SD			
Viburnum dentatum L.	southern arrow-wood		SD			
Viburnum lentago L.	nannyberry, sheepberry		SD			
Viburnum prunifolium L.	black-haw		SD TD			
***Viburnum setigerum* Hance**	**tea viburnum**		**SD**			
Apiaceae						
Angelica venenosa (Greenway) Fernald	deadly angelica, hairy angelica		HP		S2	X
Cicuta maculata L. var. *maculata*	spotted water-hemlock, beaver-poison, musquash-root, spotted cowbane		HP			
Cryptotaenia canadensis (L.) DC	honewort, wild-chervil		HP			
***Daucus carota* L.**	**Queen Anne's-lace, wild carrot**		**HB**			
Osmorhiza longistylis (Torr.) DC	anise-root, long-style sweet-root		HP			
Sanicula canadensis L.	Canadian sanicle, Canadian black snakeroot		HB			
Zizia aptera (A.Gray) Fernald	golden-alexander, meadow zizia		HP		O	X
Apocynaceae						
Apocynum cannabinum L.	Indian hemp		HP		O	
Asclepias syriaca L.	common milkweed		HP			
Asclepias verticillata L.	whorled milkweed		HP		S1	
Asclepias viridiflora Raf.	green milkweed		HP		S2	
Aquifoliaceae						
Ilex opaca Aiton	American holly	PT	TE			
Ilex verticillata (L.) A.Gray	common winterberry, black-alder		SD			

HIGHER TAXON Family Genus, species (& variety or subspecies)	common name(s)	2010 PABS status	growth form	C_3 / C_4 (grasses)	grass-land specialist	extirpa-ted (?)
Araliaceae						
Aralia nudicaulis L.	wild sarsaparilla		HP			
Asteraceae						
***Achillea millefolium* L.**	**common yarrow, milfoil**		**HP**			
Ageratina altissima (L.) R.M.King & H.Robinson var. *altissima*	white-snakeroot		HP			
Ageratina aromatica (L.) Spach	small-leaf white-snakeroot	PR	HP		S2	
Ambrosia artemisiifolia L.	common ragweed		HA		S3	
Ambrosia trifida L.	giant ragweed		HA			
Antennaria neglecta Greene	overlooked pussytoes, field pussytoes		HP		O	
Antennaria plantaginifolia (L.) Hook.	plantain-leaf pussytoes, woman's tobacco		HP		S3	
***Arctium minus* (Hill) Bernh.**	**woodland burdock, lesser burdock**		**HB**			
***Carduus nutans* L.**	**nodding thistle, musk thistle**		**HB**			
***Cichorium intybus* L.**	**blue chicory, blue-sailors**		**HP**			
***Cirsium arvense* (L.) Scop.**	**Canada thistle**		**HP**			
Cirsium muticum Michx.	swamp thistle		HB		S2	
Cirsium pumilum (Nutt.) Spreng.	pasture thistle		HB			
***Conyza canadensis* (L.) Cronquist**	**fleabane, Canadian horseweed**		**HA**			
Erigeron annuus (L.) Pers.	eastern daisy fleabane		HA HB			
Erigeron philadelphicus L.	Philadelphia fleabane, daisy fleabane		HP			
Eupatorium perfoliatum L.	common boneset		HP		O	X
Eurybia divaricata (L.) Nesom	white wood aster		HP			
Euthamia graminifolia (L.) Nutt.	grass-leaf goldenrod, flat-top goldenrod		HP		O	
Helianthus giganteus L.	swamp sunflower, giant sunflower		HP		O	
Hieracium venosum L.	rattlesnake-weed		HP			
Lactuca canadensis L.	wild lettuce, Canada lettuce		HA HB		O	

(Table continues on next page.)

HIGHER TAXON Family Genus, species (& variety or subspecies)	common name(s)	2010 PABS status	growth form	C_3 / C_4 (grasses)	grass-land specialist	extirpa-ted (?)
***Lactuca serriola* L.**	**prickly lettuce**		**HA HB**			
***Leucanthemum vulgare* Lam.**	**ox-eye daisy**		**HP**			
Packera anonyma (A.W.Wood) W.A.Weber & A.Love	Small's ragwort, Appalachian groundsel	PR	HP		S2	
Prenanthes altissima L.	tall rattlesnake-root		HP			
Prenanthes serpentaria Pursh	lion's-foot, cankerweed	PT	HP		S2	X
Pseudognaphalium obtusifolium (L.) Hilliard & B.L.Burtt.	fragrant cudweed, rabbit-tobacco		HA HB			
Rudbeckia hirta L.	black-eyed-susan		HB HP			
Rudbeckia laciniata L.	cutleaf coneflower, green-headed coneflower		HP			
***Senecio vulgaris* L.**	**common groundsel, old-man-in-the-spring**		**HA**			
Sericocarpus asteroides (L.) Britton, Stearns & Poggenb.	white-topped aster		HP		O	
Solidago canadensis L.	Canada goldenrod		HP		O	
Solidago juncea Aiton	early goldenrod		HP		O	
Solidago nemoralis Aiton	gray goldenrod		HP		S3	
Solidago rugosa P.Mill.	wrinkle-leaf goldenrod		HP		S3	
***Sonchus asper* (L.) Hill**	**spiny-leaf sow-thistle**		**HA**			
Symphyotrichum cordifolium (L.) Nesom	blue wood aster		HP			
Symphyotrichum depauperatum (Fernald) Nesom	serpentine aster	PT	HP		S1E	
Symphyotrichum ericoides (L.) Nesom	white heath aster	PT	HP		S3	X
Symphyotrichum laeve (L.) A.Love & D.Love var. *laeve*	smooth blue aster		HP		S2	X
Symphyotrichum lateriflorum (L.) A.Love & D.Love	calico aster		HP		S3	
Symphyotrichum pilosum (Willd.) Nesom	heath aster, Pringle's aster		HP		S3	

HIGHER TAXON **Family** Genus, species (& variety or subspecies)	common name(s)	2010 PABS status	growth form	C_3 / C_4 (grasses)	grass-land specialist	extirpa-ted (?)
***Taraxacum officinale* F.H.Wigg.**	**common dandelion**		**HP**			
***Tragopogon dubius* Scop.**	**yellow goatsbreard, yellow salsify**		**HB**			
Vernonia noveboracensis (L.) Michx.	New York ironweed		HP			
Boraginaceae						
Hackelia virginiana (L.) I.M.Johnst.	beggar's-lice, stickseed		HB			
Campanulaceae						
Lobelia inflata L.	Indian-tobacco		HA			
Lobelia puberula Michx.	downy lobelia	PE	HP		O	X
Lobelia spicata Lam. var. *spicata*	spiked lobelia		HP		S3	
Caprifoliaceae						
***Lonicera japonica* Thunb.**	**Japanese honeysuckle**		**VW**			
***Lonicera maackii* (Rupr.) Maxim.**	**Amur honeysuckle**		**SD**			
***Lonicera morrowii* A.Gray**	**Morrow's honeysuckle**		**SD**			
Convolvulaceae						
Calystegia spithamaea (L.) Pursh	low bindweed		VP			
Gentianaceae						
Sabatia angularis (L.) Pursh	common marsh-pink, rose-pink		HA		S2	
Lamiaceae						
***Clinopodium vulgare* L.**	**wild basil**		**HP**			
Lycopus virginicus L.	bugleweed, water-horehound, Virginia water-horehound		HP			
***Perilla frutescens* (L.) Britton**	**perilla, beefsteak-plant**		**HA**			
Prunella vulgaris L. ssp. *lanceolata* (Barton) Hulten	heal-all, self-heal, lance self-heal		HP		O	
Pycnanthemum tenuifolium Schrad.	narrow-leaf mountain-mint		HP		S3	
Pycnanthemum virginianum (L.) Durand & Jacks. ex B.L.Rob. & Fernald	Virginia mountain-mint		HP		O	

(Table continues on next page.)

HIGHER TAXON Family Genus, species (& variety or subspecies)	common name(s)	2010 PABS status	growth form	C_3 / C_4 (grasses)	grass-land specialist	extirpa-ted (?)
Scutellaria integrifolia L.	hyssop skullcup, helmet-flower		HP		O	
Trichostema dichotomum L.	blue-curls, forked bluecurls		HA		O	
Oleaceae						
Fraxinus americana L. var. *americana*	white ash		TD			
***Ligustrum obtusifolium* Siebold & Zucc.**	**border privet, obtuse-leaf privet**		**SD**			
Orobanchaceae						
Aureolaria pedicularia (L.) Raf.	cut-leaf false-foxglove, fernleaf yellow false-foxglove		HA		O	X
Epifagus virginiana (L.) W.P.C.Barton	beechdrops		HA			
Plantaginaceae						
Callitriche terrestris Raf. emend. Torr.	water-starwort, terrestrial water-starwort		HA			
Chelone glabra L.	white turtlehead		HP			
***Plantago lanceolata* L.**	**English plantain, ribgrass, narrow-leaf plantain**		**HP HA**			
Plantago rugelii Decne.	Rugel's plantain, broad-leaf plaintain, black-seed plantain		HP			
***Veronica arvensis* L.**	**corn speedwell**		**HA**			
***Veronica persica* Poir.**	**bird's-eye speedwell**		**HA**			
Rubiaceae						
Galium aparine L.	bedstraw, cleavers, goosegrass, stickywilly		HA			
Galium circaezans Michx.	wild licorice, licorice bedstraw		HP			
***Galium mollugo* L.**	**white bedstraw, wild madder, false baby's-breath**		**HP**			
Galium pilosum Aiton	hairy bedstraw, cleavers		HP		O	
Galium triflorum Michx.	sweet-scented bedstraw, fragrant bedstraw		HP			

HIGHER TAXON **Family** Genus, species (& variety or subspecies)	common name(s)	2010 PABS status	growth form	C_3 / C_4 (grasses)	grass-land specialist	extirpa-ted (?)
Houstonia caerulea L.	bluets, Quaker-ladies, azure bluet		HP		S3	
Mitchella repens L.	partridge-berry		HP			
Scrophulariaceae						
***Verbascum blattaria* L.**	**moth mullein**		**HB**			
***Verbascum thapsus* L.**	**common mullein, flannel-plant**		**HB**			
Solanaceae						
Physalis subglabrata Mack. & Bush	long-leaf ground-cherry		HP			
Solanum carolinense L.	horse-nettle		HP		O	
***Solanum nigrum* L.**	**black nightshade**		**HA**			
Verbenaceae						
Verbena urticifolia L.	white vervain		HA HP			
NON-COMMELINID MONOCOTS						
Alliaceae						
***Allium vineale* L.**	**field garlic, scallions**		**HP**			
Araceae						
Arisaema triphyllum (L.) Schott	jack-in-the-pulpit		HP			
Symplocarpus foetidus (L.) Salisb. ex W.P.C.Barton	skunk-cabbage		HP			
Colchicaceae						
Uvularia perfoliata L.	bellwort, perfoliate bellwort		HP			
Hyacinthaceae						
***Ornithogalum umbellatum* L.**	**star-of-Bethlehem, sleepy-dick**		**HP**			
Iridaceae						
Sisyrinchium angustifolium P.Mill.	narrow-leaf blue-eyed-grass		HP			
Sisyrinchium mucronatum Michx.	needletip blue-eyed-grass		HP		S2	

(Table continues on next page.)

HIGHER TAXON **Family** Genus, species (& variety or subspecies)	common name(s)	2010 PABS status	growth form	C_3 / C_4 (grasses)	grass-land specialist	extirpa-ted (?)
Liliaceae						
Erythronium americanum Ker Gawl.	yellow trout-lily, dogtooth-violet		HP			
Melanthiaceae						
Aletris farinosa L.	colic-root, white colic-root	PE	HP			X
Orchidaceae						
Galearis spectabilis (L.) Raf.	showy orchis		HP			
Isotria verticillata (Muhl. ex Willd.) Raf.	whorled-pogonia		HP			
Platanthera lacera (Michx.) G.Don	ragged fringed-orchid, green fringed orchid		HP		O	
Ruscaceae						
Maianthemum racemosum (L.) Link..	false Solomon's-seal, Solomon's-plume		HP			
Polygonatum biflorum (Walter) Elliott	smooth Solomon's-seal		HP			
Polygonatum pubescens (Willd.) Pursh	hairy Solomon's-seal		HP			
Smilacaceae						
Smilax glauca Walter	catbrier, cat greenbrier		VW		S2	
Smilax herbacea L.	carrion-flower, smooth carrion-flower		VP			
Smilax rotundifolia L.	common greenbrier, round-leaf greenbrier		VW		S2	
COMMELINID MONOCOTS						
Commelinaceae						
***Commelina communis* L.**	**Asiatic dayflower**		**HA**			
Cyperaceae						
Carex albicans Spreng.	white-tinged sedge		HP			
Carex amphibola Steud.	eastern narrow-leaf sedge		HP			
Carex bicknellii Britton	Bicknell's sedge	PE	HP		S1	
Carex blanda Dewey	eastern woodland sedge		HP			

HIGHER TAXON Family Genus, species (& variety or subspecies)	common name(s)	2010 PABS status	growth form	C_3 / C_4 (grasses)	grass-land specialist	extirpa-ted (?)
Carex digitalis Willd.	slender woodland sedge		HP			
Carex glaucodea Tuck.	blue sedge		HP		S2	
Carex hirsutella Mack.	fuzzy-wuzzy sedge		HP		S3	
Carex hystericina Willd.	bottlebrush sedge		HP		S2	X
Carex pensylvanica Lam.	Pennsylvania sedge		HP			
Carex richardsonii R.Br.	Richardson's sedge	PE	HP		S1	
Carex scoparia Schkuhr ex Willd.	broom sedge		HP		O	X
Carex swanii (Fernald) Mack.	Swan's sedge		HP		O	
Carex umbellata Willd.	parasol sedge		HP		O	
Cyperus strigosus L.	straw-colored flatsedge		HP		O	X
Eleocharis tenuis (Willd.) Schult.	slender spike-rush		HP		O	
Fimbristylis annua (All.) Roem. & Schult.	annual fimbry	PT	HA		S1	
Schoenoplectus tabernaemontani (Gmel.) Palla	great bulrush, soft-stem bulrush		HP			
Scirpus atrovirens Willd.	black bulrush, green bulrush		HP		S2	X
Scirpus georgianus R.M.Harper	Georgia bulrush		HP			
Scleria pauciflora Muhl ex Willd.	few-flowered nut-rush	PT	HP		S1	
Scleria triglomerata Michx.	whip-grass, nut-rush	PE	HP		S2	X
Trichophorum planifolium (Sprengel) Palla	club-rush, bashful bulrush		HP			
Juncaceae						
Juncus acuminatus Michx.	sharp-fruited rush, tapertip rush		HP		O	X
Juncus dichotomus Elliott	forked rush	PE	HP		S2	X
Juncus effusus L.	soft rush, lamp rush		HP			
Juncus secundus P.Beauv. ex Poir.	lopsided rush		HP		S2	
Juncus tenuis Willd. var. *tenuis*	path rush, poverty rush		HP		S3	
Luzula multiflora (Ehrh.) Lej.	field woodrush, common woodrush		HP			

(Table continues on next page.)

