DISTRIBUTION OF RARE PLANTS ON THE CENTRAL PLAIN OF MARTHA'S VINEYARD: IMPLICATIONS FOR CONSERVATION AND MANAGEMENT

A Thesis Presented
By
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ABSTRACT

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Rare plants in coastal New England sandplains are often restricted to sites disturbed by humans. On the central plain of Martha’s Vineyard, which has one of the highest concentrations of rare plant species in Massachusetts, disturbances include plowed and mowed firelanes. Little is known about pre-European rare plant habitat or how modern management impacts these species. To better understand the factors influencing the distribution of rare plants in coastal habitats, I examined the influence of vegetation structure, species composition, environmental characteristics and disturbance history on existing rare plant populations and potential natural habitat in the 2100-ha Manuel F. Correllus State Forest. This was accomplished by sampling more than 100, 100-m^2 plots in firelanes (including 22 at rare plant occurrences) and forested/shrubland areas. I also conducted extensive searches for rare species.

Rare species almost never occur in forests and shrublands undisturbed for decades. Grassland species do, however, occur in openings in these habitats (particularly scrub oak stands) with significantly lower duff depth and higher lichen cover than randomly located plots. Scrub oak stands maintained by fire and topographically controlled microclimatic disturbances may have supported rare plants in the past. Future research could investigate whether disturbances, with presumed pre-colonial analogs, can create rare plant habitat.

Firelanes support rare plants which, with the exception of *Scleria pauciflora* var. *caroliniana*, are associated with lanes that differ in at least one environmental characteristic from random plots. *Aristida purpurascens* occurs with lower herb cover, *Linum intercursum* with lower duff depth, *Nabalus serpentarius* with higher litter depth/cover and lower lichen cover, and *Sisyrinchium fuscatum* with lower moss cover and higher litter depth than random firelanes. *Linum* and *Scleria* are frequent in firelanes including in recently plowed areas, whereas *Nabalus*, *Sisyrinchium*, and *Aristida* are generally more frequent and abundant in areas not plowed for many decades. The maintenance of appropriate habitat over a long period of time may mitigate biological limitations (e.g. low survival or seed set) characterizing *Nabalus*, *Sisyrinchium*, and *Aristida*. Plowing followed by repeated mowing created suitable habitat for five rare plant species on the central plain, and will presumably continue to into the foreseeable future.

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CHAPTER 1

INTRODUCTION

The coastal sandplains of New England support several regionally and globally rare species (Vickery and Dunwiddie 1997, MNHESP 2001). They are among a suite of rare and declining species associated with early successional habitats, which are being increasingly lost to succession and development throughout the eastern United States (Motzkin and Foster 2002). In this region there are few natural large-scale disturbances that create early successional habitats (Runkle 1985, Lorimer and White 2003). In coastal New England relatively recent historical disturbances appear to have created much of what is now modern rare plant habitat. The lack of understanding of what constitutes "natural" sandplain habitat for rare species is a major impediment to their conservation (Motzkin and Foster 2002). Rare species appear to be largely restricted to grasslands and heathlands that have been plowed or otherwise disturbed, although systematic searches of other habitats have not been made. An extensive sampling effort is needed within various sandplain habitats to evaluate the suitability of sites for rare species, particularly with respect to their disturbance histories.

The unique physical and vegetative characteristics of sandplains support communities that are globally rare, and in New England they may be one of only a few systems in which early successional communities occur in the absence of human disturbance. Coastal sandplain soils are coarse-textured, well-drained, and nutrient poor (Fletcher and Roffinoli 1986, Copenheaver et al. 2000, Jordan et al. 2003). Vegetation supported on these soils - known as “barrens” (including oak shrublands and woodlands and pitch pine forests) - is xeric and pyrogenic. Many barrens species produce volatile hydrocarbons that make live foliage flammable (Crary 1986). Sandy soils create frequently dry conditions which result in high fuel loading and low fuel moisture. Fire has been an important disturbance process in barrens throughout New England for millennia (Patterson and Backman 1988, Parshall and Foster 2002) but coastal barrens such as those on Martha’s Vineyard may have been especially fire-prone (Stevens 1996, Foster et al. 2002). Furthermore, coastal barrens are characterized by disturbances that are unique, or more frequent, as a result of their maritime positions, including salt spray (Stevens 1996, Griffiths and Orians 2003) and hurricanes (Foster et al. 2002).

Prior to intensive land management by Europeans, extensive grasslands like those supporting rare species today did not occur in the interior of Martha’s Vineyard (Motzkin and Foster 2002), although the upland vegetation there may have had a grassy component (Stevens 1996). Vegetation at the Manuel F. Correllus State Forest (MFCSF) on the central plain is assumed to have been profoundly altered since European settlement by altered fire regimes including nearly complete fire suppression since about 1950 (Mouw 2002). Over the last half of the 20th century more than 60% of short stature oak stands at MFCSF succeeded to forested stands (Mouw 2002). Early successional coastal sandplain communities prior to European settlement may have included open oak woodlands (Stevens 1996, Lezberg et al. in press) and scrub oak shrublands with occasional heath openings.

Understanding the disturbance history of modern rare plant habitat is crucial to conservation of disturbance-adapted species (Motzkin and Foster 2002), and because there is increasing interest in managing barrens to reduce wildfire hazard, there is an immediate need to gain an understanding of the habitat requirements of rare species and the effects of management on those habitats. Early awareness of the fire hazard posed by sandplain vegetation prompted the creation of a network of firelanes on MFCSF in the early 1900s. In recent decades, development has increased dramatically on the perimeter of MFCSF, placing human resources in close proximity to natural areas with abundant fuels. More than four decades of fire suppression have altered the vegetation of MFCSF, in some cases making it less flammable, but catastrophic fires are still possible (Mouw 2002). A new awareness of the need to reduce the risk of damaging wildfires has resulted in a new large-scale firelane expansion project at MFCSF (Mouw 2002). Because much of MFCSF has not been plowed and grasslands are not native to the central plain, managers are interested in finding alternatives to plowing for firelane expansion with the goal of conserving rare species while reducing wildfire hazard.

Although plowing is unlikely to be used in the future (Varkonda, pers. comm.) and does not have any historical analog, firelanes offer the unique opportunity to study how rare species have responded to firelane creation and maintenance. This is relevant to conserving these rare species elsewhere and it may shed light on rare species' autecology. There is also a general interest in conserving sandplain grasslands in New England, because they are dominated by native grass and forb species (Dunwiddie et al. 1996, Swain and Kearsley 2001), support numerous rare species, and are considered globally endangered (MNESP 2001). Sandplain grasslands and heathlands are a major center of biodiversity in Massachusetts (MNESP 2001). Considerable research and management has been conducted in an effort to preserve these early successional communities, which are threatened by development and incursion by woody species (Rudnicky et al. 1997, Dunwiddie 1998; and see Motzkin and Foster 2002). My research provides data on the long-term effects of plowing followed by repeated mowing on grassland communities and rare plant habitat.

The major goal of this research is to document the distribution of rare species at MFCSF, particularly with respect to associated plant communities, environmental conditions and past (human or natural) disturbances in forests, shrublands and grassy firelanes. To address this goal, searches were conducted widely in forests and shrublands that many perceive to be unsuitable for these species including in more open areas that may be more likely to support them. Environmental conditions related to disturbance history and habitat suitability were evaluated. Sandplain soils have been evaluated elsewhere and have been shown to be fairly homogenous (Dunwiddie 1996, Frey and Raleigh 1998) even following plowing (Motzkin et al. 1996), however other environmental factors may influence the occurrence of these species.

The Manuel F. Correllus State Forest was selected as a location to address these questions, because it supports large populations of species listed in Massachusetts as endangered (4), threatened (1), and of special concern (5) (see Table 1) and has a matrix of highly flammable vegetation near concentrated human settlement. At MFCSF, there are also more than 35 miles of firelanes at MFCSF supporting at least 170 hectares of grassland and heathland vegetation. Most firelanes were plowed in the early 1900s, but unlike most other plowed areas in New England, they were presumably never used for agriculture or pasturage. These older firelanes as well as those that have been created or widened in the past decade offer an unusual opportunity to investigate whether long-term firelane management permits rare plants to be supported at the same locations for long periods and to assess the immediate effects of plowing and other firelane creation techniques. MFCSF also lies on one of the largest (5200 acres) undeveloped sandplains in Massachusetts (most other southern New England barrens having been plowed and/or grazed, Finton 1998) where several wildfires have occurred in recent decades (Foster and Motzkin 1999, Varkonda pers. comm). As a result, MFCSF provided me the opportunity to determine whether a range of natural sandplain habitats, including those burned in recent decades, support rare plants.

CHAPTER 2

LITERATURE REVIEW

Pre-colonial Disturbance Regimes

Large Native American Indian populations likely impacted the vegetation of Martha's Vineyard for millennia through land use and altered fire regimes. Historical accounts suggest that Martha's Vineyard may have supported a human population of 3,000 at the time of European settlement in the 17th century (Banks 1911, Cook 1976, Richardson 1985). This is equivalent to 35 people/mi^2 and greatly exceeds population densities of approximately 5 people/mi^2 reported for mainland and other coastal areas (Cook 1976). However, even if estimates of contact-period population sizes are accurate, little is known of Native population sizes of earlier periods. Archaeological evidence suggests that pre-contact Native Americans were semi-sedentary and subsisted primarily on fish and shellfish although hunting, especially for deer, was also practiced (Chilton 2000). Horticulture - although not with domesticated plants until about 1000 years BP (Richardson 1985) - and gathering were also employed (Bragdon 1996). Native American populations of Martha's Vineyard did not create large settlements or use widespread agriculture (McAndrews 1988; see Motzkin and Foster 2002)

It is likely that the greater importance of fire in coastal New England relative to other areas of the Northeast was a function of Native American burning activity (Patterson and Sassaman 1988, but see Foster et al. 2002). Charcoal: pollen ratios in sediments dating to between 800 and 1500 years ago from Martha's Vineyard are among the highest in the region and decline following European settlement – a phenomenon seen only in cores from a few other sites on Cape Cod and Nantucket (Patterson and Backman 1988, Stevens 1996). Fire may have been particularly important on the central plain. Some of the highest ratios recorded from pre-colonial sediments in New England come from Duarte and Lagoon Ponds north of the plain (Stevens 1996, Foster et al. 2002). Native Americans may have used fire to clear areas around settlements, to create better game habitat, or promote mast production (e.g. Day 1953).

Pre-colonial Vegetation

There has long been interest in describing the pre-colonial vegetation of Martha's Vineyard (e.g. Ogden 1961), and this has intensified as interest in conserving rare species has increased (Stevens 1996, Foster and Motzkin 1999, Foster et al. 2002). Motzkin and Foster (2002) synthesized ecological, paleoecological, archaeological and historical evidence to evaluate whether grasslands, heathlands and other early successional communities existed in coastal New England prior to European arrival. Modern grasslands and heathlands generally have a history of plowing, and intensive management has been necessary in recent decades to prevent incursion of woody species and perpetuate these communities. Severe disturbances are necessary to create and maintain these communities in areas away from the immediate coastline.

The presence of rare species on the coastal plain supports the notion that early successional communities must have existed in pre-colonial times, but it is unclear whether their autecology can provide insight into characteristics of pre-colonial habitats. Many rare species are probably now associated with altered habitats and with different species than they were in the past (Motzkin and Foster 2002). Many plant species appear to be tolerant of fire, but without a clear modern link between fire occurrence and rare plant populations, the suggestion of a historical link with fire is conjectural.

Historical accounts are often contradictory and may have been intentionally biased. However they suggest that grasslands may have occurred along coastlines and that burning may have promoted shrublands or woodlands with grass or herbaceous components (Motzkin and Foster 2002). Paleoecological data represent the most reliable source of information about pre-colonial vegetation although they are fraught with uncertainties including imprecise taxonomy of pollen grains, varying deposition rates across taxa, and the lack of suitable deposition sites (Stevens 1996).