HIGHER TAXON Family Genus, species (& variety or subspecies)	common name(s)	2010 PABS status	growth form	C_3 / C_4 (grasses)	grass-land specialist	extirpa-ted (?)
Poaceae						
***Agrostis gigantea* Roth**	**redtop**		**HP**	**C_3**		
Agrostis perennans (Walter) Tuck.	autumn bent, upland bent		HP	C_3	S3	
Andropogon gerardii Vitman	big bluestem, turkeyfoot		HP	C_4	S3	
Andropogon gyrans Ashe	Elliott's beardgrass, Elliott's bluestem	PR	HP	C_4	O	
Andropogon virginicus L.	broomsedge		HP	C_4		
***Anthoxanthum odoratum* L.**	**sweet vernalgrass**		**HP**	**C_3**		
Aristida dichotoma Michx.	churchmouse three-awn, povertygrass		HA	C_4	S3	
Aristida longespica Poir. var. *longespica*	slender three-awn, slimspike three-awn	TU	HA	C_4	S2	X
Aristida purpurascens Poir.	arrow-feather three-awn	PT	HP	C_4	S2	
Bouteloua curtipendula (Michx.) Torr.	side-oats grama, tall grama	PT	HP	C_4	S1	
***Bromus inermis* Leyss.**	**smooth brome**		**HP**	**C_3**		
***Dactylis glomerata* L.**	**orchardgrass**		**HP**	**C_3**		
Danthonia spicata (L.) P.Beauv. ex Roem. & Schult.	povertygrass, poverty oatgrass		HP	C_3	S3	
Deschampsia cespitosa (L.) P.Beauv.	tufted hairgrass	PT	HP	C_3	S1	
Dichanthelium acuminatum (Sw.) Gould and C.A.Clark	tapered rosette grass, tapered panic-grass		HP	C_3	S2	
Dichanthelium clandestinum (L.) Gould	deer-tongue		HP	C_3	S3	
Dichanthelium depauperatum (Muhl.) Gould	poverty panic-grass, starved panic-grass		HP	C_3	S3	
Dichanthelium dichotomum (L.) Gould	cypress panic-grass		HP	C_3	S3	
Dichanthelium oligosanthes (Schult.) Gould	Heller's rosette grass, Heller's witch grass	PT	HP	C_3	S2	
Dichanthelium sphaerocarpon (Elliott) Gould	round-seeded panic-grass		HP	C_3	S2	
Dichanthelium villosissimum (Nash) Freckmann	long-haired panic-grass, whitehair rosette grass	PE	HP	C_3	S3	

HIGHER TAXON **Family** Genus, species (& variety or subspecies)	common name(s)	2010 PABS status	growth form	C_3 / C_4 (grasses)	grass-land specialist	extirpa-ted (?)
Digitaria filiformis (L.) Koeler	slender crabgrass	SP	HA	C_4	S3	X
Eragrostis pectinacea (Michx.) Nees	Carolina lovegrass, tufted lovegrass		HA	C_4		X
Eragrostis spectabilis (Pursh) Steud.	purple lovegrass, tumblegrass		HP	C_4	S3	
Leersia oryzoides (L.) Sw.	rice cutgrass		HP	C_3	O	X
Leersia virginica Willd.	whitegrass		HP	C_3		
***Microstegium vimineum* (Trin.) A.Camus.**	**stiltgrass, Japanese stiltgrass, Nepalese browntop**		**HA**	$\mathbf{C_4}$		
***Miscanthus sinensis* var. *sinensis* Andersson**	**Chinese silvergrass, eulalia, maiden grass**		**HP**	$\mathbf{C_4}$		
Muhlenbergia mexicana (L.) Trin.	Mexican muhly, satingrass		HP	C_4	S2	
Muhlenbergia sylvatica (Torr.) Torr. ex A.Gray	woodland muhly, woodland dropseed		HP	C_4		X
Panicum anceps Michx.	beaked panic-grass		HP	C_4	O	
Panicum philadelphicum Bernh. ex Trin.	Philadelphia panic-grass		HA	C_4	S2	
***Phleum pratense* L.**	**timothy**		**HP**	$\mathbf{C_3}$		
***Poa compressa* L.**	**Canada bluegrass**		**HP**	$\mathbf{C_3}$		
***Poa pratensis* L.**	**Kentucky bluegrass**		**HP**	$\mathbf{C_3}$		
***Schedonorus pratensis* (Huds.) P.Beauv.**	**meadow fescue**		**HP**	$\mathbf{C_3}$		
Schizachyrium scoparium (Michx.) Nash var. *scoparium*	little bluestem		HP	C_4	S3	
***Setaria pumila* (Poir.) Schult.**	**yellow foxtail**		**HA**	$\mathbf{C_4}$		
Sorghastrum nutans (L.) Nash	Indian-grass		HP	C_4	S3	
Sphenopholis obtusata (Michx.) Scribn. var. *obtusata*	prairie wedgegrass, prairie wedgescale		HP	C_3	S2	
Sporobolus vaginiflorus (Torr. ex A.Gray) A.W.Wood	poverty dropseed, poverty-grass		HA	C_4	S3	
Tridens flavus (L.) A.Hitchc.	purpletop		HP	C_4	S3	

(Table continues on next page.)

INDEX TO THE VASCULAR PLANTS OF THE UNIONVILLE BARRENS

Acalypha rhomboidea 117
Acer platanoides 120
Acer pseudoplatanus 120
Acer rubrum 120
Achillea millefolium 123
Adoxaceae 122
Ageratina altissima 123
Ageratina aromatica 123
Agrimonia parviflora 119
Agrimonia pubescens 119
agrimony, downy 119
agrimony, soft 119
agrimony, southern 119
Agrostis gigantea 130
Agrostis perennans 130
ailanthus 120
Ailanthus altissima 120
Aletris farinosa 128
Allegheny blackberry 120
Alliaceae 127
Alliaria petiolata 116
Allium vineale 127
alum-root, American 115
Amaranthaceae 113
Ambrosia artemisiifolia 123
Ambrosia trifida 123
Amelanchier arborea 119
American alum-root 115
American beech 118
American black elderberry 122
American chestnut 118
American elder 122
American filbert 116
American hazelnut 116
American hog-peanut 117
American holly 122
American hornbeam 116
American planetree 114
American sycamore 114
Amphicarpaea bracteata 117
Amur honeysuckle 125
Anacardiaceae 116
Andropogon gerardii 130
Andropogon gyrans 130
Andropogon virginicus 130
Angelica venenosa 122
angelica, deadly 122
angelica, hairy 122
anise-root 122
annual fimbry 129
Antennaria neglecta 123
Antennaria plantaginifolia 123
Anthoxanthum odoratum 130
Apiaceae 122
Apios americana 117
Apocynaceae 122
Apocynum cannabinum 122
Appalachian groundsel 124
Aquifoliaceae 122
Arabis lyrata 116
Araceae 127
Aralia nudicaulis 123
Araliaceae 123
Arctium minus 123
Arenaria serpyllifolia 114
Arisaema triphyllum 127
Aristida dichotoma 130
Aristida longespica 130
Aristida purpurascens 130
Aristolochia serpentaria 113
Aristolochiaceae 113
arrow-feather three-awn 130
arrow-leaf violet 120
arrow-wood, southern 122
Asclepias syriaca 122
Asclepias verticillata 122
Asclepias viridiflora 122
ash, white 126
Asiatic dayflower 128
aspen, bigtooth 120
Asplenium platyneuron 112
aster, blue wood 124
aster, calico 124
aster, Pringle’s 124
aster, serpentine 124
aster, smooth blue 124
aster, white heath 124
aster, white wood 123
aster, white-topped 124
Asteraceae 123
Asterids 121
Athyrium filix-femina 112
Aureolaria pedicularia 126
autumn bent 130
autumn-olive 117
avens, white 119
azalea, pink 121
azure bluet 127
baby’s-breath, false 126
Balsaminaceae 121
Baptisia tinctoria 117
Barbarea vulgaris 116
barberry, Japanese 113
barrens chickweed 114
bashful bulrush 129

basil, wild 125
bayberry 119
bayberry, northern 119
beaked panic-grass 131
bean, wild 117
beardgrass, Elliott's 130
beaver-poison 122
bedstraw 126
bedstraw, hairy 126
bedstraw, white 126
beech, American 118
beechdrops 126
beefsteak-plant 125
beggar's-lice 125
bellwort 127
bellwort, perfoliate 127
bent, autumn 130
bent, upland 130
Berberidaceae 113
Berberis thunbergii 113
Betulaceae 116
Bicknell's hoary rockrose 116
Bicknell's sedge 128
big bluestem 130
bigtooth aspen 120
bindweed, low 125
bird cherry 119
bird's-eye speedwell 126
bitter dock 114
bittercress, hairy 116
bittercress, Pennsylvania 116
bittersweet, Oriental 116
black bulrush 129
black cherry 119
black elderberry, American 122
black huckleberry 121
black locust 117
black medic 117
black nightshade 127
black oak 118
black raspberry 120
black snakeroot, Canadian 122
black walnut 118
black-alder 122
black-cap 120
black-eyed-susan 124
black-gum 121
black-haw 122
black-seed plantain 126
blackberry, Allegheny 120
blackberry, common 120
blackberry, Pennsylvania 120
blackjack oak 118
blisterwort 115
bloodroot 114
blue aster, smooth 124
blue chicory 123
blue sedge 129
blue violet, common 120
blue wood aster 124
blue-curls 126
blue-eyed-grass, narrow-leaf 127
blue-eyed-grass, needletip 127
blue-sailors 123
blueberry, lowbush 121
bluecurls, forked 126
bluegrass, Canada 131
bluegrass, Kentucky 131
bluestem, big 130
bluestem, Elliott's 130
bluestem, little 131
bluet, azure 127
bluets 127
Boehmeria cylindrica 120
boneset, common 123
Boraginaceae 125
border privet 126
Botrychium dissectum 112
Botrychium virginianum 112
bottlebrush sedge 129
Bouteloua curtipendula 130
bracken fern, northern 113
Brassicaceae 116
broad-leaf plaintain 126
brome, smooth 130
Bromus inermis 130
broom sedge 129
broomsedge 130
browntop, Nepalese 131
bugleweed 125
bulbous buttercup 115
bulrush, bashful 129
bulrush, black 129
bulrush, Georgia 129
bulrush, great 129
bulrush, green 129
bulrush, soft-stem 129
bur cucumber 117
bur cucumber, one-seeded 117
burdock, lesser 123
burdock, woodland 123
burning-bush 116
bush-clover, round-headed 117
bush-clover. slender 117
Bush's oak 118
buttercup, bulbous 115
buttonwood 114
calico aster 124
Callitriche terrestris 126
Calystegia spithamaea 125
Campanulaceae 125
campion, starry 114
Canada bluegrass 131
Canada goldenrod 124
Canada lettuce 123
Canada thistle 123
Canadian black snakeroot 122

(Table continues on next page.)

Canadian horseweed 123
Canadian sanicle 122
cankerweed 124
Cannabaceae 116
Caprifoliaceae 125
Cardamine hirsuta 116
Cardamine pensylvanica 116
Carduus nutans 123
Carex albicans 128
Carex amphibola 128
Carex bicknellii 128
Carex blanda 128
Carex digitalis 129
Carex glaucodea 129
Carex hirsutella 129
Carex hystericina 129
Carex pensylvanica 129
Carex richardsonii 129
Carex scoparia 129
Carex swanii 129
Carex umbellata 129
Carolina lovegrass 131
Carolina rose 119
Carpinus caroliniana 116
carrion-flower 128
carrion-flower, smooth 128
carrot, wild 122
Carya glabra 118
Caryophyllaceae 114
Castanea dentata 118
cat greenbrier 128
catbrier 128
Ceanothus americanus 119
Celastraceae 116
Celastrus orbiculatus 116
Celtis occidentalis 116
Cerastium nutans 114
Cerastium velutinum 114
Chamaecrista nictitans 117
Chelone glabra 126
Chenopodium album 113
cherry, bird 119
cherry, black 119
cherry, sweet 119
cherry, wild black 119
chestnut oak 118
chestnut oak, dwarf 118
chestnut, American 118
chickweed, barrens 114
chickweed, common 114
chickweed, giant 114
chickweed, nodding 114
chicory, blue 123
Chimaphila maculata 121
Chinese silvergrass 131
Christmas fern 113
churchmouse three-awn 130
Cichorium intybus 123
Cicuta maculata 122
cinquefoil, dwarf 119
Circaea canadensis 115
Cirsium arvense 123
Cirsium muticum 123
Cirsium pumilum 123
Cistaceae 116
Claytonia virginica 115
cleavers 126
cleavers 126
Clematis virginiana 115
Clinopodium vulgare 125
clover, field 117
clover, red 117
club-rush 129
clubmoss, deep-root 112
clubmosses 112
Colchicaceae 127
colic-root 128
colic-root, white 128
Commelina communis 128
Commelinaceae 128
commelinid monocots 128
common blackberry 119
common blue violet 120
common boneset 123
common chickweed 114
common dandelion 125
common greenbrier 128
common groundsel 124
common hackberry 116
common marsh-pink 125
common milkweed 122
common mullein 127
common pear 119
131 common pepperweed 116
common polypody 113
common ragweed 123
common serviceberry 119
common three-seeded mercury 117
common winterberry 122
common wintercress 116
common woodrush 129
common yarrow 123
coneflower, cutleaf 124
coneflower, green-headed 124
Convolvulaceae 125
Conyza canadensis 123
corn speedwell 126
Cornaceae 121
Cornus florida 121
Corylus americana 116
cowbane, spotted 122
crabapple 119
crabapple, sweet 119
crabgrass, slender 131
crowfoot, hooked 115
Cryptotaenia canadensis 122
cucumber, one-seeded bur 117

Cucurbitaceae 117
cudweed, fragrant 124
Cupressaceae 113
cut-leaf false-foxglove 126
cut-leaf grape-fern 112
cutgrass, rice 131
cutleaf coneflower 124
Cyperaceae 128
Cyperus strigosus 129
cypress panic-grass 130
Dactylis glomerata 130
daisy fleabane 123
daisy fleabane, eastern 123
daisy, ox-eye 124
dandelion, common 125
Danthonia spicata 130
darning-needles, devil's 115
Daucus carota 122
dayflower, Asiatic 128
deadly angelica 122
deep-root clubmoss 112
deep-rooted running-pine 112
deer-tongue 130
deerberry 121
Dennstaedtia punctilobula 112
Deparia acrostichoides 112
Deptford pink 114
Deschampsia cespitosa 130
Desmodium ciliare 117
Desmodium marilandicum 117
Desmodium obtusum 117
Desmodium paniculatum 117
devil's darning-needles 115
dewberry, northern 120
dewberry, prickly 120
Dianthus armeria 114
Dichanthelium acuminatum 130
Dichanthelium clandestinum 130
Dichanthelium depauperatum 130
Dichanthelium dichotomum 130
Dichanthelium oligosanthes 130
Dichanthelium sphaerocarpon 130
Dichanthelium villosissimum 130
Digitaria filiformis 131
Diphasiastrum tristachyum 112
dock, bitter 114
dogtooth-violet 128
dogwood, flowering 121
downy agrimony 119
dropseed, poverty 131
dropseed, woodland 131
Dryopteris carthusiana 112
Dryopteris intermedia 112
Dryopteris marginalis 112
Duchesnea indica 119
dwarf chestnut oak 118
dwarf cinquefoil 119
dwarf sumac 116
dwarf upland willow 120
early goldenrod 124
early saxifrage 115
eastern daisy fleabane 123
eastern marsh fern 113
eastern narrow-leaf sedge 128
eastern poison-ivy 116
eastern red-cedar 113
eastern woodland sedge 128
ebony spleenwort 112
Elaeagnaceae 117
Elaeagnus angustifolia 117
Elaeagnus umbellata 117
elder, American 122
elderberry, American black 122
Eleocharis tenuis 129
Elliott's beardgrass 130
Elliott's bluestem 130
enchanter's-nightshade 115
English plantain 126
Epifagus virginiana 126
Epigaea repens 121
Eragrostis pectinacea 131
Eragrostis spectabilis 131
Ericaceae 121
Erigeron annuus 123
Erigeron philadelphicus 123
Erythronium americanum 128
Euasterids 122
Eudicots 113
eulalia 131
Euonymus alatus 116
euonymus, winged 116
Eupatorium perfoliatum 123
Euphorbiaceae 117
Eurosids 116
Eurybia divaricata 123
Euthamia graminifolia 123
evening-primrose, little 115
evening-primrose, narrow-leaf 115
evergreen wood-fern 112
Fabaceae 117
Fagaceae 118
Fagus grandifolia 118
false baby's-breath 126
false nettle 120
false Solomon's-seal 128
false-foxglove, cut-leaf 126
false-foxglove, fernleaf yellow 126
fameflower, quill 115
fancy fern 112
Faxon oak 118
fern, Christmas 113
fern, eastern marsh 113
fern, ebony 112
fern, fancy 112
fern, hay-scented 112
fern, interrupted 112
fern, New York 113

(Table continues on next page.)

fern, northern bracken 113
fern, rattlesnake 112
fern, royal 112
fern, sensitive 112
fern, silvery glade 112
fern, southern 112
fernleaf yellow false-foxglove 126
ferns 112
fescue, meadow 131
few-flowered nut-rush 129
field clover 117
field garlic 127
field pepperweed 116
field pussytoes 123
field woodrush 129
fieldcress 116
filbert, American 116
Fimbristylis annua 129
fimbry, annual 129
flannel-plant 127
flat-branched ground-pine 112
flat-top goldenrod 123
flatsedge, straw-colored 129
flax, slender yellow 118
fleabane 123
fleabane, daisy 123
fleabane, eastern daisy 123
fleabane, Philadelphia 123
flowering dogwood 121
forked bluecurls 126
forked rush 129
foxtail, yellow 131
Fragaria virginiana 119
fragrant bedstraw 126
fragrant cudweed 124
Fraxinus americana 126
fringed loosestrife 121
fringed orchid, green 128
fringed-orchid, ragged 128
frost grape 115
fuzzy-wuzzy sedge 129
Galearis spectabilis 128
Galium aparine 126
Galium circaezans 126
Galium mollugo 126
Galium pilosum 126
Galium triflorum 126
garden yellow rocket 116
garlic mustard 116
garlic, field 127
Gaylussacia baccata 121
Gentianaceae 125
Georgia bulrush 129
Geraniaceae 115
Geranium maculatum 115
geranium, spotted 115
geranium, wood 115
Geum canadense 119
giant chickweed 114
giant ragweed 123
giant sunflower 123
glade fern, silvery 112
goatsbreard, yellow 125
golden-alexander 122
goldenrod, Canada 124
goldenrod, early 124
goldenrod, flat-top 123
goldenrod, grass-leaf 123
goldenrod, gray 124
goldenrod, wrinkle-leaf 124
goosegrass 126
grama, side-oats 130
grama, tall 130
grape-fern, cut-leaf 112
grape, frost 115
grape, pigeon 115
grape, summer 115
grass-leaf goldenrod 123
gray goldenrod 124
great bulrush 129
green bulrush 129
green fringed orchid 128
green milkweed 122
green-headed coneflower 124
greenbrier, cat 128
greenbrier, common 128
greenbrier, round-leaf 128
ground-cherry, long-leaf 127
ground-pine, flat-branched 112
groundnut 117
groundsel, Appalachian 124
groundsel, common 124
gymnosperms 113
hackberry, common 116
Hackelia virginiana 125
hairgrass, tufted 130
hairy angelica 122
hairy bedstraw 126
hairy bittercress 116
hairy small-leaf tick-trefoil 117
hairy Solomon's-seal 128
Hamamelidaceae 114
Hamamelis virginiana 114
harvestlice 119
hay-scented fern 112
hazelnut, American 116
heal-all 125
heath aster 124
heath aster, white 124
Helianthemum bicknellii 116
Helianthus giganteus 123
Heller's rosette grass 130
Heller's witch grass 130
helmet-flower 126
Heuchera americana 115
hickory, pignut 118
Hieracium venosum 123

hoary frostweed 116
hog-peanut, American 117
holly, American 122
honewort 122
honeysuckle, Amur 125
honeysuckle, Japanese 125
honeysuckle, Morrow's 125
hooked crowfoot 115
hop-clover, low 117
hornbeam, American 116
horse-nettle 127
horseflyweed 117
horseweed, Canadian 123
Houstonia caerulea 127
huckleberry, black 121
Hyacinthaceae 127
Hypericaceae 118
Hypericum punctatum 118
hyssop skullcup 126
Ilex opaca 122
Ilex verticillata 122
Impatiens capensis 121
Indian strawberry 119
Indian-grass 131
Indian-hemp 122
Indian-pipe 121
Indian-tobacco 125
indigo, wild 117
intermediate wood-fern 112
interrupted fern 112
Iridaceae 127
ironweed, New York 125
ironwood 116
Isotria verticillata 128
jack-in-the-pulpit 127
Japanese barberry 113
Japanese honeysuckle 125
Japanese stiltgrass 131
jewelweed 121
jewelweed, orange 121
Juglandaceae 118
Juglans nigra 118
jumpseed 114
Juncaceae 129
Juncus acuminatus 129
Juncus dichotomus 129
Juncus effusus 129
Juncus secundus 129
Juncus tenuis 129
juneberry 119
Juniperus virginiana 113
Kalmia latifolia 121
Kentucky bluegrass 131
king-of-the-meadow 115
knotweed, pleat-leaf 114
knotweed, slender 114
Lactuca canadensis 123
Lactuca serriola 124
lady's-thumb, Oriental 114
lamb's-quarters 113
Lamiaceae 125
lamp rush 129
lance self-heal 125
Lauraceae 113
Leersia oryzoides 131
Leersia virginica 131
Lepidium campestre 116
Lepidium densiflorum 116
Lespedeza capitata 117
Lespedeza virginica 117
lespedeza, roundhead 117
lesser burdock 123
lettuce, Canada 123
lettuce, prickly 124
lettuce, wild 123
Leucanthemum vulgare 124
licorice bedstraw 126
Ligustrum obtusifolium 126
Liliaceae 128
Linaceae 118
Lindera benzoin 113
Linum virginianum 118
lion's-foot 124
Liriodendron tulipifera 113
little bluestem 131
little evening-primrose 115
Lobelia inflata 125
Lobelia spicata 125
lobelia, spiked 125
locust, black 117
long-haired panic-grass 130
long-leaf ground-cherry 127
long-style sweet-root 122
Lonicera japonica 125
Lonicera maackii 125
Lonicera morrowii 125
loosestrife, fringed 121
loosestrife, whorled 121
loosestrife, whorled yellow 121
lopsided rush 129
lovegrass, Carolina 131
lovegrass, purple 131
lovegrass, tufted 131
low bindweed 125
low hop-clover 117
low smartweed 114
lowbush blueberry 121
Luzula multiflora 129
Lycopodiaceae 112
Lycopodium obscurum 112
lycopods 112
Lycopus virginicus 125
lyre-leaf rockcress 116
Lysimachia ciliata 121
Lysimachia quadrifolia 121
madder, wild 126
Magnoliaceae 113

(Table continues on next page.)

Magnoliids 113
Maianthemum racemosum 128
maiden grass 131
Malus coronaria 119
Malus sp. 119
mandrake 113
maple-leaf viburnum 122
maple, Norway 120
maple, sycamore 120
marginal wood-fern 112
marsh fern 113
marsh fern, eastern 113
marsh-pink, common 125
Maryland tick-clover 117
mayapple 113
meadow fescue 131
meadow zizia 122
meadow-rue, tall 115
meadowsweet, white 120
medic, black 117
Medicago lupulina 117
Melanthiaceae 128
Melilotus alba 117
mercury, common three-seeded 117
Mexican muhly 131
Michaux’s stitchwort 114
Microstegium vimineum 131
milfoil 123
milkweed, common 122
milkweed, green 122
milkweed, whorled 122
milkwort, whorled 119
Minuartia michauxii 114
Miscanthus sinensis 131
Mitchella repens 127
Monotropa uniflora 121
Moraceae 119
Morrow’s honeysuckle 125
Morus alba 119
moss phlox 121
moss-pink 121
moth mullein 127
mountain-laurel 121
mountain-mint, narrow-leaf 125
mountain-mint, Virginia 125
mouse-ear, water 114
Muhlenbergia mexicana 131
Muhlenbergia sylvatica 131
muhly, Mexican 131
muhly, woodland 131
mulberry, white 119
mullein, common 127
mullein, moth 127
multiflora rose 119
musk thistle 123
musquash-root 122
mustard, garlic 116
Myosoton aquaticum 114
Myrica pensylvanica 119
Myricaceae 119
Myrsinaceae 121
nannyberry 122
narrow-leaf blue-eyed-grass 127
narrow-leaf evening-primrose 115
narrow-leaf mountain-mint 125
narrow-leaf plantain 126
narrow-leaf sedge, eastern 128
needletip blue-eyed-grass 127
Nepalese browntop 131
nettle, false 120
nettle, smallspike false 120
nettle, stingless 120
131 New Jersey tea 119
New York fern 113
New York ironweed 125
nightshade, black 127
nodding chickweed 114
nodding thistle 123
non-commelinid monocots 127
northern bayberry 119
northern bracken fern 113
northern dewberry 120
northern red oak 118
Norway maple 120
nut-rush 129
nut-rush, few-flowered 129
Nyssa sylvatica 121
Nyssaceae 121
oak, black 118
oak, blackjack 118
oak, Bush’s 118
oak, chestnut 118
oak, dwarf chestnut 118
oak, Faxon 118
oak, northern red 118
oak, pin 118
oak, post 118
oak, scarlet 118
oak, water 118
oak, white 118
oatgrass, poverty 130
obtuse-leaf privet 126
Oenothera fruticosa 115
Oenothera perennis 115
old-man-in-the-spring 124
Oleaceae 126
olive....(see autumn-olive, Russian-olive)
Onagraceae 115
one-seeded bur cucumber 117
Onoclea sensibilis 112
Ophioglossaceae 112
orange jewelweed 121
orchardgrass 130
orchid, green fringed 128
Orchidaceae 128
orchis, showy 128
Oriental bittersweet 116

Oriental lady's-thumb ... 114
Ornithogalum umbellatum ... 127
Orobanchaceae ... 126
Osmorhiza longistylis ... 122
Osmunda claytoniana ... 112
Osmunda regalis ... 112
Osmundaceae ... 112
overlooked pussytoes ... 123
ox-eye daisy ... 124
Oxalidaceae ... 119
Oxalis dillenii ... 119
Packera anonyma ... 124
panic-grass, beaked ... 131
panic-grass, cypress ... 130
panic-grass, long-haired ... 130
panic-grass, Philadelphia ... 131
panic-grass, poverty ... 130
panic-grass, round-seeded ... 130
panic-grass, starved ... 130
panic-grass, tapered ... 130
panicled-leaf tick-trefoil ... 117
Panicum anceps ... 131
Panicum philadelphicum ... 131
Papaveraceae ... 114
parasol sedge ... 129
Parthenocissus quinquefolia ... 115
partridge pea, sensitive ... 117
partridge-berry ... 127
pasture rose ... 119
pasture thistle ... 123
path rush ... 129
pear, common ... 119
Pennsylvania bittercress ... 116
Pennsylvania blackberry ... 120
Pennsylvania sedge ... 129
pepper-grass, wild ... 116
pepperweed, common ... 116
pepperweed, field ... 116
perfoliate bellwort ... 127
perilla ... 125
Perilla frutescens ... 125
Persicaria longiseta ... 114
Persicaria virginiana ... 114
Phemeranthus teretifolius ... 115
Philadelphia fleabane ... 123
Philadelphia panic-grass ... 131
Phleum pratense ... 131
Phlox subulata ... 121
phlox, moss ... 121
Physalis subglabrata ... 127
Phytolacca americana ... 114
Phytolaccaceae ... 114
pigeon grape ... 115
pignut hickory ... 118
pin oak ... 118
Pinaceae ... 113
pine, shortleaf ... 113
pine, yellow ... 113
pink azalea ... 121
pink, Deptford ... 114
Pinus echinata ... 113
pinxter-flower ... 121
pipsissewa ... 121
plaintain, broad-leaf ... 126
planetree, American ... 114
Plantaginaceae ... 126
Plantago lanceolata ... 126
Plantago rugelii ... 126
plantain-leaf pussytoes ... 123
plantain, black-seed ... 126
plantain, English ... 126
plantain, narrow-leaf ... 126
plantain, Rugel's ... 126
Platanaceae ... 114
Platanthera lacera ... 128
Platanus occidentalis ... 114
pleat-leaf knotweed ... 114
Poa compressa ... 131
Poa pratensis ... 131
Poaceae ... 130
Podophyllum peltatum ... 113
poison-ivy ... 116
poison-ivy, eastern ... 116
pokeweed ... 114
Polemoniaceae ... 121
Polygala verticillata ... 119
Polygalaceae ... 119
Polygonaceae ... 114
Polygonatum biflorum ... 128
Polygonatum pubescens ... 128
Polygonum aviculare ... 114
Polygonum tenue ... 114
Polypodiaceae ... 112
Polypodium virginianum ... 113
polypody, common ... 113
polypody, rock ... 113
Polystichum acrostichoides ... 113
poplar ... (see bigtooth aspen, tuliptree)
Populus grandidentata ... 120
Portulacaceae ... 115
post oak ... 118
Potentilla canadensis ... 119
poverty dropseed ... 131
poverty oatgrass ... 130
poverty panic-grass ... 130
poverty rush ... 129
poverty-grass ... 131
povertygrass ... 130
povertygrass ... 130
prairie wedgegrass ... 131
prairie wedgescale ... 131
prairie willow ... 120
Prenanthes altissima ... 124
Prenanthes serpentaria ... 124
prickly dewberry ... 120
prickly lettuce ... 124
prince's-pine, striped ... 121

(Table continues on next page.)