Paleoecological data suggest that the coastal islands were largely wooded, and if grasslands occurred on Martha's Vineyard it was most likely along coastlines (Dunwiddie 1990, Stevens 1996). The highest pre-historic grass pollen percentages (as high as 40%) found by Stevens (1996) were from pre-historical sediments in coastal ponds on what is now the south shore. While consistently high pollen percentages for grass and the poorly dispersed Tubuliflorae (Composite subfamily) could indicate nearby terrestrial grassland vegetation, they may also be of wetland origin. In general, little grass pollen was found in pre-historic sediments collected away from the coast, and grass pollen percentages prior to European settlement are generally lower than those found today suggesting that large grasslands probably did not occur away from the coast. For individual cores, high grass pollen percentages are not correlated with high charcoal values across New England (Foster et al. 2002, Motzkin and Foster 2002).

The pollen record suggests that shrublands/woodlands of the central plain were shaped by fire, but it can do little to confirm the presence or absence of a grass or herb component in these communities. Although the pollen record may not be adequate for detecting small grassy or heathy openings within other plant communities (Stevens 1996), some of the highest charcoal: pollen ratios, lowest arboreal pollen levels, and highest pre-European grass pollen levels in New England have been recorded on the central plain of Martha’s Vineyard, suggesting that grassy openings may have occurred. Stevens recorded less than 10% grass pollen in surface sediments even when grasslands comprise 30 to 35% of the source area vegetation and where frequent small grassy patches occur within forest and shrub vegetation. She attributes the under-representation of grass pollen in those surface sediments to wetland edge shrub communities impeding pollen deposition and/or the swamping of grass pollen by more abundant arboreal pollen.

Post-colonial Disturbance Regimes and Vegetation

Colonial-era land-use history along the coast of Martha’s Vineyard was similar to that in other parts of New England. Forests were cleared for wood products and agriculture. By the mid 1700s, when European populations had grown to approximately 1500 on the Island, most of the perimeter was deforested. Tax records indicate that in the early 1800s - at the height of grazing on Martha’s Vineyard - 20,000 sheep, 400 horses and 3500 cattle were on the island (Foster and Motzkin 1999). By the early 1800s cordwood shortages were reported. Agriculture and timber cutting declined by the late 1800s, but populations continued to expand as resources were increasingly shipped from the mainland. Fields were abandoned and forest cover increased. Many areas that are now forested were probably cut several times during the historical period as evidenced by the few large trees that could be found on the Island in the mid-1900s (Ogden 1958).

Due to its droughty soils and lack of surface water, the central plain was unsuitable for agriculture and probably not used for pasturage. Little plowing occurred, and that which did, was not until the late 1800s (Foster and Motzkin 1999). Wood cutting, on the other hand, was widespread. By the mid 1800s a lack of wood forced the closure of a brickworks (Foster and Motzkin 1999). Cutting continued to a lesser extent through the 19th century but was of minor importance after 1900.

Although fire appears to have decreased in importance from the pre- to post-colonial period, we do not know how size, frequency or seasonality of fires changed. Fires through the 1940's were frequent and often large; 23 fires greater than 1000 acres occurred between 1855 and 1955. They burned primarily in the spring; with more than twice as many in April, May and June than in other months. Fires on the central plain spread rapidly, burning many hundreds of acres as documented on early aerial photos (Mouw 2002). A dramatic reduction in fire size in the last half of the 20th century is attributed to successful fire suppression efforts (Mouw 2002). This effective fire suppression resulted in the development of oak and pine overstories in scrub oak shrublands, resulting in a 60% decline in young oak stands between 1938 and 1995 (Mouw 2002).

In the early-to-mid 1900s, conifer plantations were established over about 23% of the state forest. By the 1970's this practice slowed (and stopped by the early 1990s) due to a lack of a local market for wood and the susceptibility of plantations to hurricane and pathogen damage (Foster and Motzkin 1999). Plantations were established in areas of native vegetation which still support native understory species. A number of older plantations have begun to fall apart, many following Hurricane Bob in 1991. In areas where salvage logging has occurred, soil disturbance has led to the establishment of weedy species (Foster and Motzkin 1999).

To the extent that MFCSF is dominated by oaks today, the paleoecological record suggests that little change in vegetation has occurred since prehistoric times (Stevens 1996). Most species at MFCSF resprout after cutting, so burning and cutting probably affected vegetation structure rather than composition. Thus the Forest was probably dominated by resprouting hardwoods through the historical period (Foster and Motzkin 1999). A legacy of this historical cutting and fire is the common occurrence of coppice oak stems in oak-dominated stands. Individual stems of these coppice oaks have been aged to 50-80 years, but their wide spacing suggests large root masses which are much older (Patterson et al. 2006).

Coastal Rare Plants

A few of New England's coastal rare plants are considered endemic and globally rare because of their restricted ranges, but most are only regionally or locally rare because they are at the northern edge of their ranges (Mehrhoff 1997). Many coastal rare species have southern and midwestern affinities and are restricted within New England to the climatically more moderate southeastern coast. The five species investigated in this study are regionally rare. Conserving edge-of-range populations is important because it may prevent range contraction, allow range expansion and preserve genetic variability (especially when populations have been isolated for lengthy periods of time; Rabinowitz 1981).

It is generally not known how long these species have been in coastal New England, however those that are endemic are presumed have been in the region for hundreds if not thousands of years. This suggests that suitable habitat has been present that long. Mehrhoff (1997) speculates that several species (including those that are endemic) migrated to New England during the hypsithermal - the warm period that began approximately 8500 years ago - and were subsequently isolated as the climate cooled and habitats became unsuitable. For other species the lack of early herbarium specimens may suggest that they are relatively recent arrivals, now expanding their ranges into New England (e.g. *Scleria pauciflora* var. *caroliniana*; Zaremba 2004).

Coastal rare plant species may never have been common in New England. Many are presently restricted to the coastal plain (e.g. *Linum intercursum* and *Sisyrinchium fuscatum* Appendix A). Although some species appear to have been more widespread in the 18th and 19th centuries, this may be attributed to the New England landscape as a whole being more open during that period (e.g. *Nabalus serpentarius*; Everett and Lepley 2002). Moreover, these species may be declining as they experience range contractions in response to the loss of open land.

Although most occurrences of rare plants in southern New England are in grasslands and heathlands of anthropogenic origin (many are found in cemeteries, roadsides, powerlines, railroad beds and even gravel pits, MNHESP) most of the five rare plant species I investigated is currently found, at least occasionally, in shrubland and forested habitats (with the exception of *Aristida purpurascens*). Most (with the exception of *S. fuscatum*, Appendix A) are also represented by one or more historical records from similar habitats. At the turn of the 20th century, *Aristida purpurascens*, *Linum intercursum* and *Nabalus serpentarius* were all collected from habitats described as "pine barrens" in Massachusetts, with a *L. intercursum* population persisting in such habitat until the 1970s. Each of these species is also recorded from habitats described as pine barrens, pine/oak savannahs, or pine forests south of New England. Two extant populations of *L. intercursum* occur on pond shores in Massachusetts, and a number of specimens of both *L. intercursum* and *A. purpurascens* were collected from wetlands described variously as ponds, swamps, bogs, and coastal plain pond shores. In the southeastern part of its range *S. pauciflora* var. *caroliniana* frequently occurs in wetlands (Godfrey and Wooten 2004), but it has not been found in wetlands in New England.

Population response to management of rare plant occurrences in New England has varied substantially. On Nantucket Island, *S. fuscatum* increased following burning and mowing in summer burn plots and following spring burns in combination with late season mowing, but another population was lost following one spring burn (Dunwiddie 1998). *Helianthemum dumosum* increased following a summer burn but remained largely unchanged after a spring burn. As in the southern Appalachians (Clinton and Vose 2000), *S. pauciflora* has responded positively to fire in Massachusetts.

Although the lack of suitable habitat is probably an important cause of rarity for a number of coastal rare plants, biological limitations may also play a role. Biological limitations could include self-incompatibility, pollinator limitation, inbreeding depression, or high rates of predation or herbivory. Vickery (2002) found that populations of Northern blazing star, *Liatris scariosa* var. *novae-angliae*, are limited by high seed predation rates and low reproductive success. Fire kills the species' moth predator, and in larger burn areas, where post-burn recolonization by the moth is slower, plants have more time for successful reproduction and establishment.

Many coastal rare plant species appear to be disturbance adapted but there is little detailed information on their biology. Some are presumably capable of long distance dispersal by animal vectors or wind (e.g. *A. purpurascens* and *N. serpentarius*; see Appendix A). At least one (*S. pauciflora* var. *caroliniana*) appears to be capable of banking seeds in the soil, possibly maintaining viable seeds for decades (Oosting and Humphreys 1940, Zaremba 2004). For many taxa, basic reproductive biology is not known. Rare species may possess adaptations that allow them to persist in small populations, self-compatibility being an example (e.g. *L. intercursum* as suggested by Nicholls 1985 and *S. pauciflora* see Fairey 1967, Reznicek et al. 2002, Zaremba 2004).

CHAPTER 3

STUDY SITE

Location

The Manuel Correllus State Forest (MFCSF) is situated at the center of the island of Martha's Vineyard, off the south coast of Massachusetts, USA (Figure 1). Martha's Vineyard, an island of approximately 250 km^2, lies approximately 6.5 km southeast of the Elizabeth Islands and 8 km south of Cape Cod. The Forest is 21 km^2 and is the largest conservation area on the island. Most of the Forest is more than 2.5 km from the ocean.

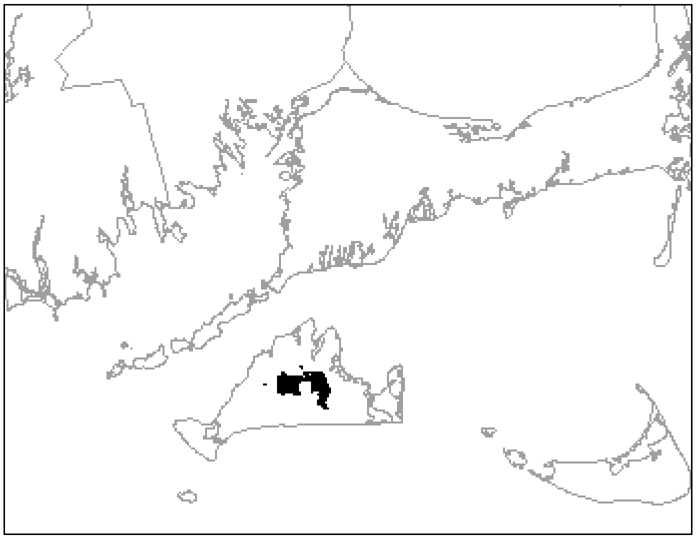


Figure 1. Map of Martha's Vineyard, MA showing the location of the Manuel F. Correllus State Forest (in black).

Climate

The climate of Martha’s Vineyard is humid continental with average monthly precipitation ranging from 12 cm in November to 7.4 cm in July (Stormfax 1990). During the growing season, periods of drought lasting up to several weeks can occur. Maritime influences moderate temperatures and maintain high humidity levels. The 30-year average annual high temperature is 21° C and the low -1.5° C. On average the last frost in the spring is May 13 and the first in the fall is October 9, the growing season lasting on average 155 days (Fletcher and Roffinoli 1986). In the summer, winds are commonly from the southwest and in the winter from the northwest.

Geology and Soils

The west and east parts of Martha’s Vineyard were formed as a terminal moraine at the end of the last advance by the Laurentide ice sheet (Oldale and Barlow 1986). The western part of the island is defined by undifferentiated sand and gravel including larger cobbles and boulders (combinations of Eastchop, Chilmark and Nantucket soil series; Fletcher and Roffinoli 1986). This area is the most topographically variable on the island with some hills attaining an elevation of >80m. The eastern side of the island is underlain by similar morainal deposits but was overtopped by outwash (from which the Carver soils were derived) which moderated the topography.

The plain in the center of the island was created by outwash deposits of differentiated sand and gravel (from which Carver, Riverhead, and Haven soils were formed). It slopes from an elevation of about 30 m in the north to sea level in the south but is generally flat, with slopes > 5% being restricted to the sides of north/south trending valleys known as frost bottoms. These frost bottoms, created by “spring sapping” (ground water seepage), have steep sides and relatively flat floors that drop up to 12 meters below the surrounding plain (Uchupi and Oldale 1994). MFCSF is situated on the outwash plain with the far northeastern corner intersecting the moraine. The soils of MFCSF are generally excessively well drained, although those to the east have slightly higher water holding capacities (Fletcher and Roffinoli 1986).