privet, border 126
privet, obtuse-leaf 126
prostrate knotweed 114
prostrate knotweed 114
Prunella vulgaris 125
Prunus avium 119
Prunus serotina 119
Pseudognaphalium obtusifolium 124
Pteridium aquilinum 113
puccoon, red 114
purple lovegrass 131
purpletop 131
pussytoes, field 123
pussytoes, overlooked 123
pussytoes, plantain-leaf 123
Pycnanthemum tenuifolium 125
Pycnanthemum virginianum 125
Pyrus communis 119
Quaker-ladies 127
Queen Anne's-lace 122
Quercus ×bushii 118
Quercus alba 118
Quercus coccinea 118
Quercus marilandica 118
Quercus marilandica × velutina 118
Quercus montana 118
Quercus nigra 118
Quercus palustris 118
Quercus prinoides 118
Quercus prinoides × alba 118
Quercus rubra 118
Quercus stellata 118
Quercus velutina 118
quill fameflower 115
rabbit-tobacco 124
ragged fringed-orchid 128
ragweed, common 123
ragweed, giant 123
ragwort, Small's 124
Ranunculaceae 115
Ranunculus bulbosus 115
Ranunculus recurvatus 115
raspberry, black 120
raspberry, wine 120
rattlesnake fern 112
rattlesnake-root, tall 124
rattlesnake-weed 123
red clover 117
red maple 120
red maple 120
red oak, northern 118
red puccoon 114
red-cedar, eastern 113
redtop 130
Rhamnaceae 119
Rhododendron periclymenoides 121
Rhus copallina 116
ribgrass 126
rice cutgrass 131
Richardson's sedge 129
Robinia pseudoacacia 117
rock polypody 113
rock sandwort 114
rockcap 113
rockcress, lyre-leaf 116
rocket, garden yellow 116
Rosa carolina 119
Rosa multiflora 119
Rosaceae 119
rose-pink 125
rose, Carolina 119
rose, multiflora 119
rose, pasture 119
rosette grass, Heller's 130
rosette grass, tapered 130
rosette grass, whitehair 130
Rosids 115
round-headed bush-clover 117
round-leaf fameflower 115
round-leaf greenbrier 128
round-seeded panic-grass 130
roundhead lespedeza 117
royal fern 112
Rubiaceae 126
Rubus allegheniensis 119
Rubus flagellaris 120
Rubus occidentalis 120
Rubus pensilvanicus 120
Rubus phoenicolasius 120
Rudbeckia hirta 124
Rudbeckia laciniata 124
Rugel's plantain 126
Rumex acetosella 114
Rumex obtusifolius 114
running-pine, deep-rooted 112
Ruscaceae 128
rush, forked 129
rush, lamp 129
rush, lopsided 129
rush, path 129
rush, poverty 129
rush, sharp-fruited 129
rush, soft 129
rush, tapertip 129
Russian-olive 117
Sabatia angularis 125
sage willow 120
Salicaceae 120
Salix humilis 120
salsify, yellow 125
Sambucus canadensis 122
sandwort, rock 114
sandwort, thyme-leaf 114
Sanguinaria canadensis 114
sanicle, Canadian 122
Sanicula canadensis 122
Sapindaceae 120

sarsaparilla, wild 123
sassafras 113
Sassafras albidum 113
satingrass 131
Saxifraga virginiensis 115
Saxifragaceae 115
saxifrage, early 115
scallions 127
scarlet oak 118
Schedonorus pratensis 131
Schizachyrium scoparium 131
Schoenoplectus tabernaemontani 129
Scirpus atrovirens 129
Scirpus georgianus 129
Scleria pauciflora 129
Scleria triglomerata 129
Scrophulariaceae 127
Scutellaria integrifolia 126
sedge, Bicknell’s 128
sedge, blue 129
sedge, bottlebrush 129
sedge, broom 129
sedge, eastern woodland 128
sedge, fuzzy-wuzzy 129
sedge, parasol 129
sedge, Pennsylvania 129
sedge, Richardson’s 129
sedge, slender woodland 129
sedge, Swan’s 129
sedge, white-tinged 128
self-heal 125
Senecio vulgaris 124
sensitive fern 112
sensitive partridge pea 117
sensitive-plant, wild 117
Sericocarpus asteroides 124
serpentine aster 124
serviceberry, common 119
Setaria pumila 131
shadbush 119
sharp-fruited rush 129
sheep sorrel 114
sheepberry 122
shining sumac 116
shortleaf pine 113
showy orchis 128
Sicyos angulatus 117
side-oats grama 130
Silene stellata 114
silvergrass, Chinese 131
silvery glade fern 112
Simaroubaceae 120
Sisyrinchium angustifolium 127
Sisyrinchium mucronatum 127
skullcap, hyssop 126
skunk-cabbage 127
sleepy-dick 127
slender bush-clover 117
slender crabgrass 131
slender knotweed 114
slender spike-rush 129
slender three-awn 130
slender woodland sedge 129
slender yellow flax 118
slender yellow wood-sorrel 119
slimspike three-awn 130
small-leaf tick-trefoil, hairy 117
small-leaf tick-trefoil, smooth 117
small-leaf white-snakeroot 123
Small’s ragwort 124
smallspike false nettle 120
smartweed, low 114
Smilacaceae 128
Smilax glauca 128
Smilax herbacea 128
Smilax rotundifolia 128
smooth blue aster 124
smooth brome 130
smooth carrion-flower 128
smooth small-leaf tick-trefoil 117
smooth Solomon’s-seal 128
smooth white violet 120
snakeroot, Canadian black 122
snakeroot, Virginia 113
soft agrimony 119
soft rush 129
soft-stem bulrush 129
Solanaceae 127
131 *Solanum carolinense* 127
Solanum nigrum 127
Solidago canadensis 124
Solidago juncea 124
Solidago nemoralis 124
Solidago rugosa 124
Solomon’s-plume 128
Solomon’s-seal, false 128
Solomon’s-seal, hairy 128
Solomon’s-seal, smooth 128
Sonchus asper 124
Sorghastrum nutans 131
sorrel, sheep 114
sour-gum 121
sourgrass 114
southern agrimony 119
southern arrow-wood 122
southern lady-fern 112
southern yellow wood-sorrel 119
sow-thistle, spiny-leaf 124
speedwell, bird’s-eye 126
speedwell, corn 126
Sphenopholis obtusata 131
spicebush 113
spike-rush, slender 129
spiked lobelia 125
spinulose wood-fern 112
spiny-leaf sow-thistle 124

(Table continues on next page.)

Spiraea latifolia 120
Sporobolus vaginiflorus 131
spotted cowbane 122
spotted geranium 115
spotted St. John's-wort 118
spotted touch-me-not 121
spotted water-hemlock 122
spotted wintergreen 121
spring-beauty 115
St. Anthony's-turnip 115
St. John's-wort, spotted 118
star-of-Bethlehem 127
starry campion 114
starved panic-grass 130
Stellaria media 114
stickseed 125
stickywilly 126
stiff tick-trefoil 117
stiltgrass 131
stiltgrass, Japanese 131
stingless nettle 120
stitchwort, Michaux's 114
straw-colored flatsedge 129
strawberry, Indian 119
strawberry, Virginia 119
strawberry, wild 119
striped prince's-pine 121
sugarberry 116
sumac, dwarf 116
sumac, shining 116
sumac, winged 116
summer grape 115
sundrops 115
sundrops 115
sunflower, giant 123
sunflower, swamp 123
swamp sunflower 123
swamp thistle 123
Swan's sedge 129
sweet cherry 119
sweet crabapple 119
sweet vernalgrass 130
sweet white violet 120
sweet-clover, white 117
sweet-root, long-style 122
sweet-scented bedstraw 126
sycamore maple 120
sycamore, American 114
Symphyotrichum cordifolium 124
Symphyotrichum depauperatum 124
Symphyotrichum ericoides 124
Symphyotrichum laeve 124
Symphyotrichum lateriflorum 124
Symphyotrichum pilosum 124
Symplocarpus foetidus 127
tall grama 130
tall meadow-rue 115
tall rattlesnake-root 124
tapered panic-grass 130
tapered rosette grass 130
tapertip rush 129
Taraxacum officinale 125
tea viburnum 122
tea, New Jersey 119
terrestrial water-starwort 126
Thalictrum pubescens 115
Thelypteris noveboracensis 113
Thelypteris palustris 113
thistle, Canada 123
thistle, musk 123
thistle, nodding 123
thistle, pasture 123
thistle, swamp 123
three-awn, arrow-feather 130
three-awn, churchmouse 130
three-awn, slender 130
three-awn, slimspike 130
three-seeded mercury, common 117
thyme-leaf sandwort 114
tick-clover 117
tick-clover, Maryland 117
tick-trefoil, hairy small-leaf 117
tick-trefoil, panicled-leaf 117
tick-trefoil, smooth small-leaf 117
tick-trefoil, stiff 117
timothy 131
touch-me-not, spotted 121
Toxicodendron radicans 116
Tragopogon dubius 125
trailing-arbutus 121
tree-of-heaven 120
Trichophorum planifolium 129
Trichostema dichotomum 126
Tridens flavus 131
Trifolium campestre 117
Trifolium pratense 117
trout-lily, yellow 128
tufted hairgrass 130
tufted lovegrass 131
tuliptree 113
tumblegrass 131
tupelo 121
turkeyfoot 130
turtlehead, white 126
upland bent 130
Urticaceae 120
Uvularia perfoliata 127
Vaccinium pallidum 121
Vaccinium stamineum 121
Verbascum blattaria 127
Verbascum thapsus 127
Verbena urticifolia 127
Verbenaceae 127
vernalgrass, sweet 130
Vernonia noveboracensis 125
Veronica arvensis 126
Veronica persica 126

vervain, white 127
Viburnum acerifolium 122
Viburnum dentatum 122
Viburnum lentago 122
Viburnum prunifolium 122
Viburnum setigerum 122
viburnum, maple-leaf 122
viburnum, tea 122
Viola macloskeyi 120
Viola sagittata 120
Viola sororia 120
Violaceae 120
violet, arrow-leaf 120
violet, smooth white 120
violet, sweet white 120
virgin's-bower 115
Virginia mountain-mint 125
Virginia snakeroot 113
Virginia strawberry 119
Virginia water-horehound 125
Virginia-creeper 115
Vitaceae 115
Vitis aestivalis 115
Vitis vulpina 115
walnut, black 118
water mouse-ear 114
water oak 118
water-hemlock, spotted 122
water-horehound 125
water-horehound, Virginia 125
water-starwort 126
water-starwort, terrestrial 126
wedgegrass, prairie 131
wedgescale, prairie 131
whip-grass 129
white ash 126
white avens 119
white bedstraw 126
white colic-root 128
white heath aster 124
white meadowsweet 120
white mulberry 119
white oak 118
white sweet-clover 117
white turtlehead 126
white vervain 127
white wood aster 123
white-snakeroot 123
white-snakeroot, small-leaf 123
white-tinged sedge 128
white-topped aster 124
whitegrass 131
whitehair rosette grass 130
whorled loosestrife 121
whorled milkweed 122
whorled milkwort 119
whorled yellow loosestrife 121
whorled-pogonia 128
widow's-frill 114
wild basil 125
wild bean 117
wild black cherry 119
wild carrot 122
wild indigo 117
wild lettuce 123
wild licorice 126
wild madder 126
wild pepper-grass 116
wild sarsaparilla 123
wild sensitive-plant 117
wild strawberry 119
wild-chervil 122
willow, dwarf upland 120
willow, prairie 120
willow, sage 120
wine raspberry 120
wineberry 120
winged euonymus 116
winged sumac 116
winterberry, common 122
wintercress, common 116
wintergreen, spotted 121
witch grass, Heller's 130
witch-hazel 114
woman's-tobacco 123
wood aster, blue 124
wood aster, white 123
wood geranium 115
wood-fern, evergreen 112
wood-fern, intermediate 112
wood-fern, marginal 112
wood-fern, spinulose 112
wood-sorrel, slender yellow 119
wood-sorrel, southern yellow 119
woodbine 115
woodland burdock 123
woodland dropseed 131
woodland muhly 131
woodland sedge, eastern 128
woodland sedge, slender 129
woodrush, common 129
woodrush, field 129
wrinkle-leaf goldenrod 124
yarrow, common 123
yellow false-foxglove, fernleaf 126
yellow flax, slender 118
yellow foxtail 131
yellow goatsbreard 125
yellow pine 113
yellow rocket, garden 116
yellow salsify 125
yellow trout-lily 128
yellow wood-sorrel, slender 119
yellow wood-sorrel, southern 119
yellow-poplar 113
Zizia aptera 122
zizia, meadow 122

Appendix C. Arthropods of Special Conservation Concern that May Inhabit Unionville Barrens

It is next to certain that arthropod species of special conservation concern are present at the Unionville Barrens. However, to date no one has done a systematic animal survey at the site. There are nearly 50 animal species of special concern, mainly insects, known so far at the State Line Barrens, a series of serpentine grasslands and woods along the Mason-Dixon Line in Pennsylvania and Maryland just 16 miles southwest of the Unionville Barrens. Even there, so far relatively little effort has been put into wildlife surveys except to search for butterflies and moths. Scientists expect to find many more kinds of rare insects and other arthropods on serpentine barrens eventually. Searches have been made of the Unionville Barrens specifically targeting three rare insect species, two plant bugs that feed on moss phlox and one beetle whose larvae feed on the native grasses little bluestem and big bluestem. The rare plant bugs were not found at Unionville but the prairie leaf beetle, which lives mainly in the prairies of the Midwest and West, was found there in 1987. To date, it is the only animal species of special conservation concern confirmed at the Unionville Barrens. Other arthropods of special conservation concern are highly likely to be found through professional surveys conducted by qualified entomologists.

Table C-1 (next page) is a preliminary list of insects of special conservation concern considered as likely past, present or future residents of the Unionville Barrens. The list includes 10 butterflies, 32 moths, 1 beetle and 2 hemipterans or “true bugs” that depend in some way on plants presently found at the site. The list is not in any way exhaustive of the endangered, threatened or rare insect species that might inhabit the Unionville Barrens. Its utility is in identifying several plant species as targets of management to enhance or sustain habitat value for serpentine barrens-dependent animal life and as additional indicators of desired conditions to be monitored.

Table C-1. **Arthropods of special conservation concern that may inhabit Unionville Barrens**. Sources: Pennsylvania Natural Heritage Program (2010); Rawlins (2007); Orndorff and Patten (2007); personal communication with B. Leppo, D. Schweitzer, A. Wheeler.

species	common name	global rank*	state rank*	known larval host plant(s) living in or near Unionville Barrens (see Table B-1 index, p. 126, for common names)
BUTTERFLIES & SKIPPERS (Lepidoptera, in part)				
Amblyscirtes vialis	roadside skipper	G5	S2 (4)	*Agrostis, Poa*
Anthocharis midea	falcate orangetip	G4G5	S3 (2)	Brassicaceae, especially *Arabis, Cardamine*
Atrytonopsis hianna	dusted skipper	G4G5	S2 (2)	*Schizachyrium scoparium, Andropogon gerardii*
Callophrys gryneus	juniper hairstreak	G5	S3 (4)	*Juniperus virginiana*
Erynnis martialis	mottled duskywing	G3	SH (1)	*Ceanothus americanus*
Erynnis persius persius	persius duskywing	G5 T1T3	S1S2	*Baptisia tinctoria*
Hesperia leonardus	Leonard's skipper	G4	S3 (2)	*Schizachyrium scoparium, Bouteloua, Agrostis*
Hesperia metea	cobweb skipper	G4G5	S2 (2)	*Schizachyrium scoparium, Andropogon*
Hesperia sassacus	Indian skipper	G5	S3S4	Poaceae
Nastra lherminier	swarthy skipper	G5	S2S3	*Schizachyrium scoparium*
MOTHS (Lepidoptera, in part)				
Anisota stigma	spiny oakworm moth	G5	S1S2 (4)	*Quercus*
Apodrepanulatrix liberaria	a geometer moth	G4	S1S3 (2)	*Ceanothus americanus*
Artace cribraria	dot-lined white moth	G5	S1 (4)	*Quercus* (*Prunus*? *Rosa*?)
Caripeta aretaria	southern pine looper moth	G4	S1S2 (2)	unknown
Catocala sp. 1 nr. *jair*	pine woods underwing	G5	S1 (4)	unknown
Catocala umbrosa	an underwing moth	G5	S1 (4)	unknown
Celastrina ladon lucia	northern spring azure	G5	S3S4	*Ceanothus americanus*
Cisthene packardii	Packard's lichen moth	G5	S1S3 (4)	lichens
Cisthene plumbea	lead-colored lichen moth	G5	S1 (4)	lichens
Citheronia regalis	regal moth	G4G5	SU	*Carya, Juglans, Rhus*

* G and S rarity ranks and conservation tier from *Pennsylvania's Comprehensive Wildlife Management Strategy: Invertebrates* (numerals in parentheses) are explained in Appendix A (pp. 109–110).

species	common name	global rank*	state rank*	known larval host plant(s) living in or near Unionville Barrens (see Table B-1 index, p. 126, for common names)
Crambidia pura	pure lichen moth	G4	SU (4)	unknown
Cyclophora nanaria	a geometrid moth	G5	S1S2 (4)	unknown
Elaphria cornutinis	a noctuid moth	G5	SU (4)	unknown
Erastria coloraria	broad-lined erastria moth	G3G4	S1 (2)	*Ceanothus americanus*
Hemileuca maia	barrens buckmoth	G5	S1S2 (4)	*Quercus*, especially *Q. ilicifolia*
Holomelina laeta	joyful holomelina moth	G4	S1S2 (2)	unknown
Hypagyrtis esther	esther moth	G5	S2S3 (4)	unknown
Idaea eremiata	a geometrid moth	G4	S1 (2)	*Quercus*
Idaea violacearia	a wave moth	G4	S1 (2)	unknown
Lagoa crispata	black-waved flannel moth	G5	S1 (4)	*Malus, Rubus, Myrica, Quercus, Populus, Prunus, Sassafras*
Macrochilo hypocritalis	an owlet moth	G4	SU (4)	unknown (*Carex*?)
Metaxaglaea semitaria	footpath sallow moth	G5	S2 (4)	*Vaccinium corymbosum* (*V. pallidum*?)
Papaipema marginidens	a borer moth	G4	SU (4)	unknown
Papaipema pterisii	bracken borer	G5	S3	*Pteridium aquilinum*
Parahypenodes quadralis	a noctuid moth	G4	SU (4)	dead leaves
Renia sp. 1 nr. *discoloralis*	a noctuid moth	G4	S1? (2)	unknown
Richia acclivis	a noctuid moth	G4G5	S1S2 (2)	unknown
Sutyna privata teltowa	a noctuid moth	G5T4	S1 (2)	(*Smilax*?)
Tolype notialis	tolype moth	G4G5	S1 (2)	conifers
Xestia elimata	southern variable dart moth	G5	S2S3 (4)	unknown
Xylotype capax	broad sallow moth	G4	S3 (2)	*Vaccinium corymbosum* (*Prunus*? *Malus*? *Quercus rubra*?)
Zanclognatha martha	pine barrens zanclognatha	G4	S1S2 (2)	unknown, probably plant detritus

* G and S rarity ranks and conservation tier from *Pennsylvania's Comprehensive Wildlife Management Strategy: Invertebrates* (numerals in parentheses) are explained in Appendix A (pp. 109–110).

(Table continues on next page,)

species	common name	global rank*	state rank*	known larval host plant(s) living in or near Unionville Barrens (see Table B-1 index, p. 126, for common names)
BEETLES (Coleoptera)				
Diabrotica cristata	prairie leaf beetle	G4G5?†	S1?†	roots of *Andropogon gerardii, Schizachyrium scoparium,* other Poaceae
TRUE BUGS (Hemiptera)				
Polymerus tinctipes	a plant bug	G3?†	S1?†	*Phlox subulata*
Trialeurodes phlogis	a whitefly	G2G3?†	S1?†	*Phlox subulata*

* G and S rarity ranks and conservation tier from *Pennsylvania's Comprehensive Wildlife Management Strategy: Invertebrates* (numerals in parentheses) are explained in Appendix A (pp. 109–110).

† Not yet ranked by NatureServe or the Pennsylvania Natural Heritage Program; ranks shown here are tentative approximations by R. Latham.

Appendix D. Notes on Design of Adaptive Management Trials

The key operational differences between adaptive management and scientifically rigorous research involve the thoroughness of replication, the degree of experimental control, and the strength of standards of evidence.

D.1 Replication

Replication is vital to interpreting the results of both controlled experiments and adaptive management, but adaptive management typically involves fewer replicates. In the context of testing management methods in a nature preserve, replicates are multiple geographically defined, environmentally similar areas in which a particular kind of management activity is applied (or areas left unmanaged to serve as controls; see *Experimental control*, pp. 151–152). These areas are often called trial plots (and control plots).

It is worth going into detail on two points to clear up common misconceptions about replication: (1) *multiple monitoring areas within trial plots are not replicates*; and (2) *different treatments have to be intermixed on the landscape for trial plots of a particular management method (or control plots) to be true replicates*.

The areas on the landscape where monitoring is done are typically much smaller than trial plots. They usually consist either of survey plots or quadrats (squares, rectangles or circles in which something is counted, measured or estimated) or transects (lines along which something is counted, measured or estimated). Quadrats and transects are not replicates, unless there is only one quadrat or transect per management trial plot (which usually would be inadequate to reflect the responses of indicators across an entire trial plot). The data from all of the quadrats or transects within a management trial plot are averaged together and the trial plot-wide averages are the data used in analyses. Treating the data from individual quadrats or transects as replicates instead of as subsamples, a common mistake, violates fundamental assumptions underlying the logic of inductive reasoning and leads to false or misleading inferences.

True replication entails spatial interspersion of treatments, that is, replicate trial plots cannot be clumped geographically by type. If trial plots subjected to one treatment (or control plots) are clumped together on the landscape, then the plots within the clump would have to be considered as subsamples, and the entire clump of trial plots—not the individual plots within it—as a single replicate. Without interspersion of treatments the trivial effect of spatial autocorrelation (the tendency of nearby samples to be more similar than more distant samples) is confounded with, and cannot reliably be distinguished from, potentially interesting effects such as those resulting from management trials. This pitfall can be avoided by making sure that trial plots treated with different management methods, including no management (control plots), are interspersed or alternate with each other across the entire area of interest.

Replication is mandatory for both scientific experiments and adaptive management. Adhering to the rules of replication is the quickest and most effective way to separate the effects of one or more management methods from localized influences that are beyond the managers' control or beyond the power of the monitoring protocol to detect. Without at least minimal replication, the risk is high that some local peculiarity of a trial plot or control plot will cause an effect that will be misinterpreted as having been caused by the management activity, or in the case of a control plot, by its absence. In adaptive management a level of replication as low as $N = 3$ or even $N = 2$ (N is the smallest number of areas in *each category* of management trials, e.g., treatment A, treatment B or control) may show clear enough trends for inferences to be drawn, which can be used to refine or modify management methods for further testing.

D.2 Randomization

For labor- and expertise-intensive metrics such as percent cover estimates for all vascular plant species, it is not feasible to collect data over more than a small fraction of the total area. But the smaller the area measured, the less likely it is to be typical of the whole or to include a range of conditions representative of the whole. In most such cases, the best way of insuring that the areas chosen for monitoring will yield useful information is to use stratified random sampling.

In scientific research, stratified random sampling is collecting data on subjects or locations picked using a randomization procedure from a number of subpopulations or categories (as always, following the rules of replication). "Stratified" refers to the different subpopulations or categories ("strata") from which subjects or locations are chosen. Stratifying insures that roughly equal numbers of subjects or locations are picked as targets of data collection from each subpopulation or category so that valid comparisons can be made.

In the case of monitoring associated with adaptive management, stratified random sampling usually means assessing indicators at data-collecting locations, chosen using a randomization procedure within two or more predetermined categories of land. Typically those categories are different vegetation types or plots where different management methods are applied. The purpose of randomization is to prevent the results from being skewed by unintentional bias, which is likely to occur where data-collecting locations are chosen by any other means.

The steps required for stratified random sampling when the sampling unit is an area of land are best given in reference to an example. Here we outline how to set up an array of permanent quadrats for monitoring indicators of desired conditions and their responses to management in the Unionville Barrens' seven management units (M.U.s):

(1) Using GIS, a local coordinate plane is set up covering the area of interest (an individual M.U. or the entire study area). Random points are scattered across the coordinate plane by multiplying the width (along the horizontal axis) and then the height (along the vertical axis) by each number in sequence on a list of random numbers between 0 and 1 (from a published random number list or made using a pseudo-random number-generating algorithm).

(2) Within each M.U., random points are added to the map until there are at least three in each of three land types plus an additional three per acre for any area above 1 acre in each land type. This will generate a number of random points far in excess of the target number of monitoring quadrats. The land types of interest are:

- existing grassland—here abbreviated EG (yellow on Map 4)

- forest and woodland to be restored to grassland—RG (overlap between green on Map 4 and yellow on Map 10)
- forest management area—FM (untinted on Map 10)

The random points are labeled numerically within each land type within each M.U. in the sequence in which they were generated. Their GPS coordinates are recorded for investigators to use in navigating to them in the field. Any point falling within 10 m (30½ feet) of the M.U. boundary is discarded.

(3) As a further hedge against selection bias, acceptance/rejection criteria are established *in advance* to be applied when evaluating each random point in the field for suitability as a potential data-collecting location. Examples:

- Each monitoring quadrat in EG must have at least 20% cover but no more than 80% cover of gravel forb community within the serpentine grassland matrix.
- Any point in EG falling in an area directly beneath a large tree is rejected.
- Any point in FM falling in an area severely disturbed by past mining or earthmoving is rejected.

(4) The number of monitoring quadrats to be placed within each land type within each M.U. is decided in advance and made roughly proportional to the available acreage; for example:

- M.U. 2—two in EG, two in RG and two in FM
- M.U. 3—one in EG, two in RG and two in FM
- M.U. 6—three in EG, three in RG and one in FM

(5) Within each land type within each M.U., random points are evaluated in the field in the numerical sequence in which they were generated. This is another safeguard against selection bias; the tendency otherwise would be to evaluate those nearest the point of access first.

(6) Random points that fulfill all acceptance/rejection criteria when examined in the field are accepted until the target number for each land type is reached. Quadrat markers and identification tags are installed.

D.3 Experimental control

Experimental control is separating the effects of the treatment or treatments under investigation from the effects of everything else. It is achieved in three basic ways; often a mixture of two or all three is used in the same trial or experiment.

(1) *Compare indicator responses between managed trial plots and unmanaged areas*. The unmanaged areas are called control plots or simply controls. Comparing data gathered using identical monitoring protocols in both kinds of plots is the way to rate the effectiveness of a management method, or to determine whether it makes a significant difference at all, by actually measuring how much difference it makes instead of relying on subjective impressions. In many cases the use of control plots is unnecessary or inappropriate, for example in the autumn-olive removal trials described on pp. 74–76.

(2) *Physically regulate or geographically exclude factors that vary across the landscape and are not part of the hypothesis being tested, if they are likely to affect ecosystem and indicator response*. This is accomplished by manipulating the extraneous variables directly to make them as consistent as possible among all trial areas (for instance, by thinning trees to a

consistent density in all plots), or by choosing trial areas that are already similar to each other, or both. Matching site conditions as fully as possible among all trial plots (and control plots, if they are used) is a robust way to distinguish treatment effects from other effects, but it is not feasible in every landscape. Where landscape variability is high, extraneous effects can be controlled for by setting up trial plots and control plots in adjacent pairs, with each pair within a relatively uniform area of the landscape even though differing from the other pairs. Meaningful comparisons are made within each treatment-control pair. Site-wide trends may or may not emerge, but comparison among plot pairs in different environments may lead to new insights about how those environmental differences interact with the treatment(s) undergoing trial to produce different effects on the indicators.

(3) *Employ both positive and negative controls*. An example is examining the effects of invasive plants on a forest ecosystem while recognizing that they depend partly on the intensity of deer browsing. In this case the best approach is to compare indicator responses in trial plots where invasive species are removed with those in unmanaged plots (negative controls), and within both types of plots comparing inside and outside fenced deer exclosures (positive controls). For some management questions, this two-tiered control approach is among the most powerful methods of producing useful information in the shortest practical amount of time.

Physically controlling variables that are not part of the hypothesis being tested is often costly in funds, time and labor, and choosing sites for management trials that are nearly alike in those extraneous variables is not always a luxury that managers have available. Adaptive management, in contrast with scientific research, does not necessarily make such stringent demands. Some adaptive management projects have been carried out without any experimental control. Although highly suspect—there is a much greater hazard of misinterpreting the results—trends inferred from uncontrolled trials may be used to refine or modify management methods, which can then be tested further. However, adhering to control procedures as strictly as resources will allow can pay off in long-term time and cost savings. The better the control, the higher the chances will be of accurately learning how well management methods perform and the lower the risk will be of mistakenly crediting (or blaming) a management method for effects that actually result from other causes.

D.4 Standards of evidence

The standard of evidence is the acceptable level of what statisticians call the type 1 error probability. That is the likelihood of inferring that a management activity caused a particular response when it actually did not. Experimenters in ecology and wildlife biology customarily use an arbitrary cutoff of a 1 in 20 (5%) probability of such an error to decide whether the difference is significant. In other words, if the chance of inferring that a measured difference between two management methods or between management and no management is an effect of the management activity when it actually is not works out to be 5% or less, then the difference is regarded as significant (sometimes, especially in medical research, a stricter standard of 1 in 100 or 1 in 1,000 is used). If the difference is large and highly consistent, then it is likely to meet the 5% criterion even in an adaptive management trial. If the difference is subtle or muddled by things that vary from place to place and are beyond the experimenters' control, then experimental replication and control procedures need to be more stringent to detect it. In adaptive management a lower standard of evidence can be accepted because adaptive management is inherently a long-term process—management is open-ended, unlike most scientific research projects—and information gained in this way is tested further in years-long cycles of assessing and modifying management methods and continuing to collect and analyze comparative monitoring data.

In adaptive management, monitoring data may be analyzed statistically if they meet the assumptions of statistical methods or, more often, they are evaluated qualitatively, for example, by examining graphs. In either case, results of each monitoring cycle are used as the basis for evaluating the effectiveness of alternative management methods in achieving and sustaining desired conditions. The methods are subject to updating based on the results revealed by monitoring. Modifications or entirely new methods might be proposed based on what is learned by analyzing monitoring data.

Standards of evidence are an important consideration in how well monitoring data perform as a basis for updating management methods. The higher the standard that is met—by judicious design of management trials (including replication, randomization and experimental control) and choice of indicators—the more confident managers can be that interpreting monitoring data will lead to wise management decisions.