MFCSF Cover Types and Disturbance History

The vegetation of the Forest has been recently characterized from aerial photos by Mouw (2002). The most common vegetation types are scrub oak (covering 29% of the Forest), oak woodlands (26%), mixed oak woodlands/scrub oak (17%) and plantations (16%). Pitch pine covers <5% of the Forest and is concentrated in a few areas in the east and northeast of the forest. Pitch pines occur where fire or hurricane damage have allowed them to persist for centuries. Scrub oak stands are now strongly, but not exclusively, associated with frost bottoms. More than twenty fires greater than 400 ha (1000 acres) occurred at MFCSF between 1855 and 1995. The approximate size and location of nine fires <6 ha that burned during the past two decades were provided by John Varkonda (Pers. comm.). The largest of these fires was 15 acres and occurred in a frost bottom.

Firelane Management

Soon after the establishment of the MFCSF (then the Heath Hen Reservation, named after the species its creation was intended to preserve) in the first several decades of the 1900s, a series of firelanes was created in a gridded pattern throughout MFCSF. These lanes dissect the western side of the forest into blocks 0.5 mile (0.8 km) on a side with firelanes 49 ft (15 m) wide (Figure 2, Appendix B). These “original” (also referred to as “old”) firelanes were created by clearing timber and brush, plowing, and harrowing (often multiple times over the course of the first several decades). Most were established to their intended 15 m width although some were narrower. Roads were maintained in the center of the lanes to allow access by firefighters. On either side of the road, the vegetation (about 5 m or 16 ft in width) was regularly mowed. Many lanes narrowed over the decades as a result of encroachment of shrubs and trees from the edges. Firelanes on the eastern side of the forest are more irregular and many were never expanded to 15 m in width. There are now over 35 miles (55 km) of firelanes comprising at least 425 acres (172 ha) of grass and heathland habitat in which all known rare plant populations occur.

With increasing human development on the island including at the perimeter of MFCSF, concern has increased over the fire hazard presented by flammable fuels on the central plain. In the winter of 1993 and the spring of 1994, selected firelanes were widened, and several new lanes were created (Mouw 2002). These are referred to as “new” lanes. The two main east/west running lanes on the western side of MFCSF (lanes C and D, see Figure 2) had been about 4-ft (1.2-m) wide on either side of a road prior to widening in 1993. These lanes were widened over their two-mile (3.2 km) length by 25 feet (7.6 m) on either side of existing lanes. A firelane on the northwest perimeter of the Forest (lane 1A) was widened from approximately 15 ft (4.6 m) to 200 ft (60 m). Along the northern edge of the Forest, new 200 ft (60-meter) wide lanes were created south of existing lanes A and B (B5E, B6E, B7E, and A8E). Just north of the Forest headquarters, firelane A9 was widened from 8 feet (2.4 m) to 200 feet (60 m). The two northernmost sections of firelane 5 (5B and 5C) were widened from 4 ft (1.2 m) to 20 ft (6 m). Each of these lanes was created or widened by clearing, harrowing, and rootraking.

Since 1994 no new areas have been cleared and plowed, but harrowing has been used to level the surface in previously harrowed areas (the one exception being a portion of the eastern-most section of firelane A- firelane A12- which was harrowed in 2001). The new portions of lanes C and D were harrowed a second time in 2000. Firelane 1A was again harrowed in 2002 (lane 1A was harrowed again in 2004, after my sampling, and is not shown in Figure 2). The new section of firelane A9 has been harrowed a number of times in the years since it was widened in 1993/1994. Since their creation these new lanes have been maintained with mowing to varying extents. The two eastern-most sections of firelane A were widened using only a brushog with the exception of the portion of firelane A12 mentioned above. Future firelane widening is likely to be done in this manner rather than with harrowing (J. Varkonda personal communication).

Study Species

Five rare species found at more than one location at MFCSF are evaluated in this study (Table 1). All are perennial but otherwise encompass different life history strategies. Two are graminoids; one a non-rhizomatous bunchgrass, *Aristida purpurascens* (Poaceae) and the other a rhizomatous sedge, *Scleria pauciflora* var. *caroliniana* (Cyperaceae). Three are forbs: *Linum intercursum*, a small, short-lived (Brumback, pers. com.) perennial of the family Linaceae; *Nabalus serpentarius*, a tall, taprooted member of the Asteraceae; and *Sisyrinchium fuscatum*, a fibrous rooted member of the Iridaceae (Gleason and Cronquist 1991). All are considered globally secure, but are state-listed in Massachusetts where they are at or near the northern edge of their ranges (Table 1). Several other rare species (one of which is the globally rare *Agalinis acuta*) have been reported from MFCSF but are not included in this study as they were either not found, or were found at only one location.

Table 1. Rare plants included in this study showing state, regional and national ranks (described below).

	MA status[1]	Global[2]	National[3]	NEPCoP division [4]	MA[5]	Other NE state listings[6]
Aristida purpurascens	T	G5	N5	2	S2	RI=S1; CT=SU
Linum intercursum	SC	G4	N4		S3	RI=S1; CT=SH
Nabalus serpentarius	E	G5	N5	2	S1	RI=SU; CT=SU; NH=SH; VT=SU
Scleria pauciflora var. *caroliniana*	E	G5T5T5	NNR	2	S1	RI=SNR; CT=S1; NH=SNR
Sisyrinchium fuscatum	SC	G5?	NNR		S3	RI=SH; CT=SNR

[1] MA legal status E: (Endangered) In danger of extinction in all or part of its range or in danger of extirpation in MA; T: (Threatened) likely to become endangered in the foreseeable future or which are declining or rare; SC: (Special Concern) have suffered a decline that could threaten the species if allowed to continue, occur in such small numbers or with such restricted distribution or in such specialized habitat requirements that they could easily become threatened (MNHESP).

[2,3,5,6] NatureServe Conservation Status Rank: Geographic scales are abbreviated G: global; N: national; S: state. Ranks are as follows 1: Critically imperiled; 2: imperiled; 3: vulnerable to extirpation or extinction; 4: apparently secure; 5: demonstrably widespread, abundant and secure. "?" denotes that the given rank is inexact; NR is used for species whose rank is not yet assessed. H: indicates species that are possibly extinct and is used when the species is known from historical records and those occurrences may still exist. U: used for species which are unrankable due to lack of adequate data. The rank T5T5 denotes the fact that the two varieties of *Scleria pauciflora* (*S. pauciflora* var. *caroliniana* and *S. pauciflora* var. *pauciflora*) are both ranked G5 (NatureServe 2005).

[4] NEPCoP Regional Division: 1: Globally rare; 2: Regionally rare; either rare throughout New England or reach the edge of their range in New England and have either fewer than 20 populations or have small populations vulnerable to extinction; 3: locally rare; 4: historic. *Linum* and *Sisyrinchium* are not listed in NEPCoP's Flora Conservanda because of the relatively large number of occurrences for these species in the region (Brumback et al. 1996).

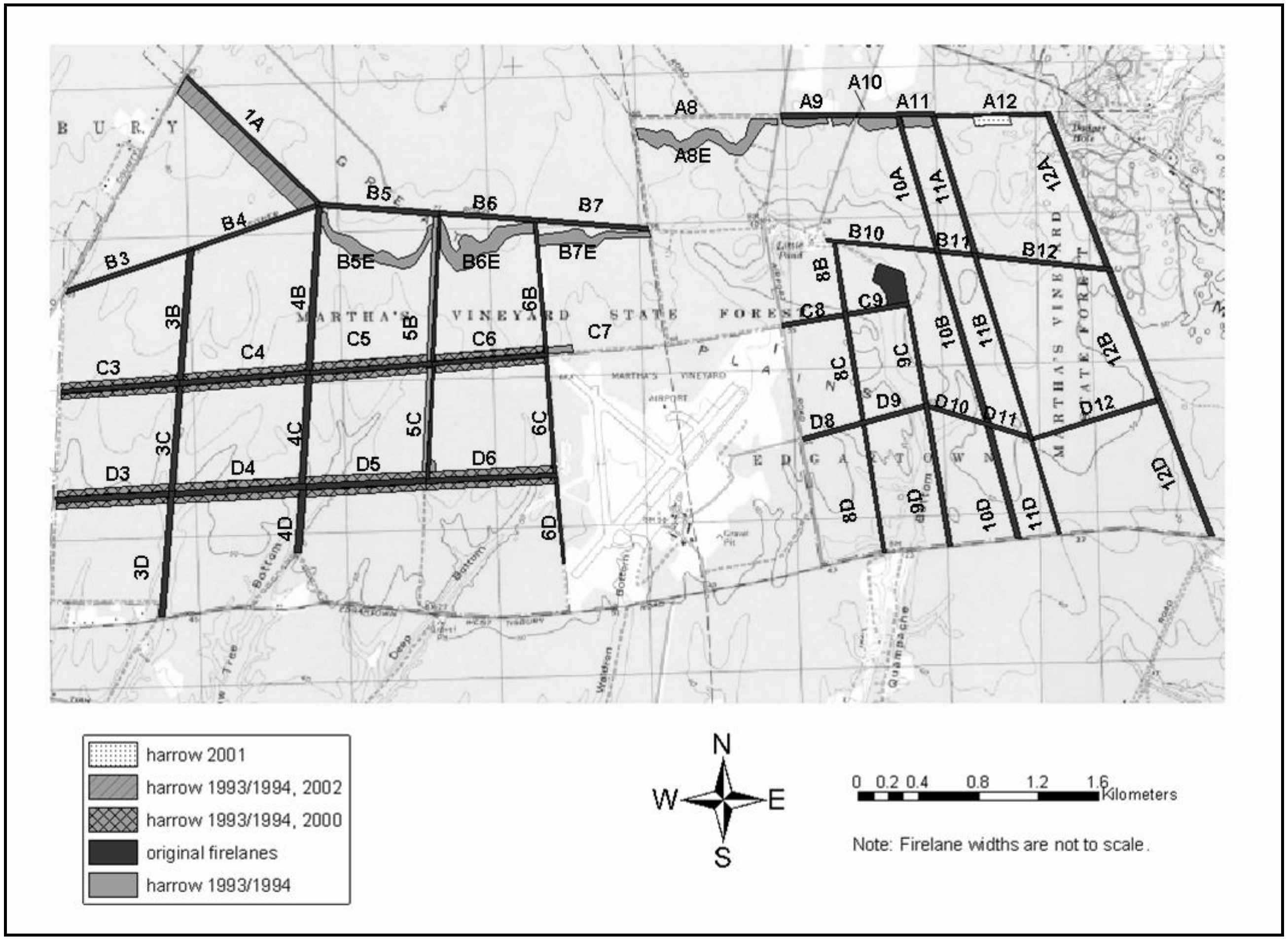


Figure 2. Map of the Manuel F. Correllus State Forest showing firelane management history. Map shows original old firelanes (harrowed in the early 20th century) and areas which have been more recently managed under firelane expansion projects, referred to as new lanes (harrowed since 1993).

CHAPTER 4

METHODS

Field Sampling

Relevés

To describe the floristic composition of the vegetation of MFCSF, 100-m^2 (10 x 10 m) relevés (Mueller-Dombois and Ellenberg 1974) were sampled in 2003 and 2004 (Figure 3). In grassland vegetation, 100 m^2 is the minimum plot size required to enumerate 90% or more of the species present (Mueller-Dombois and Ellenberg 1974). Plots were elongated (to 5 x 20, 2 x 50 or 1 x 100 m) when firelanes were less than 10 m wide, to keep the plot within areas of similar management. Plots were oriented along the cardinal directions except in firelanes where they departed slightly (due to the positioning of firelanes themselves).

At each relevé, complete lists of vascular plant species were made within physiognomic strata, and cover categories were assigned to each species by strata. Percent cover was estimated using categories modified from Braun-Blanquet: 6 = >75%, 5 = 50-75%, 4 = 25-50%, 3 = 5-25%, 2 = 1-5%, 1 = 0-1% and t = solitary or few individual stems (Mueller-Dombois and Ellenberg 1974). Each stratum as a whole was also described with respect to height and cover (Küchler 1967 cited in Mueller-Dombois and Ellenberg 1974). An additional 200 m^2 was searched around the perimeter of each plot, and additional species found were recorded. When plants were unidentifiable at the time of survey (because they were immature or not flowering), plots were revisited later in the growing season and/or the following year to make a positive identification. This occurred regularly in firelanes, so all firelane plots were visited both early and late in the growing season. Forested and shrubland plots were only occasionally revisited.