Appendix E. Online Information Sources for Major Invasive Species in the Unionville Barrens

ailanthus (*Ailanthus altissima*)

Hoshovsky, M. C. 1988. Element stewardship abstract for *Ailanthus altissima*, tree-of-heaven. The Nature Conservancy, Arlington, Virginia. 13 pp. (http://www.invasive.org/weedcd/pdfs/tncweeds/ailaalt.pdf)

Swearingen, J. M. and P. D. Pannill. 2009. Fact sheet: Tree of heaven. Alien Plant Working Group, Plant Conservation Alliance, Bureau of Land Management, Washington, D.C. 5 pp. (http://www.nps.gov/plants/alien/fact/aial1.htm)

Fryer, J. L. 2010. *Ailanthus altissima*. Fire Effects Information System [online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, Montana. (http://www.fs.fed.us/database/feis/plants/tree/ailalt/all.html)

garlic mustard (*Alliaria petiolata*)

Nuzzo, V. 2000. Element stewardship abstract for *Alliaria petiolata (Alliaria officinalis)*, garlic mustard. The Nature Conservancy, Arlington, Virginia. 19 pp. (http://www.invasive.org/weedcd/pdfs/tncweeds/allipet.pdf)

Rowe, P. and J. M. Swearingen. 2005. Fact sheet: garlic mustard. Alien Plant Working Group, Plant Conservation Alliance, Bureau of Land Management, Washington, D.C. 3 pp. (http://www.nps.gov/plants/alien/fact/alpe1.htm)

Munger, G. T. 2001. *Alliaria petiolata*. Fire Effects Information System [online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, Montana. (http://www.fs.fed.us/database/feis/plants/forb/allpet/all.html)

Japanese barberry (*Berberis thunbergii*)

Swearingen, J. M. 2005. Fact sheet: Japanese barberry. Alien Plant Working Group, Plant Conservation Alliance, Bureau of Land Management, Washington, D.C. 3 pp. (http://www.nps.gov/plants/alien/fact/beth1.htm)

Zouhar, K. 2008. *Berberis thunbergii*. Fire Effects Information System [online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, Montana. (http://www.fs.fed.us/database/feis/plants/shrub/berthu/all.html)

Oriental bittersweet (*Celastrus orbiculatus*)

Dreyer, G. D. 1994. Element stewardship abstract for *Celastrus orbiculatus*, Asiatic bittersweet. The Nature Conservancy, Arlington, Virginia. 12 pp. (http://www.invasive.org/weedcd/pdfs/tncweeds/celaorb.pdf)

Swearingen, J. M. 2006. Fact sheet: Oriental bittersweet. Alien Plant Working Group, Plant Conservation Alliance, Bureau of Land Management, Washington, D.C. 4 pp. (http://www.nps.gov/plants/alien/fact/ceor1.htm)

Fryer, J. L. 2011. *Celastrus orbiculatus*. Fire Effects Information System [online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, Montana. (http://www.fs.fed.us/database/feis/plants/vine/celorb/all.html)

Canada thistle (*Cirsium arvense*)

Nuzzo, V. 1997. Element stewardship abstract for *Cirsium arvense*, Canada thistle, creeping thistle, Californian thistle. The Nature Conservancy, Arlington, Virginia. 32 pp. (http://www.invasive.org/weedcd/pdfs/tncweeds/cirsarv.pdf)

Thunhorst, G. and J. M. Swearingen. 2005. Fact sheet: Canada thistle. Alien Plant Working Group, Plant Conservation Alliance, Bureau of Land Management, Washington, D.C. 3 pp. (http://www.nps.gov/plants/alien/fact/ciar1.htm)

Zouhar, K. 2001. *Cirsium arvense*. Fire Effects Information System [online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, Montana. (http://www.fs.fed.us/database/feis/plants/forb/cirarv/all.html)

autumn-olive (*Elaeagnus umbellata*)

Sather, N. and N. Eckardt. 1987. Element stewardship abstract for *Elaeagnus umbellata*. The Nature Conservancy, Arlington, Virginia. 4 pp. (http://www.invasive.org/weedcd/pdfs/tncweeds/elaeumb.pdf)

Munger, G. T. 2003. *Elaeagnus umbellata*. Fire Effects Information System [online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, Montana. (http://www.fs.fed.us/database/feis/plants/shrub/elaumb/all.htm)

winged euonymus (*Euonymus alatus*)

Martin, T. 2000. Weed alert! *Euonymus alatus* (Thunb.) Siebold (burning bush, winged euonymus, winged wahoo, winged spindle-tree, Japanese spindle-tree). Center for Invasive Species and Ecosystem Health. (http://www.invasive.org/gist/alert/alrteuon.html)

Fryer, J. L. 2009. *Euonymus alatus*. Fire Effects Information System [online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, Montana. (http://www.fs.fed.us/database/feis/plants/shrub/euoala/all.html)

Japanese honeysuckle (*Lonicera japonica*)

Nuzzo, V. 1997. Element stewardship abstract for *Lonicera japonica*, Japanese honeysuckle. The Nature Conservancy, Arlington, Virginia. 22 pp. (http://www.invasive.org/weedcd/pdfs/tncweeds/lonijap.pdf)

Bravo, M. A. 2005. Fact sheet: Japanese honeysuckle. Alien Plant Working Group, Plant Conservation Alliance, Bureau of Land Management, Washington, D.C. 3 pp. (http://www.nps.gov/plants/alien/fact/loja1.htm)

Munger, G. T. 2002. *Lonicera japonica*. Fire Effects Information System [online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, Montana. (http://www.fs.fed.us/database/feis/plants/shrub/lonjap/all.html)

Amur honeysuckle (*Lonicera maackii*) and other nonnative bush honeysuckles

Batcher, M. S. and S. A. Stiles. 2000. Element stewardship abstract for *Lonicera maackii* (Rupr.) Maxim (Amur honeysuckle), *Lonicera morrowii* A. Gray (Morrow's honeysuckle), *Lonicera tatarica* L. (Tatarian honeysuckle), *Lonicera* × *bella* Zabel (Bell's honeysuckle), the bush honeysuckles. The Nature Conservancy, Arlington, Virginia. 12 pp. (http://www.invasive.org/weedcd/pdfs/tncweeds/loni_sp.pdf)

Williams, C. E. 2005. Fact sheet: exotic bush honeysuckles. Alien Plant Working Group, Plant Conservation Alliance, Bureau of Land Management, Washington, D.C. 3 pp. (http://www.nps.gov/plants/alien/fact/loni1.htm)

Munger, G. T. 2005. *Lonicera* spp. Fire Effects Information System [online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, Montana. (http://www.fs.fed.us/database/feis/plants/shrub/lonspp/all.html)

stiltgrass (*Microstegium vimineum*)

Tu, M. 2000. Element stewardship abstract for *Microstegium vimineum*, Japanese stilt grass, Nepalese browntop, Chinese packing grass. The Nature Conservancy, Arlington, Virginia. 8 pp. (http://www.invasive.org/weedcd/pdfs/tncweeds/micrvim.pdf)

Swearingen, J. M. and A. Sheherezade. 2008. Fact sheet: Japanese stiltgrass. Alien Plant Working Group, Plant Conservation Alliance, Bureau of Land Management, Washington, D.C. 4 pp. (http://www.nps.gov/plants/alien/fact/mivi1.htm)

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. (http://www.fs.fed.us/database/feis/plants/graminoid/micvim/all.html)

mile-a-minute (*Persicaria perfoliata;* syn. *Polygonum perfoliatum*)

Gerlach, J. A., J. Hough-Goldstein and J. Swearingen. 2010. Fact sheet: mile-a-minute weed. Alien Plant Working Group, Plant Conservation Alliance, Bureau of Land Management, Washington, D.C. 4 pp. (http://www.nps.gov/plants/alien/fact/pepe1.htm)

Stone, K. R. 2010. *Polygonum perfoliatum*. Fire Effects Information System [online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, Montana. (http://www.fs.fed.us/database/feis/plants/vine/polpef/all.html)

lesser celandine (*Ranunculus ficaria;* syn. *Ficaria verna*)

Swearingen, J. M. 2010. Fact sheet: Fig buttercup. Alien Plant Working Group, Plant Conservation Alliance, Bureau of Land Management, Washington, D.C. 3 pp. (http://www.nps.gov/plants/alien/fact/rafi1.htm)

black locust (*Robinia pseudoacacia*)

Converse, C. K. 1984. Element stewardship abstract for *Robinia pseudoacacia*, black locust. The Nature Conservancy, Arlington, Virginia. 14 pp. (http://www.invasive.org/weedcd/pdfs/tncweeds/robipse.pdf)

Wieseler, S. 2005. Fact sheet: black locust. Alien Plant Working Group, Plant Conservation Alliance, Bureau of Land Management, Washington, D.C. 3 pp. (http://www.nps.gov/plants/alien/fact/rops1.htm)

Stone, K. R. 2009. *Robinia pseudoacacia*. Fire Effects Information System [online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, Montana. (http://www.fs.fed.us/database/feis/plants/tree/robpse/all.html)

multiflora rose (*Rosa multiflora*)

Eckardt, N. 1987. Element stewardship abstract for *Rosa multiflora*, rambler rose, multiflowered rose. The Nature Conservancy, Arlington, Virginia. 8 pp. (http://www.invasive.org/weedcd/pdfs/tncweeds/rosamul.pdf)

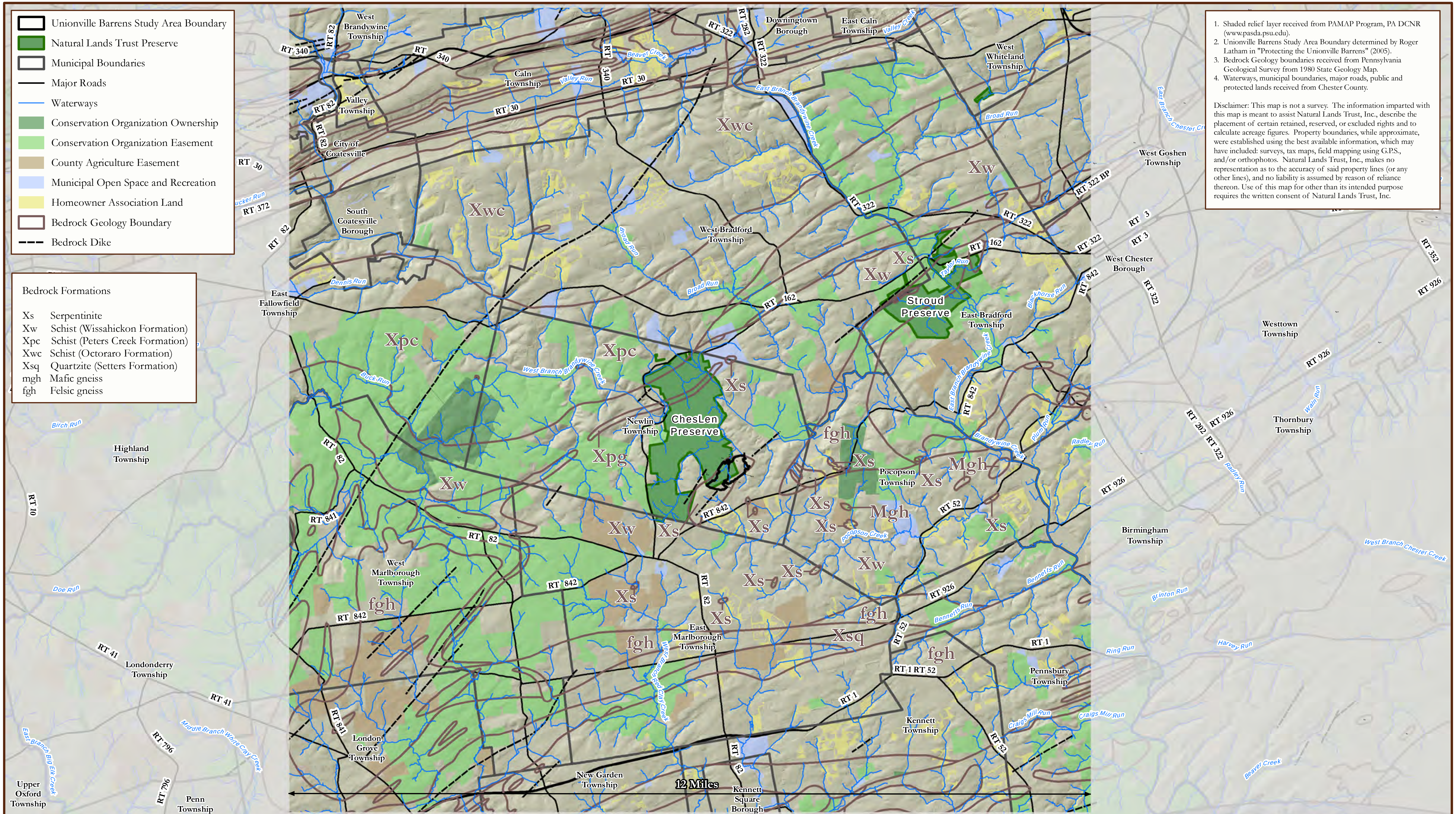
Bergmann, C. and J. M. Swearingen. 2005. Fact sheet: multiflora rose. Alien Plant Working Group, Plant Conservation Alliance, Bureau of Land Management, Washington, D.C. 3 pp. (http://www.nps.gov/plants/alien/fact/romu1.htm)

Munger, G. T. 2002. *Rosa multiflora*. Fire Effects Information System [online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, Montana. (http://www.fs.fed.us/database/feis/plants/shrub/rosmul/all.html)

wineberry (*Rubus phoenicolasius*)

Spencer, N. R. 2005. Fact sheet: wineberry. Alien Plant Working Group, Plant Conservation Alliance, Bureau of Land Management, Washington, D.C. 2 pp. (http://www.nps.gov/plants/alien/fact/ruph1.htm)

Innes, R. 2009. *Rubus phoenicolasius*. Fire Effects Information System [online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, Montana. (http://www.fs.fed.us/database/feis/plants/shrub/rubpho/all.html)



Map 1. Landscape context

UNIONVILLE BARRENS STUDY

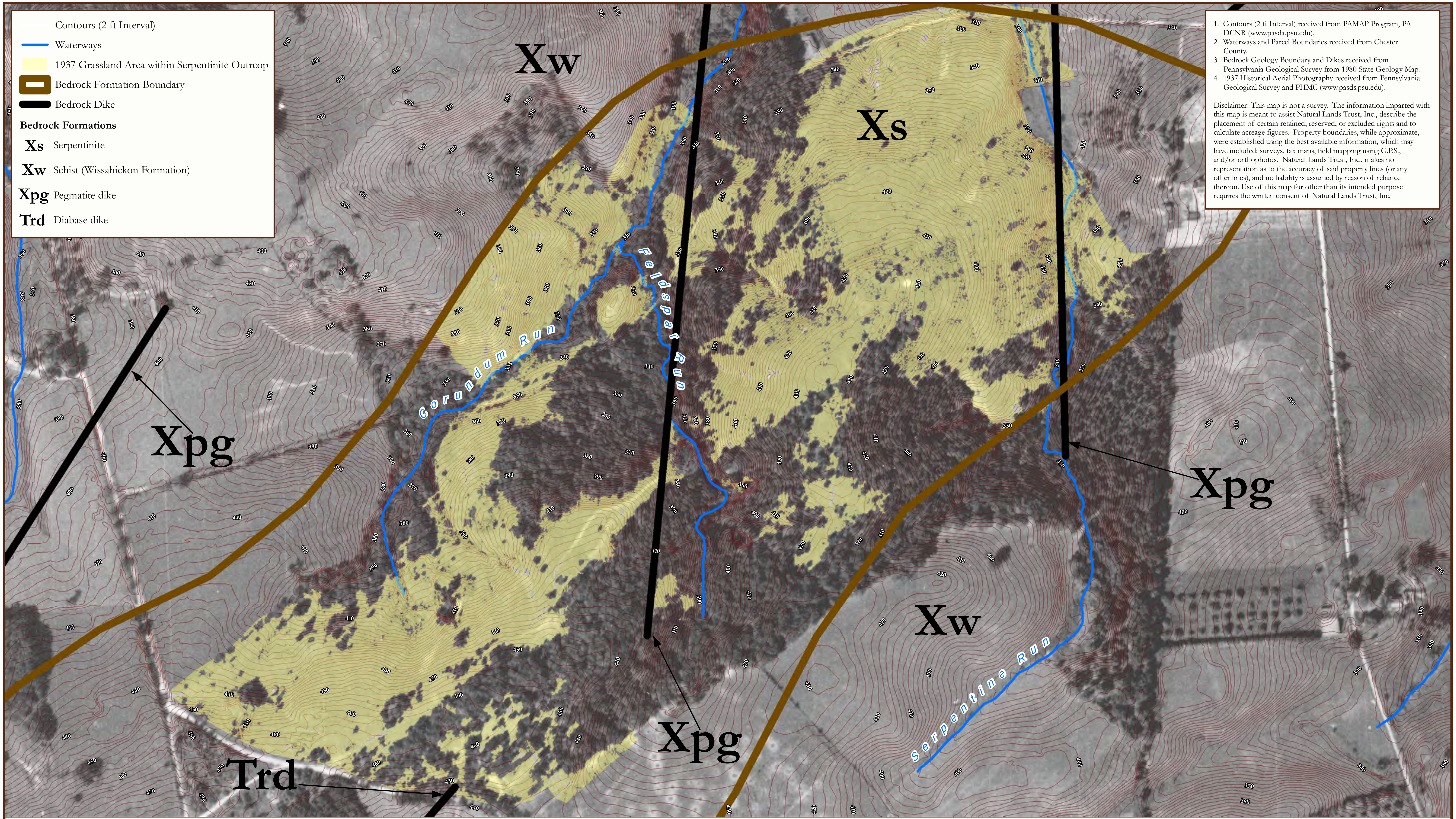
Newlin Township, Chester County, Pennsylvania

Natural Lands Trust
1031 Palmers Mill Road, Media, PA 19063
610-353-5587 ~ www.natlands.org

N

0 2 4 Miles

Compiled By: MTM 12/19/11



Natural Lands Trust
1031 Palmers Mill Road, Media, PA 19063
610-353-5587 ~ www.natlands.org

Map 2. Serpentine grasslands, 1937

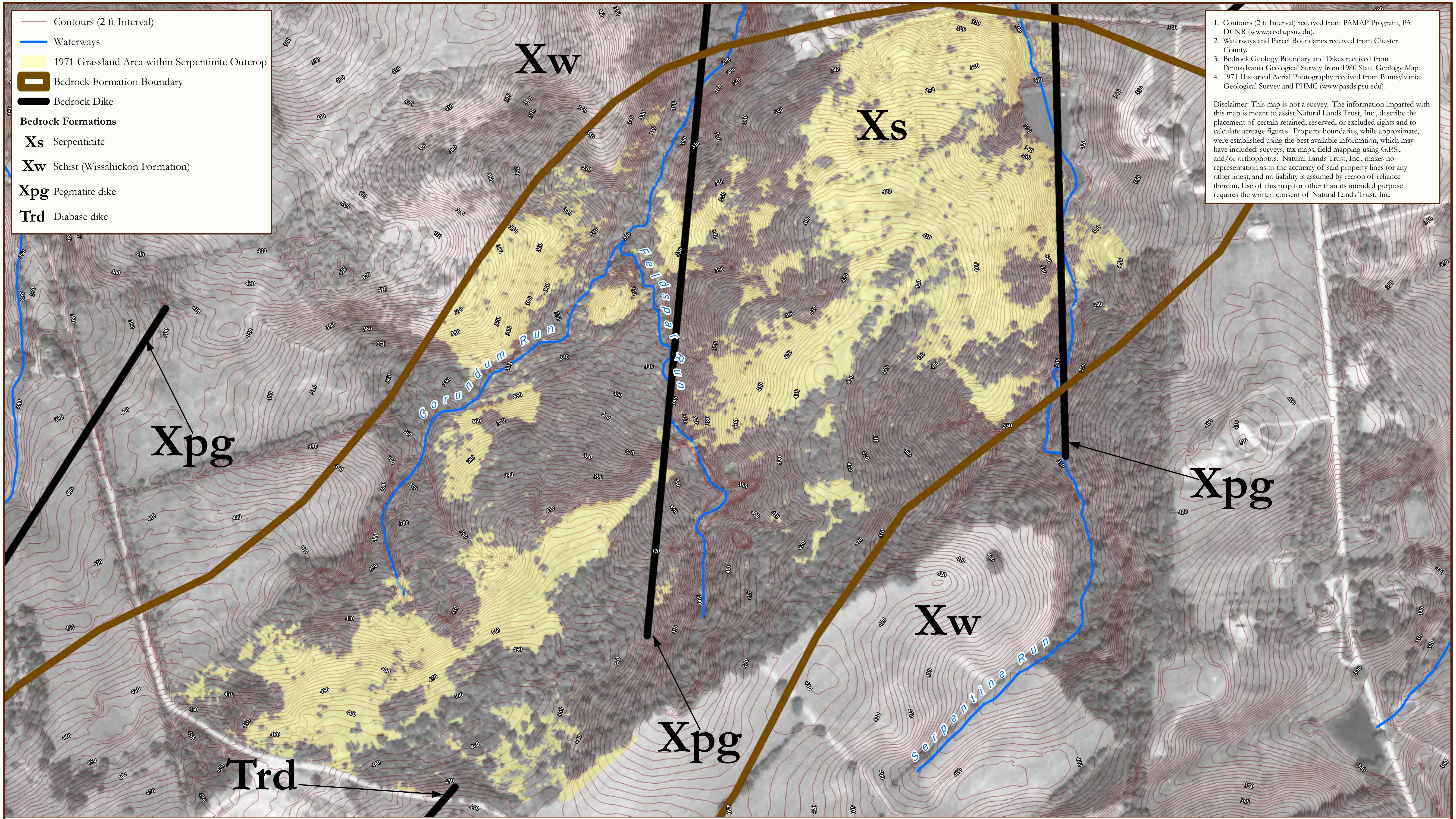
UNIONVILLE BARRENS STUDY

Newlin Township, Chester County, Pennsylvania

N

Feet
0 150 300

Compiled By: MTM 12/16/11



Map 3. Serpentine grasslands, 1971

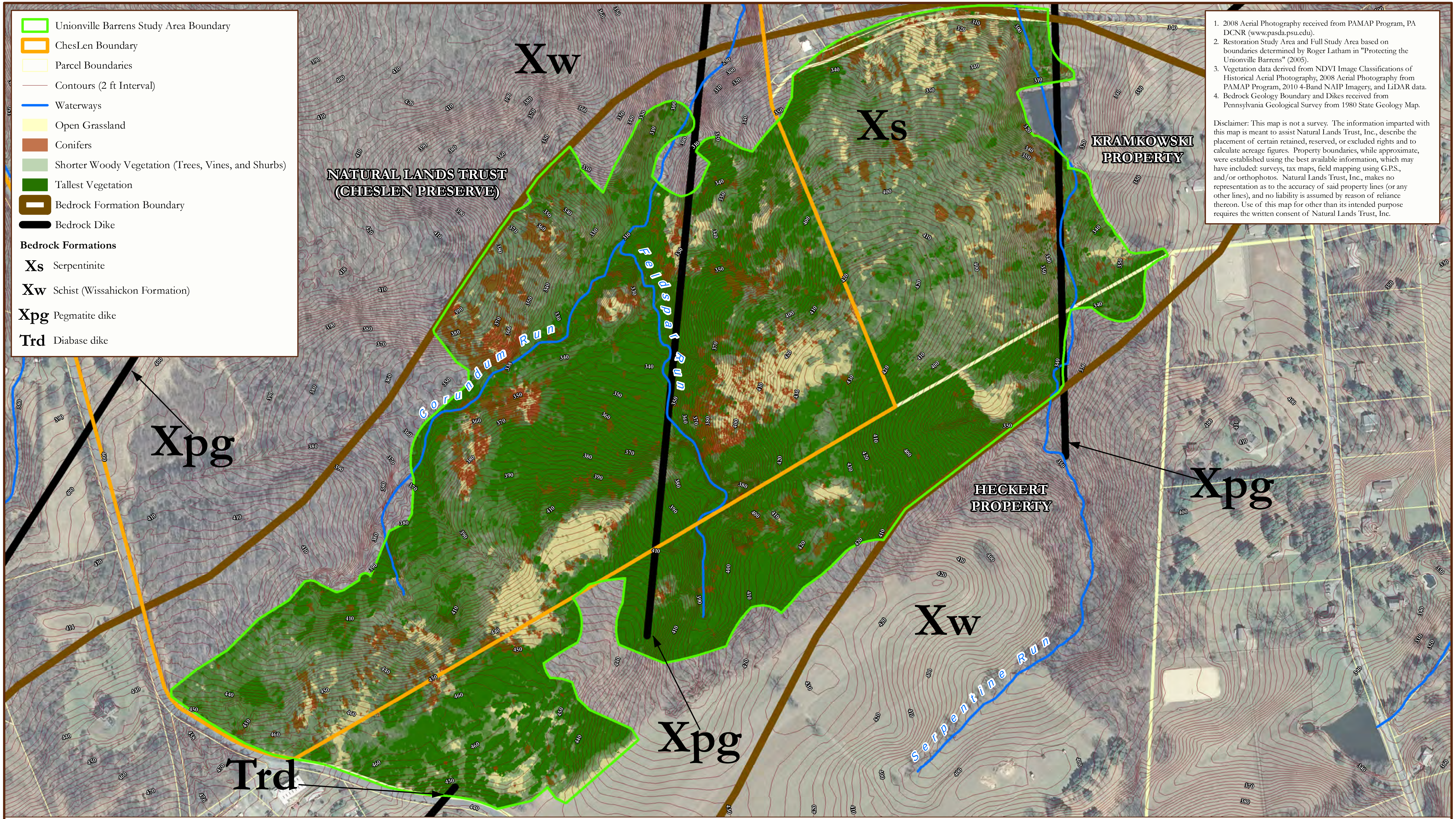
UNIONVILLE BARRENS STUDY

Newlin Township, Chester County, Pennsylvania

Natural Lands Trust
1031 Palmers Mill Road, Media, PA 19063
610-353-5587 ~ www.natlands.org

0 150 300 Feet

Compiled By: MTM 12/16/11



Map 4. Vegetation structure, 2008

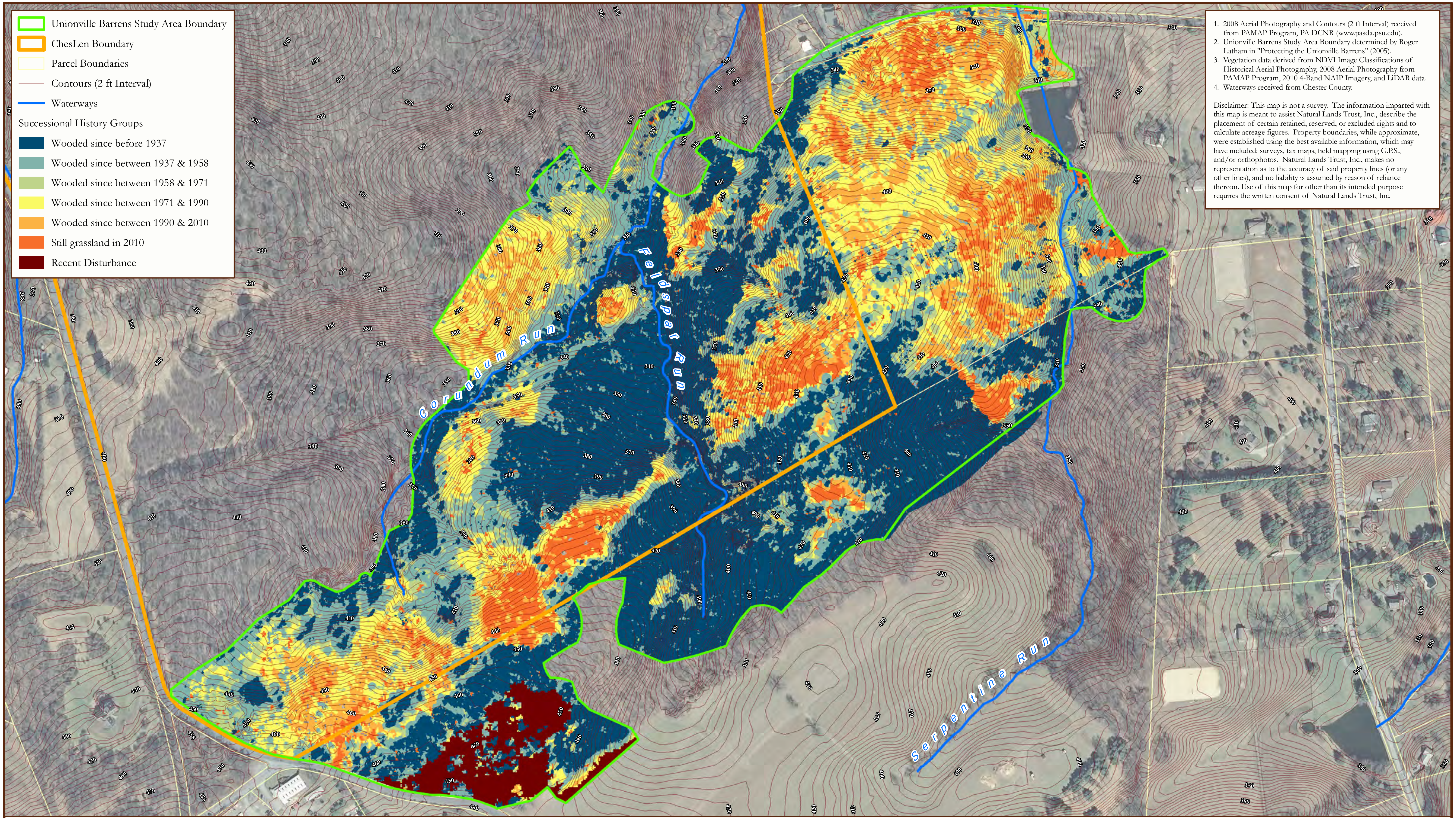
UNIONVILLE BARRENS STUDY

Newlin Township, Chester County, Pennsylvania

Natural Lands Trust
1031 Palmers Mill Road, Media, PA 19063
610-353-5587 ~ www.natlands.org

Feet 0 150 300

Compiled By: MTM 12/16/11



Natural Lands Trust
1031 Palmers Mill Road, Media, PA 19063
610-353-5587 ~ www.natlands.org