Nomenclature follows Gleason and Cronquist (1991) except for *Nabalus serpentarius* which follows Kim et al. (1996) and *Scleria pauciflora* var. *caroliniana* which follows Reznicek et al. (2002). Higher taxonomic groups (generally the genus level) were used when identification was problematic or where necessary based on a suspected bias in the timing of sampling among plots. Cryptogams were identified as either lichen or moss. Higher taxonomic groups were considered equivalent to species for the purpose of analyses. When population sizes permitted, voucher specimens of rare species were collected and archived at the Herbarium at the University of Massachusetts, Amherst (MASS).

Sample Plot Location

In addition to sampling relevés at rare plant locations, plots were also sampled at UTM points generated by a random point locator in ArcView that selected random points from all polygons characterized of a particular vegetation type. Sixteen plots were sampled within each of the scrub oak, oak woodland, oak woodland/scrub oak, pitch pine and grassland (firelanes) vegetation types. This ensured stratified random sampling across all major vegetation types, including the less frequent grassland (firelane) type. I sampled at random GPS locations even if they did not fall within the intended vegetation type, because I reclassified the vegetation *post hoc* (see cluster analysis, Appendix C), except when points fell outside intended pitch pine stands. Because pitch pine stands are less common than those dominated by oaks, I relocated points which fell outside targeted pitch pine stands. I used a randomly chosen bearing (toward the intended stand) and distance. In each instance this resulted in a plot which contained greater than 50% Pitch Pine cover. To better document the impacts of firelane management, additional plots (to a total to 6 per management history type) were randomly located within lanes that were harrowed only in 1993/1994 (lanes B5E, B6E, B7E, A8E – see Figure 2) and within those harrowed both in 1993/1994 and 2002 (1A). In addition the four sites in lanes C and D were sampled twice in each location (with one plot in the "old" and one in the "new" portion of the lane for a total of eight plots). Finally 22 plots were centered at rare plant locations in firelanes. In the end, 54 plots were sampled in firelanes and 64 plots were sampled in forests and shrublands outside firelanes.

Rare plant occurrences were located with records from the Massachusetts Natural Heritage and Endangered Species Program, discussions with local botanists, and through searches. Because *L. intercursum* occurred in randomly located plots and those sampled at other rare species, additional plots were not located at *Linum* occurrences.

Searches

Searches for rare plants were conducted in all major vegetation types at and when traveling to the 64 randomly located plots in forests and shrublands sampled in 2003. More than 600 hours were spent sampling and traveling to these points throughout the study area. Additional searches targeted open areas identified from aerial photos and areas that burned in wildfires in the last two decades. Over the course of three summers more than 50 hours were spent searching in these areas more likely to support rare species. Extensive searches were also made in firelanes in 2003 and 2004.

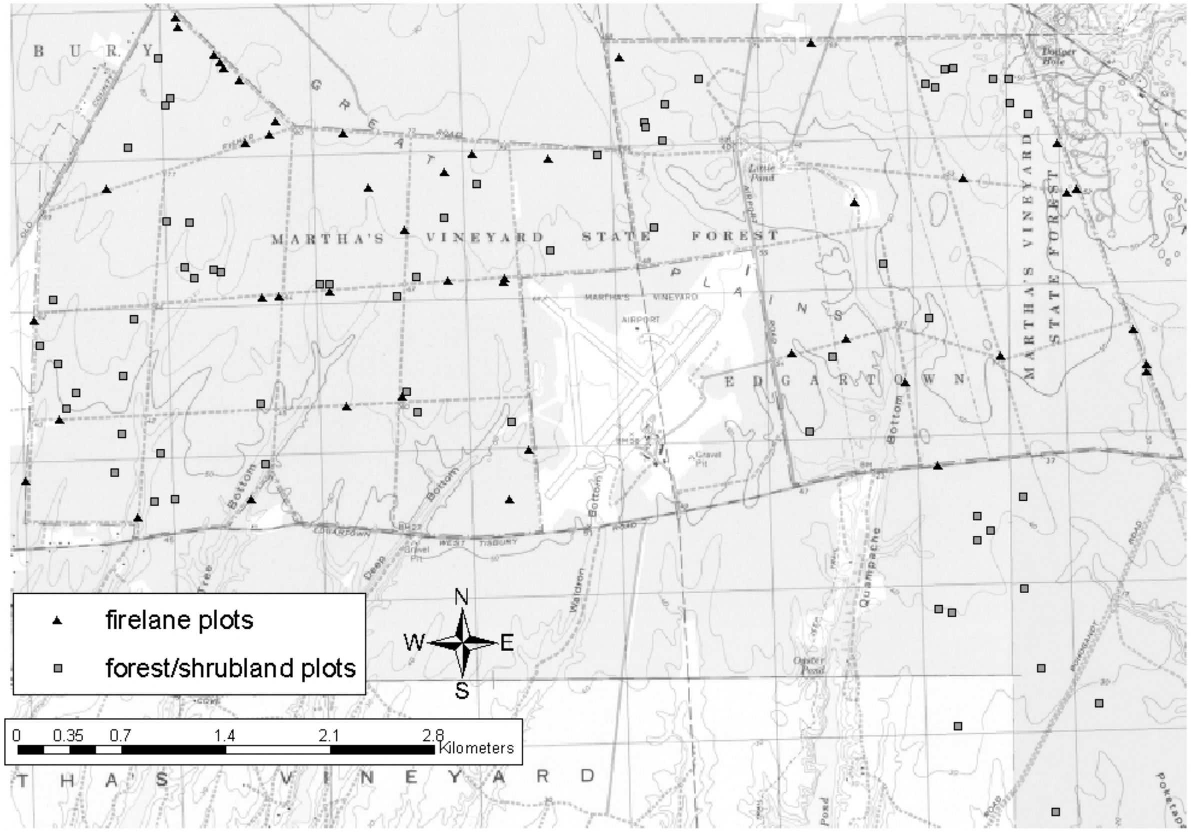


Figure 3. Map of the Manuel F. Correllus State Forest showing plots sampled over the course of this study both in firelanes and in forested/shrubland habitats.

Plot Environmental Characteristics

Basic habitat characteristics thought to be associated with disturbance and rare plant occurrence were assessed at all relevés in 2003 and 2004. Vegetation structure and ground cover type (bare soil, litter, duff, lichen, and moss) were characterized by point intercept sampling at a minimum of 100, evenly-spaced points per plot. Vegetation structure was measured by tallying the presence of graminoid, herbaceous, and woody vegetation in four height categories (0-0.5, 0.5-1, 1-1.5, and >1.5 m). In most plots five, 10-m-long, parallel transects, 2-m apart, were sampled at 0.5 m intervals. In 14 plots that were elongated to 5 x 20 m, three 20-m-long transects spaced 1.5 m apart were sampled (120 points). And in 14, 2 x 50 m plots, points were sampled at 1-m intervals along two, 50-m-long transects spaced 0.5 m apart. Vegetative point intercept data was analyzed as the percentage of sampling points at which a given growth form occupied one or more strata.

Litter and duff depths were measured at a minimum of 15 locations per plot. In 10 m x 10 m plots, these measurements were made at three locations (2.5, 5, and 7 m) along each of five lines. In 5 m x 20 m plots, measurements were made at 5 points along the three transects (at 4, 8, 12, 16, 20 m), and in plots that were 2 m x 50 m, nine points were sampled per transect (every 5 m from 5 to 45 m). Average litter and duff depths were calculated for each plot.

Vegetative cover was sampled with a concave spherical densitometer at four evenly spaced locations in plots. At each location readings were taken in the four cardinal directions at 1.4 and at 0.5 m above the ground. In 10 x 10 meter plots readings were taken at the center of each quarter, and in linear plots readings were equally spaced along a line running parallel to the long axis, at the center of the plot. Average vegetative cover was calculated by plot and height above the ground.

Data Analysis

Importance values (IV) were computed for each species in each plot according to the following: IV= sum of the Braun-Blanquet cover values across strata minus the number of strata the species occurred within, plus one (Clark and Patterson 1985). Prior to calculating IVs, the value of 1 was added to each cover value and values of “t” were given a value of 1. Additional species located in searches outside of plots increased species lists on average by 10% for firelane plots and 23% for forested plots, suggesting that larger plots could have been sampled outside firelanes. However, species found outside of plots were included in analyses (and given an abundance of 1) except where noted otherwise, in analyses of species richness/unit area.

Univariate Analyses

Univariate analyses were run in SPSS version 11.5. Non parametric Kruskal-Wallis tests were used to test for differences in environmental variables among vegetation types, and Mann-Whitney tests to make individual pairwise comparisons. G-tests were used to test for significant differences in species’ frequencies of occurrence between firelanes and shrubland/forest plots.

Multivariate Analyses

Multivariate analyses performed with PC-ORD version 4.0 were run excluding species occurring in only one plot and rare species. Species occurring in only one plot do not contribute to multivariate analyses which look for patterns in co-occurrence. To determine whether rare species have affinities for particular plant communities, classifications should not be influenced by the rare species themselves. Rare species, with only one exception were classified as having cover less than 5%, and thus are not likely to have been important in vegetation classification (*Scleria pauciflora* on one occasion had between 5-25% cover).

Cluster analysis

Vegetation was classified using hierarchical cluster analyses. Sorensen's distance measure was used, as it has generally performed well with datasets with high beta diversity (average Sorensen distance between firelane plots was 0.44 and between forested and shrubland plots was 0.42; see McCune and Grace 2002). A compatible (group-average) linkage method was used. Cluster analyses were pruned at the point where the number of significant indicator species plotted against number of clusters recognized leveled off (McCune and Grace 2002).

Nonmetric multidimensional scaling (NMS)

Nonmetric multidimensional scaling (NMS) ordinations were run to visualize the relationship among plots based on similarities in species composition and abundance; that is, to better understand which plots are more or less similar to which other plots beyond simply categorizing them into groups with a cluster analysis. NMS is a non-parametric ordination technique used with ecological datasets when it is inappropriate to assume linear relationships among variables or between variables and underlying environmental gradients (McCune and Grace 2002). The NMS procedure seeks to display the multivariate structure in the dataset (specifically interplot distances from a similarity matrix) in a small number of dimensions. The NMS procedure involves assessing the amount of distortion that has occurred in depicting the structure in fewer and fewer dimensions and selects an appropriate number of dimensions. Ordinations were run using the slow and thorough option in autopilot mode (random starting configuration, 40 runs with real data, Monte Carlo test using 50 runs with randomized data) and Sorenson's distance measure.

NMS uses an iterative technique to find the ordination structure (measured as the Euclidean distance between points in the reduced ordination space) which is most faithful to the original data structure (measured as the distance between points in the original data space). A dissimilarity matrix from the original data, in this case based on Sorensen's dissimilarity measure, is used to create a ranking of interplot distances. The Shephard diagram, useful for conceptualizing the NMS procedure, displays interplot distances in original data space on the y axis (plot pairs ordered from closest to farthest pairs) and the Euclidean interplot distances in reduced space on the x axis (plot pairs ordered as on the y axis). Stress, conceptualized as departure from monotonicity in the Shepard diagram, is minimized according to the mathematical algorithm used by NMS. Stress is used to assess the "goodness of fit" of the reduced ordination. In the procedure, entities - plots in this case - are randomly positioned in the reduced ordination space, from which a distance matrix is calculated and stress determined. Plots are then shifted slightly in the direction which is determined to lower stress, according to the steepest decent algorithm, and a distance matrix and stress are again calculated. This iterative process is continued (with progressively shorter step lengths) until the variation in the stress over some number of past iterations drops below a pre-defined level. Ordinations were run several times with new random starting configurations. This ensures that the final solution, the one with the least stress of all runs, represents the best "global" solution (McCune and Grace 2002). The Monte Carlo procedure randomizes data within plots or rows and provides an assessment of the likelihood that the stress of the final ordination could have resulted from chance alone. The p value is the fraction of randomized runs with stress less than or equal to the best real run (plus one), divided by the total number of randomized runs, plus one (McCune and Grace 2002).

Indicator species analysis

Indicator species analysis (Dufrêne and Legendre 1997) was performed to identify common species that might be indicators of rare species occurrence. The procedure derives Indicator Values (INDVALs) reflecting the degree to which individual species are faithful to a group of samples, in this case samples with (group 1) or without (group 2) a particular rare species.

Indicator values (INDVAL) are calculated for each species in each group as follows: $INDVAL_i = RA_i \times RF_i \times 100$ (frequency and abundance are expressed as decimals). The relative abundance in group 1 (RA_1) is the average abundance of the species in the group 1 samples divided by the sum of the average abundance over both groups. The relative frequency in group 1 (RF_1) is the percentage of group 1 plots that the species occurs in. Although the INDVAL does not explicitly account for the difference in a species' frequency of occurrence between the groups, the Monte Carlo randomization procedure, used to test the significance of the INDVAL, assesses the uniqueness of the pattern of occurrence and abundance between groups.

The Monte Carlo procedure is performed as follows. The INDVAL calculated from the actual data is compared to the maximum INDVAL obtained from 1000 random assignments of the observed values to groups (simulating results that could be expected by chance) and "the probability of type 1 error is the proportion of times that the randomized INDVALs equal or exceed the actual value" (McCune and Grace 2002). The more infrequent a species, the less likely it will be identified as a significant indicator of a group, because randomized runs will frequently produce INDVALs equivalent to observed values (McCune and Grace 2002).

Separate indicator species analyses were run for each rare species. Because plots were not randomly located (but rather were located at rare plant occurrences) the INDVAL can not be strictly interpreted as the degree of association between species, and the large plot sizes used here result in species associations being made on the community level (Greig-Smith 1983).

CHAPTER 5

RESULTS

Environmental Variables Associated with Rare Species

Despite extensive searches, rare plants are found almost exclusively in firelanes, all of which have had a history of intensive disturbance. Exceptions include occurrences for two species (*L. intercursum* and *S. fuscatum*) on well-worn paths within other vegetation types. Vegetation at sites of rare plant occurrences is generally dominated by native grass and herb species like *Schizachyrium scoparium*, *Carex pensylvanica*, *Baptisia tinctoria*, *Panicum* sp., and *Solidago* sp., and is characterized by high species richness in contrast to areas off of firelanes (Figure 4).

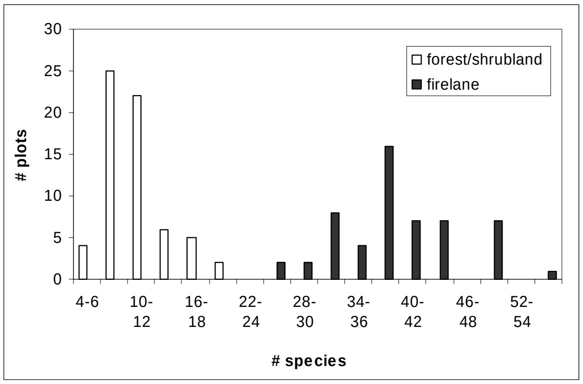


Figure 4. Frequency distribution of plot-level species richness for plots on and off firelanes. Only species occurring within 10 x 10 m relevés were included.

The cluster analysis identifies vegetation types we define as scrub oak, pitch pine, oak woodland and oak woodland/ scrub oak (Appendix C), and grasslands (firelanes) which are readily differentiated by environmental variables sampled. Each environmental variable differs significantly (for all comparisons $X^2>37$, $p<0.001$) among forested, and shrubland vegetation types and firelanes with and without rare species. Pairwise comparisons were conducted separately for each rare species in order to describe their habitat preferences individually (Figures 5–9). In general, firelanes, whether occupied or not by individual rare species, have significantly more bare soil and graminoid cover, and less litter, woody species and vegetative cover (above 0.5m), and lower litter and duff depths when compared to plots outside firelanes (in each case $X^2>14$, $p<0.05$). Plots with rare species are generally quite similar to random firelane plots, although for each rare species (with the exception of *Scleria pauciflora*) at least one environmental variable differs significantly between occupied and unoccupied firelane plots (Figures 5-9).

Aristida purpurascens

There are at least four populations of *Aristida purpurascens* at MFCSF, and the total number of stems (conservatively estimated at 800; Table 7) is similar to the largest reported occurrence elsewhere in the Commonwealth (Table 8). In the largest of these, many hundreds of stems (possibly more than a thousand) extend over more than 1.5 kilometers. All occurrences are in old lanes established in the early 20th century. In only one instance were plants found in an old firelane widened with harrowing (in 1993 and 2000), where six clumps were found in the old portion of the firelane and ten in the new. Of plots sampled with *A. purpurascens*, five are in old lanes and one is in the newly harrowed portion of the widened firelane just described. *Aristida purpurascens* has been reported at MFCSF for two decades; occurrences were first reported there in 1985 and 2001.

A. purpurascens is found in areas with significantly lower vegetative cover (above 0.5 m; U=52, p= 0.01) and significantly lower herb cover (U=74, p=0.05) compared to randomly placed firelane plots (Figure 5). Cover of bare soil and litter is similar between the two and is variable in firelanes supporting this species, ranging from 0 to 52% and 44 to 98% respectively. Although not statistically significant, plots with *A. purpurascens* have greater grass cover than random firelane plots. Occupied plots are variable in this respect (varying from 32 to 96% cover) with 1/2 of the occupied plots having grass cover >75%, while fewer than 10% of random plots have equivalent grass cover. Several species occurring with *A. purpurascens* do so with greater frequency and/or abundance than is expected by chance (see Table 2; p< 0.05) including *Hypericum gentianoides* (INDVAL=65) and *Polygonella articulata* (INDVAL=38).

Table 2. Statistically significant indicator species for *Aristida purpurascens* ($p \leq 0.05$) showing the percent of perfect indication (INDVAL) of common species in firelane plots with and without the rare species. Significance test is based on a comparison between observed maximum INDVAL and that obtained from a randomized Monte Carlo test.

	P	INDVAL in plots with *Aristida purpurascens* (n=5)	INDVAL in plots without *Aristida purpurascens* (n=49)
Hypericum gentianoides	0.019	65	24
Polygonella articulata	0.025	38	0
Chrysopsis falcata	0.03	49	3
Viola pedata	0.03	63	18

Linum intercursum

Linum intercursum has the highest constancy of the five rare plant species at MFCSF (Table 7). More than 5500 stems were found in firelanes at MFCSF, making this by far the largest reported occurrence in the Commonwealth (Table 8). Half of the 22 plots sampled at *L. intercursum* occurrences are located in areas harrowed since 1993. The species is frequent in widened lanes C and D including in the newly harrowed portions of these lanes (Figure 2). *Linum intercursum* is also found regularly in newly harrowed lanes including in lanes B5E, B6E, B7E, A8E and 1A that are more isolated with respect to potential seed sources (i.e. the nearest known occurrence). Stems found in these new lanes are up to 0.25 km away from the nearest known *L. intercursum* occurrence. Records from MNHESP suggest that the species has occurred at MFCSF for at least two decades; by the mid-1980s at least four (and by the mid-1990s at least ten) scattered occurrences had been reported.

Plots with *Linum* have significantly lower duff depths (U=199, p= 0.01) and less vegetative cover (above 1.4 m; U=174, p=0.01) compared to randomly placed firelane plots (Figure 6). Cover of bare soil, lichen, and woody species is highly varied in occupied plots (from 0 to 64%, 0 to 65%, and 2 to 80% respectively) and is not significantly different between occupied and unoccupied plots. A number of species occur with *L. intercursum* with greater abundance and/or frequency than expected by chance (Table 3). Many of the strongest indicator species are absent from north and northwest lanes, but have successfully established in the newly harrowed sections of lanes C and D. These species include *Hypericum gentianoides* (INDVAL=62), *Polygala nuttallii* (INDVAL=65), and *Aristida dichotoma* (INDVAL=69). Other significant indicators are more common in lanes C and D than in other firelanes and include *Aletris farinosa* (INDVAL=23), and *Kalmia angustifolia* (INDVAL=41. The rare species *Scleria pauciflora* var. *caroliniana* (INDVAL=57) and *Nabalus serpentarius* (INDVAL=29) are also positively associated with *L. intercursum* in the dataset.

Table 3. Statistically significant indicator species for *Linum intercursum* ($p \leq 0.05$) showing the percent of perfect indication (INDVAL) of common species in firelane plots with and without the rare species. Significance test is based on a comparison between observed maximum INDVAL and that obtained from a randomized Monte Carlo test.

	P	INDVAL in plots with *Linum intercursum* (n=22)	INDVAL in plots without *Linum intercursum* (n=32)
Aristida dicotoma	0.001	69	10
Hypericum gentianoides	0.001	62	20
Lechea minor	0.001	62	29
Polygala nuttallii	0.001	65	14
Viola pedata	0.001	54	11
Aster spectabilis	0.002	63	19
Aletris farinosa	0.007	23	0
Kalmia angustifolia	0.007	41	5
Rubus sp.	0.007	46	8
Aster paternus	0.012	47	12
Nabalus serpentarius	0.013	29	0
Viola sp.	0.018	43	11
Polygala polygama	0.021	18	0
Tephrosia virginiana	0.025	41	11
Aronia sp.	0.028	42	11
Danthonia spicata	0.03	56	40
*Schizachyrium scoparium**	0.031	57	37
Scleria pauciflora	0.034	26	2
negatively associated with *Linum intercursum*			
Chrysopsis falcata	0.006	0	31
Carex pensylvanica	0.027	34	57

Nabalus serpentarius

Over 100 stems of *Nabalus serpentarius* were located in firelanes of MFCSF (Table 7), making the MFCSF occurrence larger than any other reported in the Commonwealth (Table 8). The majority of stems (more than 100) are located in the old portions of lanes C and D, where only 12 stems were reported to MNHESP in 1998. Eleven stems are found within the adjacent newly harrowed portions of these lanes. Seven of eight plots with *N. serpentarius* are in lanes C and D. I found several isolated individual stems more than 1 km from the nearest known occurrence.

N. serpentarius occurs in plots with significantly lower lichen cover (U=97, p=0.03) and higher litter cover (U=85, p=0.01) and depth (U=94, p=0.03) compared to unoccupied firelane plots (Figure 7). Cover of graminoid, herbaceous, and woody vegetation is variable in plots with *Nabalus serpentarius* (45-81%, 15-50%, and 23-79% respectively) and does not differ between occupied and unoccupied plots. Significant indicators for *N. serpentarius* include a number of species that are more common in lanes C and D than in other firelanes of MFCSF such as the rare species *L. intercursum* (Table 4). A number of woody species are positive indicators of the presence of *N. serpentarius* including *Kalmia angustifloia* (INDVAL=59), *Rubus* spp. (INDVAL=65), and *Amelanchier* spp. (INDVAL=43). *Gaylussacia baccata* (INDVAL=65) occurs frequently in firelanes but generally occurs with less than 1% cover, whereas in plots occupied by *N. serpentarius* in the old portions of lanes C and D its cover is frequently between 5-25%.

Table 4. Statistically significant indicator species for *Nabalus serpentarius* ($p \leq 0.05$) showing the percent of perfect indication (INDVAL) of common species in firelane plots with and without the rare species. Significance test is based on a comparison between observed maximum INDVAL and that obtained from a randomized Monte Carlo test.

	p	INDVAL in plots with *Nabalus serpentarius* (n=8)	INDVAL in plots without *Nabalus serpentarius* (n=46)
Gaylussacia baccata	0.001	65	26
Kalmia angustifolia	0.001	59	6
Linum intercursum	0.002	66	8
Rubus sp.	0.003	65	9
Amelanchier sp.	0.004	43	2
Aronia sp.	0.005	65	10
Solidago rugosa	0.007	64	23
Apocynum sp.	0.01	44	1
Vaccinium angustifolium	0.015	60	36
Aristida dicotoma	0.025	58	19
Aletris farinosa	0.028	34	0
Deschampsia flexuosa	0.028	51	15
Euthamia sp.	0.028	62	31
Quercus prinoides	0.033	56	19
Pyrola elliptica	0.04	23	0

Scleria pauciflora* var. *caroliniana

More than 1300 stems of *S. pauciflora* var. *caroliniana* were found at MFCSF in 2004 (Table 7) making this the second largest known occurrence in the Commonwealth (Table 8). At MFCSF, the species appears to exhibit the highest densities in newly harrowed firelanes. The species is found in several instances in lanes B5E, B6E, B7E, A8E, and 1A, frequently more than 0.25 km away from the nearest known occurrence. This species is infrequent in the old sections of lanes C and D, and establishment in the newly harrowed portions of these lanes occurred only within about 0.25 km of occurrences in old portions of these lanes. Of the ten plots sampled where *S. pauciflora* occurred, four are in old lanes and six in newly-harrowed areas. Records from the MNHESP indicate that five scattered occurrences were reported at MFCSF in the 1980s.