Map 5. Grassland succession history, 1937-2010

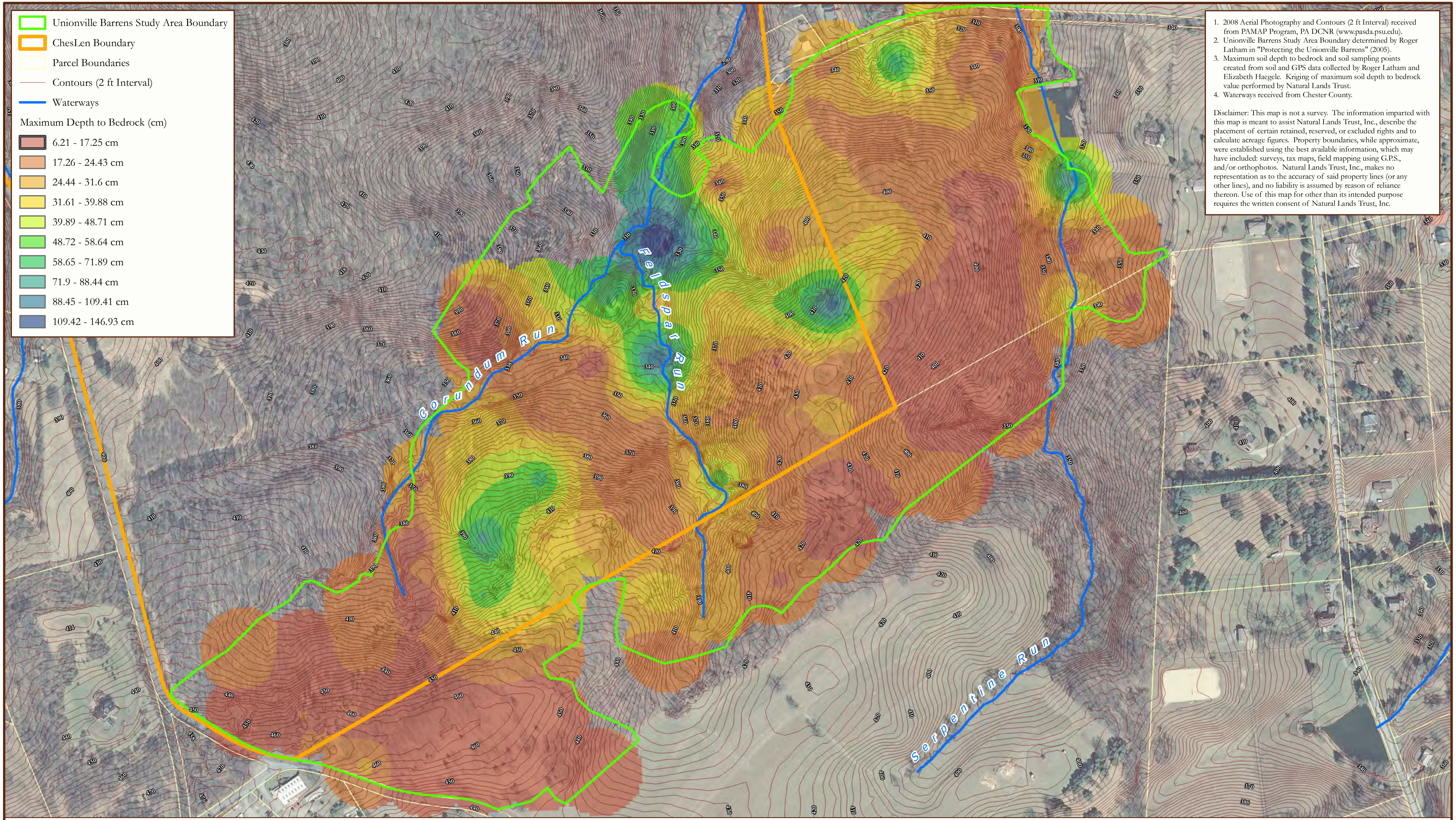
UNIONVILLE BARRENS STUDY

Newlin Township, Chester County, Pennsylvania

N

0 300 Feet

Compiled By: MTM 12/19/11



Natural Lands Trust
1031 Palmers Mill Road, Media, PA 19063
610-353-5587 ~ www.natlands.org

Map 6. Estimated soil depth to bedrock

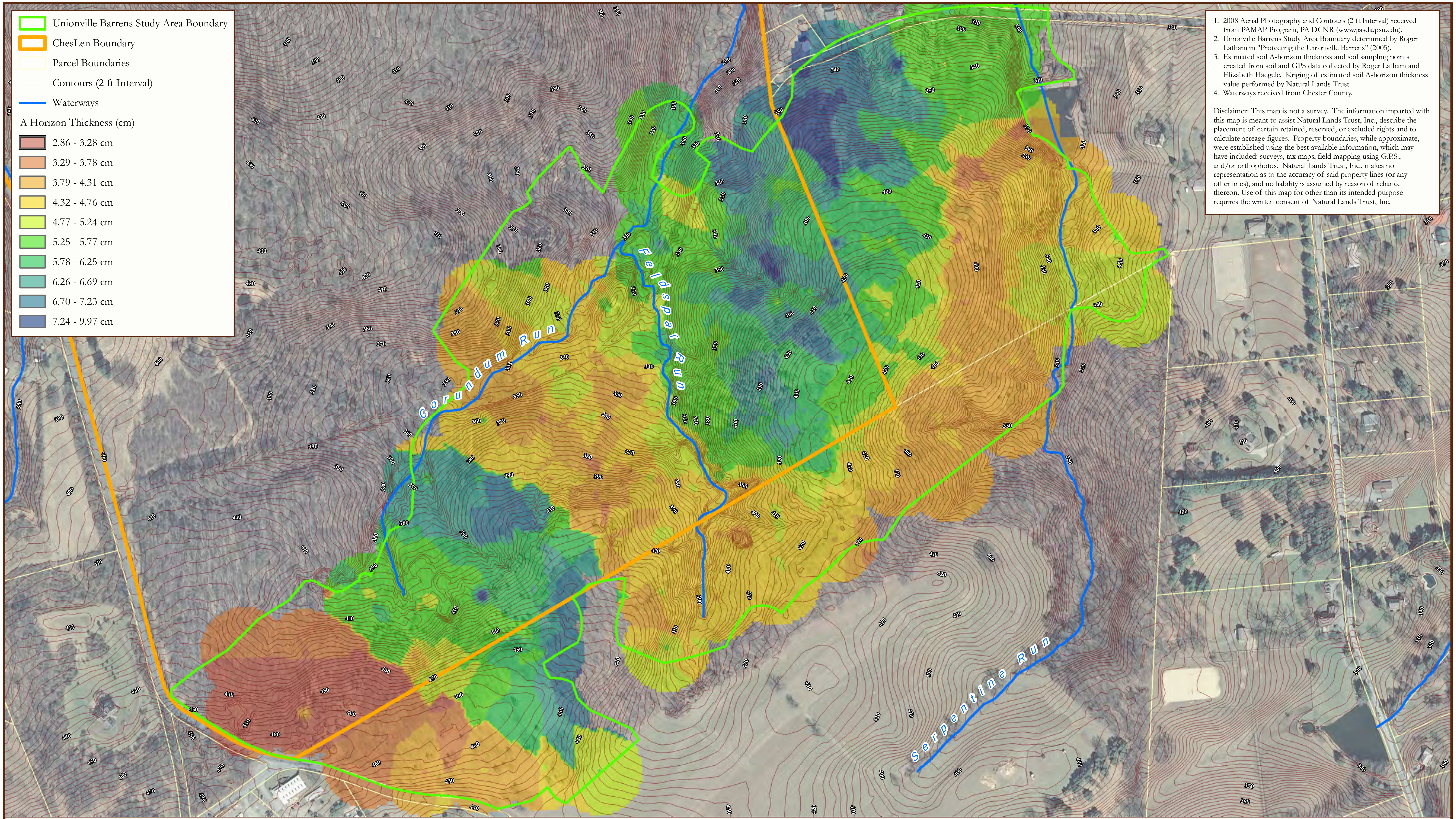
UNIONVILLE BARRENS STUDY

Newlin Township, Chester County, Pennsylvania

N

Feet
0 300

Compiled By: MTM 12/19/11



Map 7. Estimated soil A-horizon thickness

UNIONVILLE BARRENS STUDY

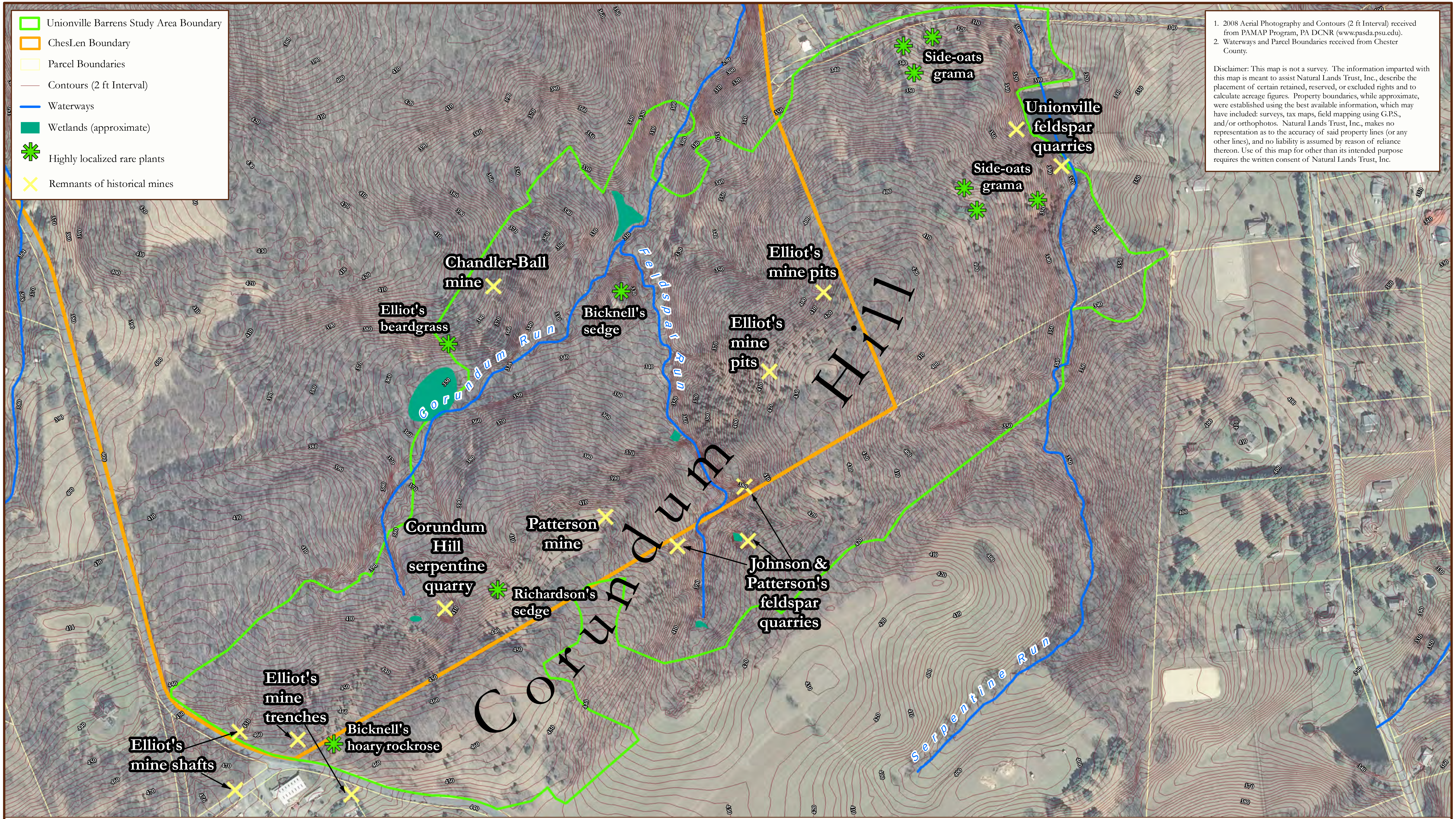
Newlin Township, Chester County, Pennsylvania

Natural Lands Trust
1031 Palmers Mill Road, Media, PA 19063
610-353-5587 ~ www.natlands.org

N

Feet
0 300

Compiled By: MTM 12/19/11



Map 8. Features of special conservation concern or historical significance

UNIONVILLE BARRENS STUDY

Newlin Township, Chester County, Pennsylvania

Natural Lands Trust
1031 Palmers Mill Road, Media, PA 19063
610-353-5587 ~ www.natlands.org

Natural Lands Trust
1031 Palmers Mill Road, Media, PA 19063
610-353-5587 ~ www.natlands.org

Map 9. Existing and potential trails, vehicular access and firebreaks

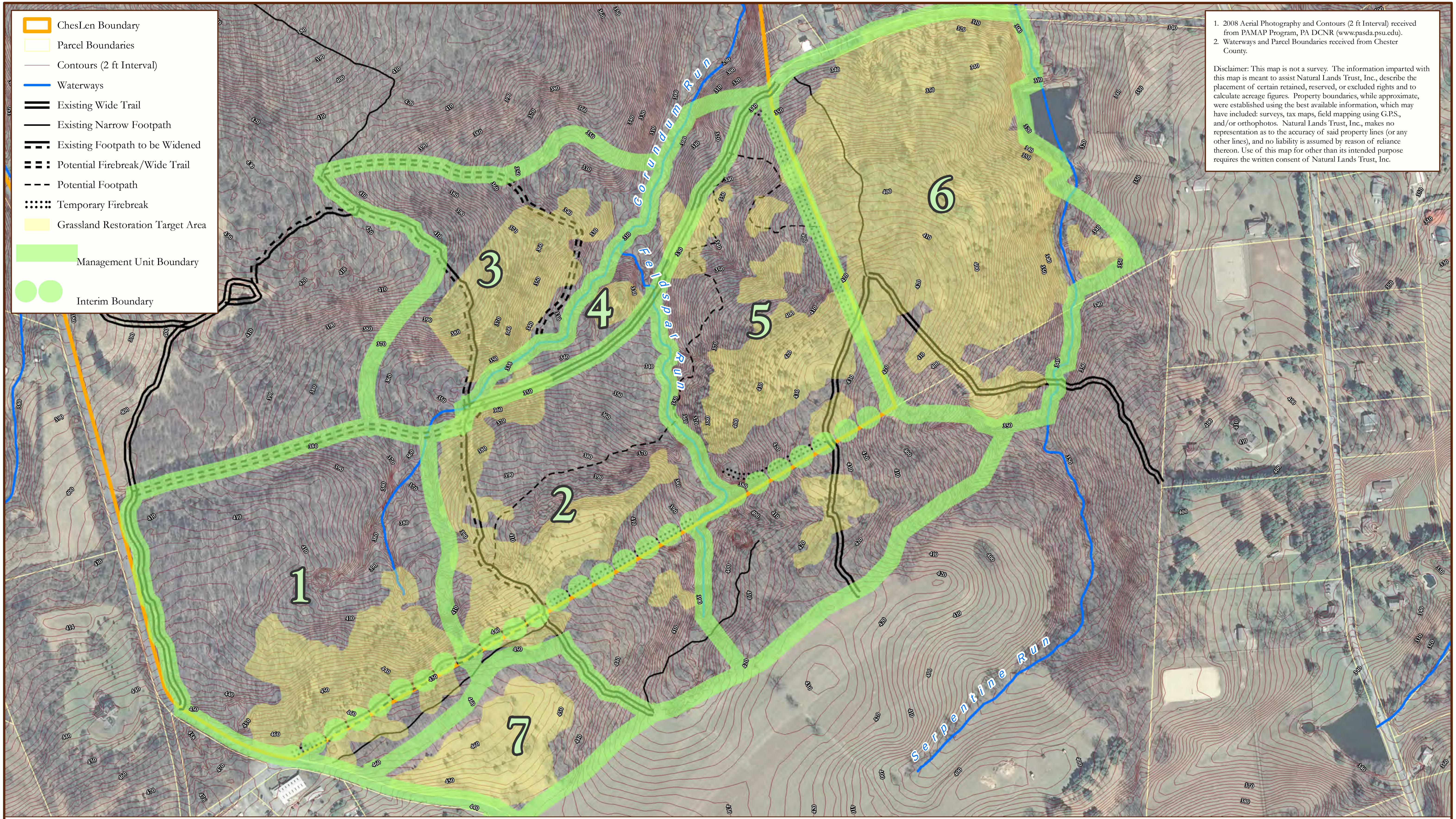
UNIONVILLE BARRENS STUDY

Newlin Township, Chester County, Pennsylvania

N

Feet
0 300

Compiled By: MTM 12/19/11



Map 10. Serpentine barrens restoration and management units

UNIONVILLE BARRENS STUDY

Newlin Township, Chester County, Pennsylvania

Natural Lands Trust
1031 Palmers Mill Road, Media, PA 19063
610-353-5587 ~ www.natlands.org

Compiled By: MTM 12/19/11