No significant differences in environmental characteristics are found between occupied and unoccupied plots (Figure 8). A number of characteristics are highly variable in occupied plots including cover of bare soil (0-64%) and lichen (0-27%) as well as graminoid (10-79%), herbaceous (10-45%) and woody (13-58%) species. Several species, including *Viola pedata* (INDVAL=67) and *Epigaea repens* (INDVAL=60) are positively associated with *S. pauciflora* in the dataset (Table 5). *Solidago odora* (INDVAL 61) is less frequent and abundant in plots containing *S. pauciflora*.

Table 5. Statistically significant indicator species for *Scleria pauciflora* var. *caroliniana* ($p \leq 0.05$) showing the percent of perfect indication (INDVAL) of common species in firelane plots with and without the rare species. Significance test is based on a comparison between observed maximum INDVAL and that obtained from a randomized Monte Carlo test. Species classified as grassland associates designated with a "*".

	P	INDVAL in plots with *Scleria pauciflora* (n=10)	INDVAL in plots without *Scleria pauciflora* (n=44)
Viola pedata	0.001	67	14
Epigaea repens	0.006	60	13
Cypripedium acaule	0.011	41	2
Tephrosia virginiana	0.019	49	12
Aster linariifolius	0.024	38	5
Aster paternus	0.036	51	15
Linum intercursum	0.039	46	12
Pinus rigida	0.043	57	37
Lespedeza capitata	0.046	57	31
Negatively associated with *Scleria pauciflora* var. *caroliniana*			
*Solidago odora**	0.008	27	61

Sisyrinchium fuscatum

More than 1300 stems of *S. fuscatum* were found in 2004 at MFCSF (Table 7) making this similar in size to the largest occurrence reported for the Commonwealth (Table 8). There are at least eight populations at MFCSF, each separated by more than 0.5 km one from the other. Most occurrences are in old firelanes and generally contained between 30 and 100 stems. However, the largest of these (with more than 600 stems) is in a newly harrowed portion of lane A9 where an occurrence existed prior to harrowing in the adjacent old portion of the firelane (with approximately 100 stems). Two individual stems are found along well-used trails - both in scrub oak bottoms, one of which is more than 0.5 km away from the nearest known *Sisyrinchium* occurrence. One occurrence with more than 100 stems was first reported to NHESP in 1935 and another with nearly 100 stems was first reported in 1980.

Plots with *S. fuscatum* have significantly lower cover of moss (U=65, p =0.03) and greater litter depth (U=55, p=0.01) than randomly located firelane plots (Figure 9). Although not statistically significant, plots with *S. fuscatum* have a greater grass cover than random firelane plots. Occupied plots are variable in this respect (varying from 18 to 96% cover), but half have grass cover >75%, whereas fewer than 10% of the random plots have equivalent grass cover. Although not significant, average vegetation cover (above 0.5 m) is lower in occupied plots than in randomly located plots. With the exception of one occupied plot in which vegetative cover is 48%, plots with *S. fuscatum* have cover <20%. Similar cover is found in only 45% of random firelane plots.

Compared to other firelane plots, those with *S. fuscatum* are unusual floristically. Five of six group separately from all other firelane plots in a cluster analysis (see

Appendix D). These outlier plots have high cover of a number of graminoid species including *Carex pensylvanica*, *Schizachyrium scoparium, Festuca filiformis* (INDVAL 60) *and Deschampsia flexuosa* and are also characterized by the presence of several species which are infrequent or absent in other firelanes, e.g. *Piptochaetium avenaceum* (INDVAL 33), *Luzula bulbosa* (INDVAL=33), *Toxicodendron radicans* (INDVAL=45), *Achillea millefolium* (INDVAL=32), *Anthoxanthum odoratum* (INDVAL=33) and *Holcus lanatus*. These five plots contain more than 15 species which were not sampled in any other plot on the Forest. All five, but especially SF7 and SF1, also lack species that occur frequently in other firelanes, e.g. *Panicum dichotomum* (INDVAL 61) *Polygala nuttallii* (INDVAL 62), *Aristida dichotoma* (INDVAL 59), *Lechea minor* (INDVAL 78), *Pteridium aquilinum* (INDVAL 76), and *Gaylussacia baccata* (INDVAL 72). Plot SF7 separates immediately from all other firelane plots and has greater cover of *Schizachyrium scoparium* (75-100%) than any other firelane plot. The five plots also have higher litter and lower lichen cover, and generally less bare soil and greater cover of grass species, than is typical of old firelanes.

Table 6. Statistically significant indicator species for *Sisyrinchium fuscatum* ($p \leq 0.05$) showing the percent of perfect indication (INDVAL) of common species in firelane plots with and without the rare species. Significance test is based on a comparison between observed maximum INDVAL and that obtained from a randomized Monte Carlo test. Species classified as grassland associates designated with a "*".

	p	INDVAL in plots with *Sisyrinchium fuscatum* (n=6)	INDVAL in plots without *Sisyrinchium fuscatum* (n=48)
Juncus sp.	0.001	83	3
Toxicodendron radicans	0.004	45	1
Prunus sp.	0.006	65	12
Luzula bulbosa	0.008	33	0
Anthoxanthum odoratum	0.012	33	0
Fragaria virginiana	0.012	33	0
Piptochaetium avenaceum	0.012	33	0
Eupatorium hyssopifolium	0.014	43	1
Achillea millefolium	0.024	32	0
Aster undulates	0.027	50	6
Festuca filiformis	0.031	60	14
Salix sp.	0.039	48	7
Comandra umbellata	0.04	29	1
negatively associated with *Sisyrinchium fuscatum*			
Lechea minor	0.001	3	78
Pteridium aquilinum	0.001	4	76
Gaylussacia baccata	0.002	3	72
*Panicum dichotomum**	0.011	32	61
Lespedeza capitata	0.02	9	61
*Helianthemum sp.**	0.028	34	59
Solidago puberula	0.029	18	59
Polygala nuttallii	0.033	2	62
Hypericum gentianoides	0.036	7	61
Aristida dichotoma	0.044	2	59

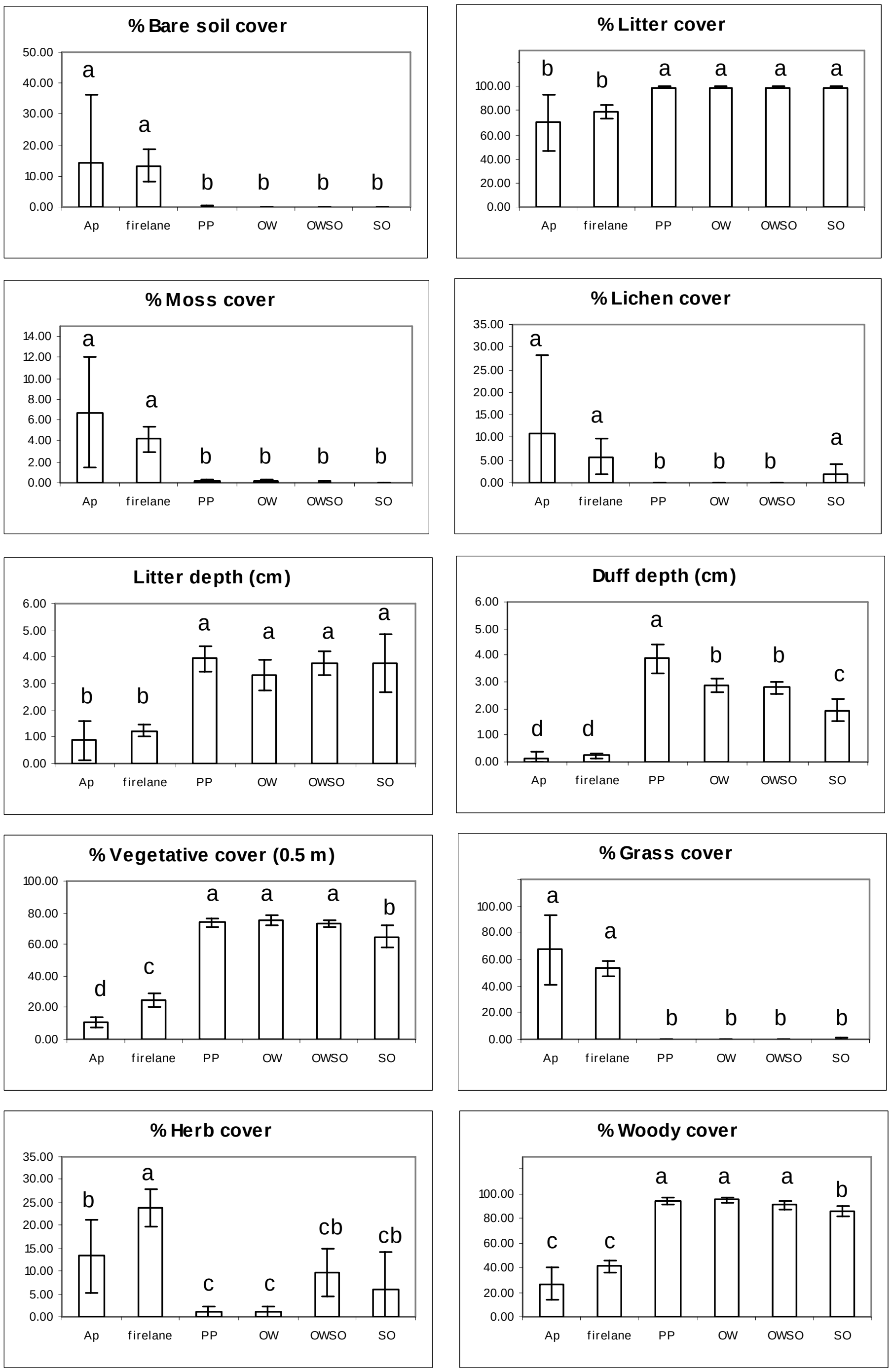
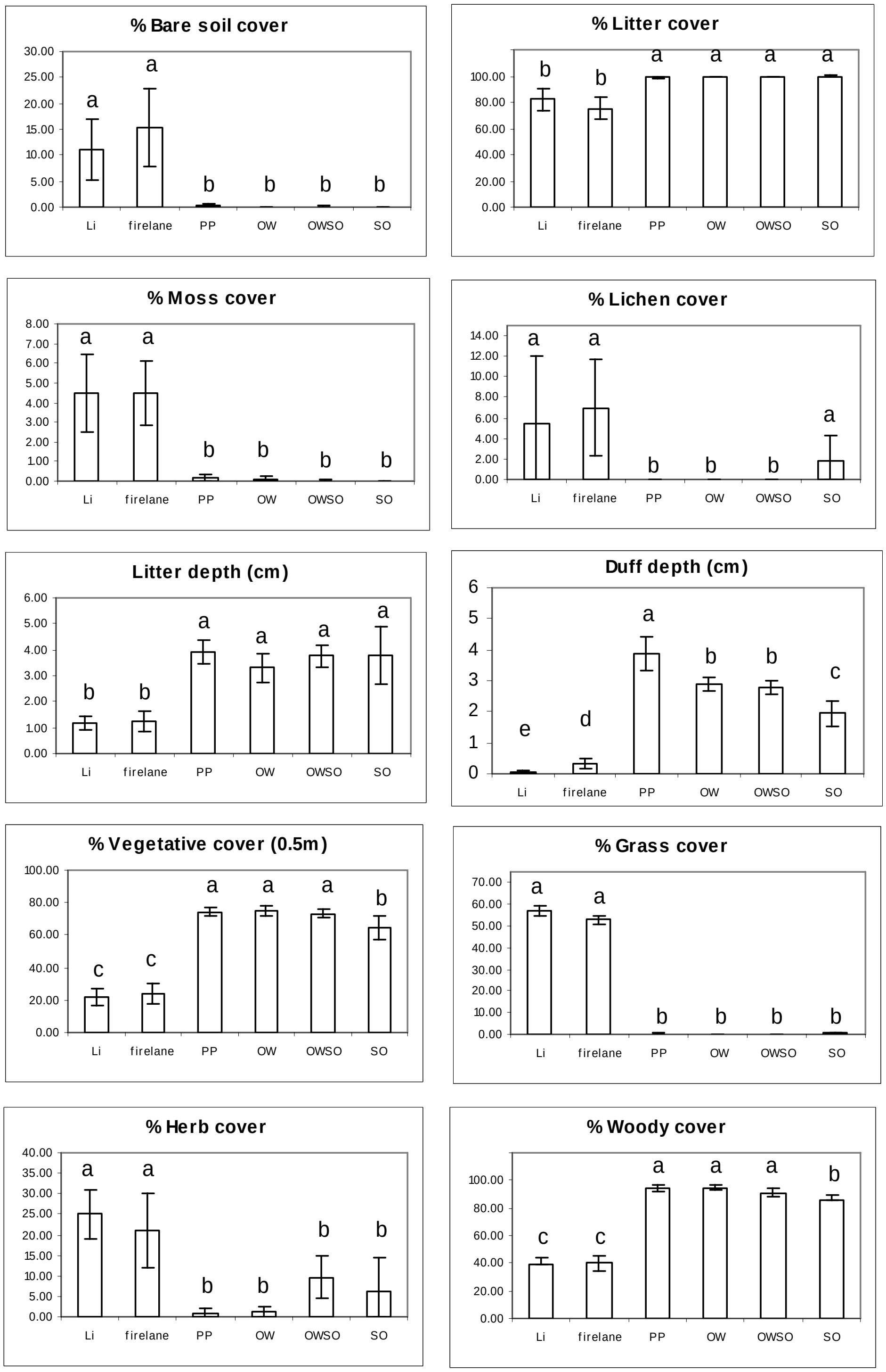


Figure 5. Mean values for environmental and vegetative structural variables in firelanes with *A. purpurascens* (Ap), and randomly located plots in firelanes (without *A. purpurascens*, noted as firelanes), pitch pine (PP), oak woodland (OW), oak woodland/scrub oak (OWSO), and scrub oak (SO) vegetation types. Error bars indicate 95% confidence interval. Values with different letters are significantly different ($p<0.05$ based on Mann-Whitney test).



% Bare soil cover

% Litter cover

% Moss cover

% Lichen cover

Litter depth (cm)

Duff depth (cm)

% Vegetative cover (0.5m)

% Grass cover

% Herb cover

% Woody cover

Figure 6. Mean values for environmental and vegetative structural variables in firelanes with *L. intercursum* (Li), and randomly located plots in firelanes (without *L. intercursum*, noted as firelanes), pitch pine (PP), oak woodland (OW), oak woodland/scrub oak (OWSO), and scrub oak (SO) vegetation types. Error bars indicate 95% confidence interval. Values with different letters are significantly different ($p<0.05$ based on Mann-Whitney test).

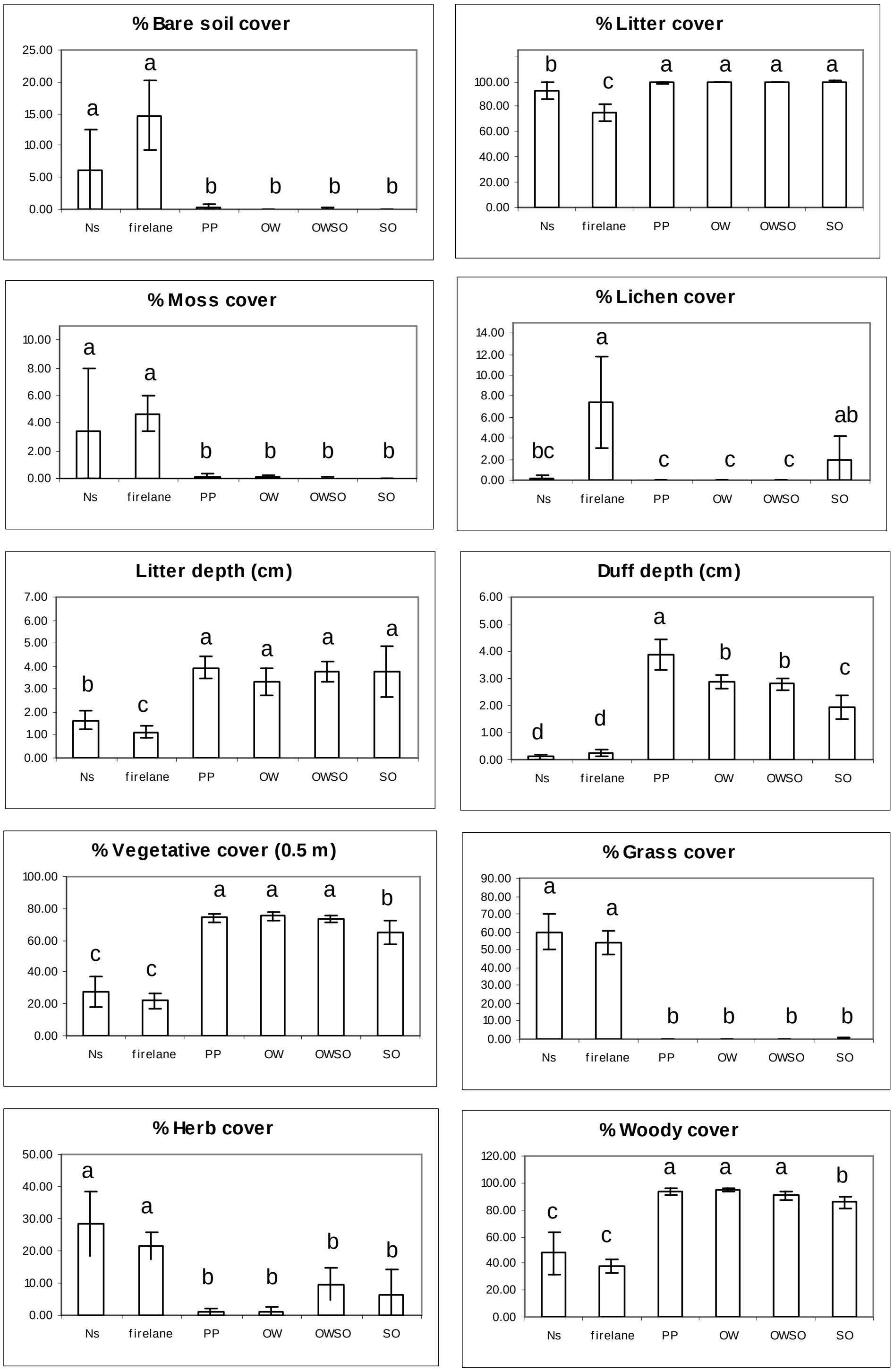


Figure 7. Mean values for environmental and vegetative structural variables in firelanes with *N. serpentarius* (Ns), and randomly located plots in firelanes (without *N. serpentarius*, noted as firelanes), pitch pine (PP), oak woodland (OW), oak woodland/scrub oak (OWSO), and scrub oak (SO) vegetation types. Error bars indicate 95% confidence interval. Values with different letters are significantly different ($p<0.05$ based on Mann-Whitney test).

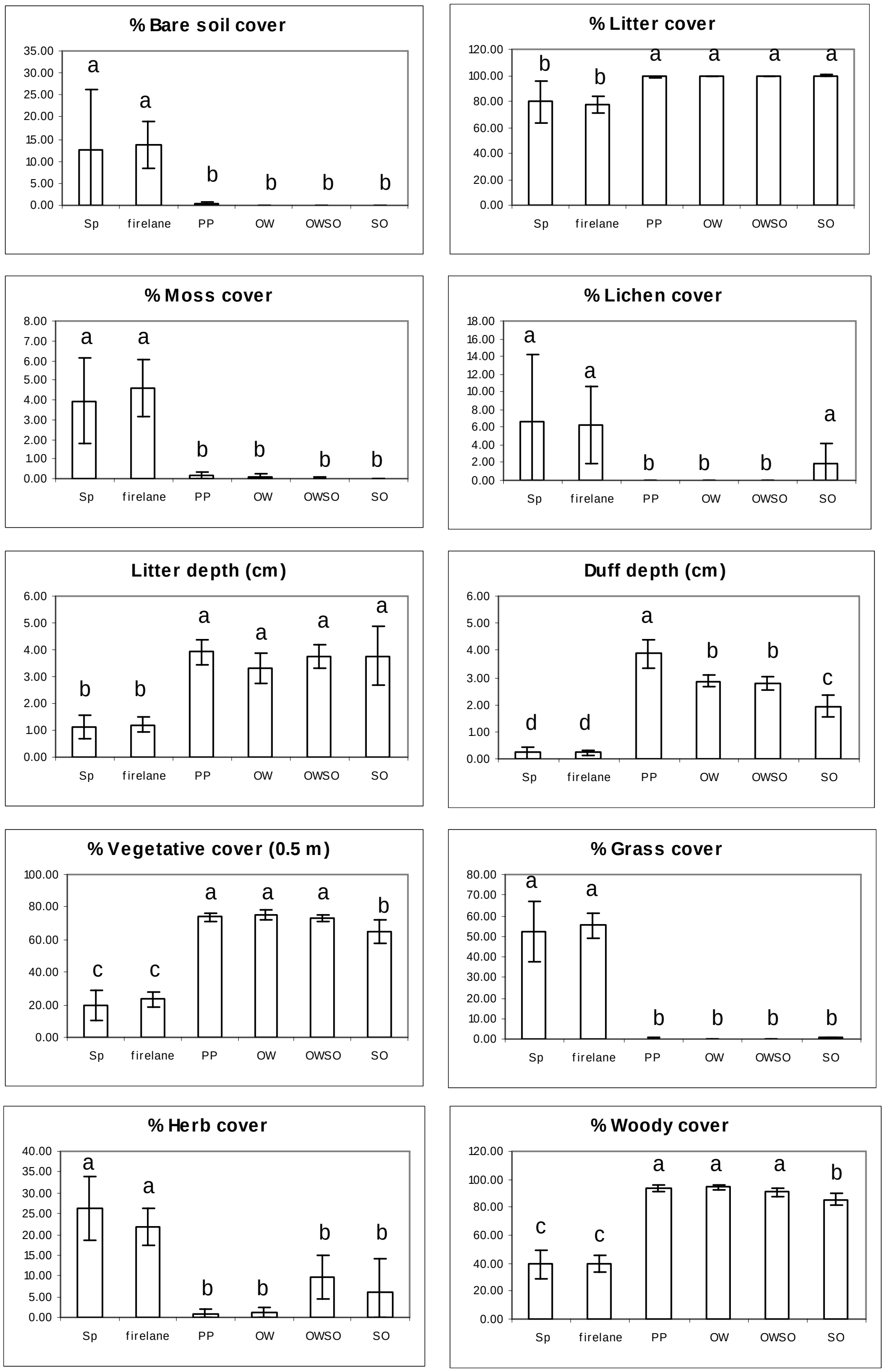


Figure 8. Mean values for environmental and vegetative structural variables in firelanes with *S. pauciflora* (Sp), and randomly located plots in firelanes (without *S. pauciflora*, noted as firelanes), pitch pine (PP), oak woodland (OW), oak woodland/scrub oak (OWSO), and scrub oak (SO) vegetation types. Error bars indicate 95% confidence interval. Values with different letters are significantly different ($p<0.05$ based on Mann-Whitney test).

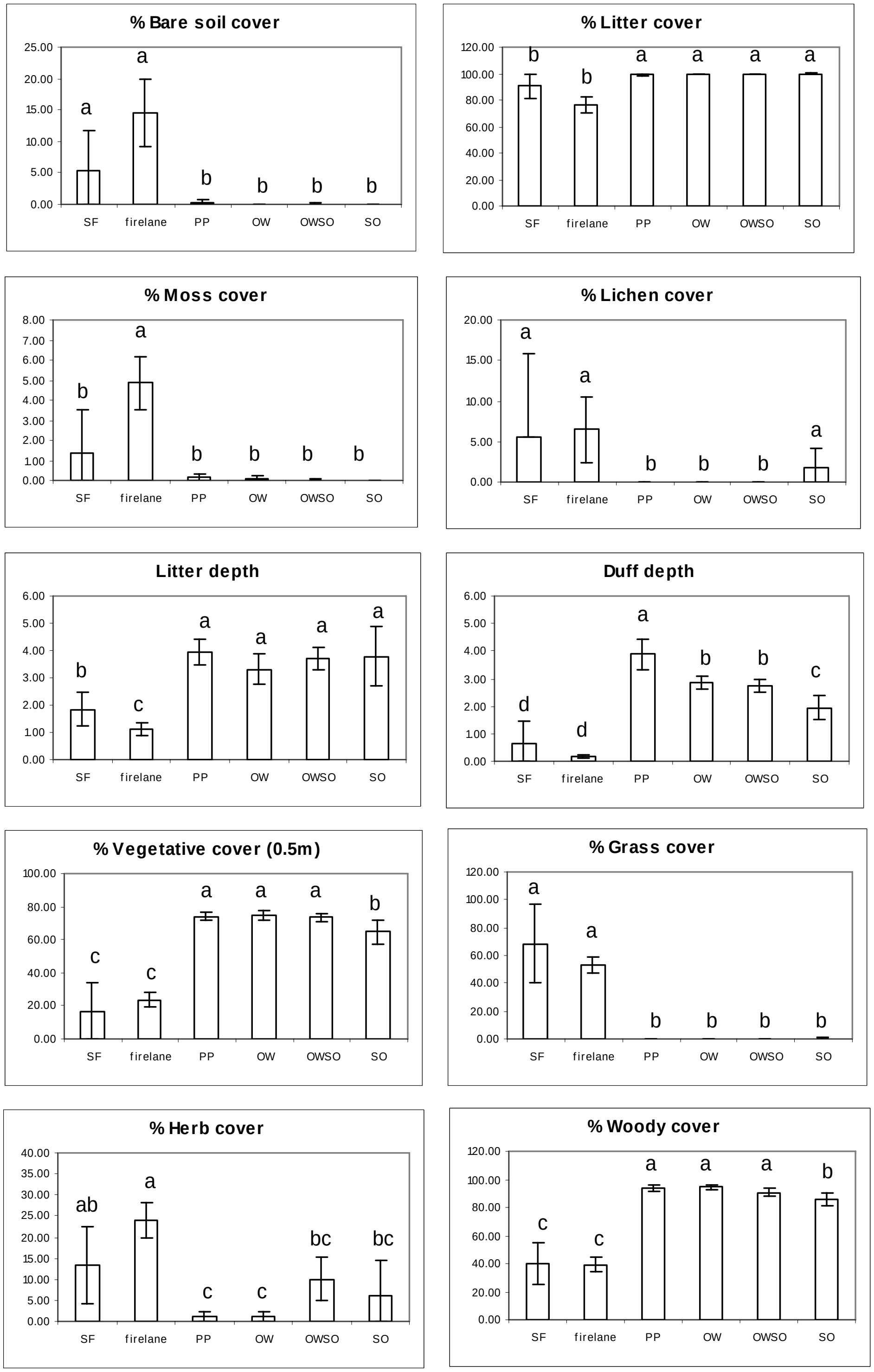


Figure 9. Mean values for environmental and vegetative structural variables in firelanes with *S. fuscatum* (Sf), and randomly located plots in firelanes (without *S. fuscatum*, noted as firelanes), pitch pine (PP), oak woodland (OW), oak woodland/scrub oak (OWSO), and scrub oak (SO) vegetation types. Error bars indicate 95% confidence interval. Values with different letters are significantly different ($p<0.05$ based on Mann-Whitney test).

Table 7. Present and historical sizes of rare plant occurrences of MFCSF. Historical data are from the Massachusetts Natural Heritage Program (MNHESP), 2004 data are the result of my sampling. The first reported survey (1^{st} survey) corresponds with the year the occurrence was first reported. The second survey represents the most recent survey made before 2003. Occurrences designated by a letter are more than 1/2 a mile from each other. Additional stems were listed separately for *L. intercursum* and *S. pauciflora* due to the high frequency of occurrence of these species.

Species	ID	1st survey (yr)	1st survey (# stems)	1st survey (total # stems)	2nd survey (yr)	2nd survey (# stems)	2nd survey (total # stems)	2004 survey (# stems)	2004 (total # stems)
Aristida purpurascens	A	1985	16+	19	2000	65+	65+	80+	800
	B	2001	3					70+	
	C							150	
	D							500-1000	
Linum intercursum	A	1982	100+	468+	1994	126	312		5500+
	B	1982	50						
	C	1982	40+		1988	2			
	D	1985	9		1994	184			
	E	1989	35						
	F	1989	25						
	G	1994	56						
	H	1994	66						
	I	1994	41						
	J	1994	1						
	K	88	10+						
	L	2001	35+						
								5500+	
Nabalas serpentaria	A	1998	11	12	2001	80	80	106	113
	B	2001	1					1	
	C							1	
	D							2	
	E							3	
Scleria pauciflora	A	1982	50	364+	1994	99	268	100+	1300+
	B	1985	50+		1988	25			
	C	1989	26					10+	
	D	1989	150+					10+	
	E	1989	52		1994	114			
	F	1994	10		2000	30		750+	
	G	1994	3					100+	
	H	1994	23					15+	
								319	
Sisyrinchium fuscatum	A	1980	100+	120+			286	30+	1300+
	B	1988	20+		1999	286		100+	
	C							130	
	D							600+	
	E							100	
	F							300	
	G							25	
	H							8	
	I							3	
	J							1	
	K							1	

Table 8. Number of reported, extant occurrences (reported since 1980) of five rare plant species in Massachusetts by approximate population size (based on data from Massachusetts Natural Heritage and Endangered Species Program). Population sizes are based on the most recent data available but do not include data collected in 2004 for this study at MFCSF. Extant occurrences with no population data collected since 1980 were omitted.

	apx. population size (# stems)					
Species	0-25	25-50	50-100	100-500	500-1000	1000+
Aristida purpurascens	4	3	2	3	3	1
Linum intercursum	11	14	5	9	1	1
Nabalus serpentarius	6	1	1	0	0	0
Scleria pauciflora var. *caroliniana*	6	1	0	2	1	1
Sisyrinchium fuscatum	8	7	6	11	1	0

Environmental Conditions in Forests and Shrublands of MFCSF

Environmental and vegetative structural characteristics differ among vegetation types outside of firelanes, with some types being more similar to firelanes (and plots supporting rare species) than others. In an ordination of forested/shrubland plots, stand structural features are highly correlated with axes 1 and 2 (Figure 10, Table 9). Scrub oak plots, which have low scores on both axes, are characterized by low cover of the canopy stratum (which is correlated with axis 1, r = 0.6 and axis 2, r = 0.62), high cover of the high shrub stratum (axis 1, r = 0.46), and low cover of the herb stratum (axis 1, r = 0.50). Vegetative cover, which is correlated with both axes 1 and 2, is significantly lower in scrub oak than other vegetation types (both when measured above 0.5 and 1.4 m, U>0, p<0.01). Scrub oak plots have significantly lower woody cover when compared to other vegetation types (U>4, p<0.01). Lichen cover is significantly higher in scrub oak plots than other forested vegetation types (U>18, p<0.05) and is equivalent to that found in plots containing each of the five rare plant species. Duff depth is strongly correlated with axis 2 (r = 0.69), and is highest in pitch pine (averaging 3.9 cm) and lowest in scrub oak (averaging 1.9 cm). Duff depth is significantly lower in scrub oak than in other vegetation types ($U > 0$, $p < 0.01$) and is more similar to that found in rare plant plots.

Although rare species are not found outside of firelanes, several grass and herb species are found in forests and shrublands. A set of grass and herb species – which I refer to as grassland associates- occur in more than 80% of firelane plots but less than 10% of forest/shrubland plots. Plots with grassland associates have significantly lower duff depth, higher lichen cover, and higher cover of herbaceous species than plots lacking those species (all $X^2 > 5$, $p < 0.04$, Table 10). Canopy cover is not significantly different between plots occupied by grassland associates and other randomly located plots. In four plots supporting grassland associates vegetative cover above 1.4 m is > 20%, where it ranges from 57 to 82%. Of the 54 forested/shrubland plots not containing grassland associates, 13 have average duff depths of less than 2.5 cm - the average found in plots with grassland associates. Grassland associates (Table 11, Appendix E) occur in four of seven plots characterized as scrub oak (SO10, SO4 ,SO0, SO15) as well as five of 57 plots characterized as oak woodland/scrub oak, oak woodland and pitch pine (PP10, PP14, OW7, SO12, SO1, and SO2; Figure 10).

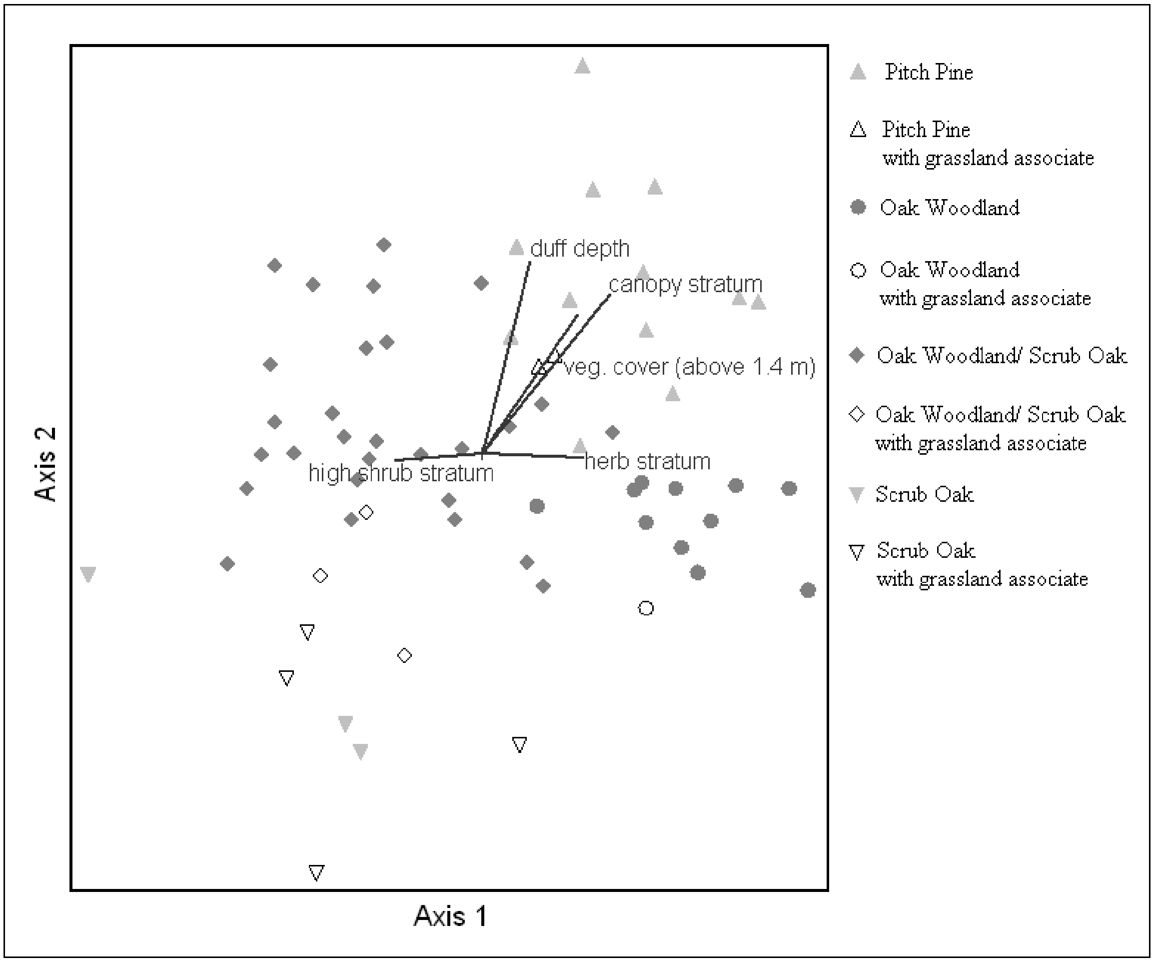


Figure 10. NMS ordination of 64 plots sampled off firelanes (final stress = 21.7 and instability = 0.001). Species occurring in only one or two plots were removed. Vegetation types were identified in cluster analysis (Appendix C); plots containing grassland associates are open. Vectors show the direction and strength of the relationship between plots and environmental variables (based on the correlation of those variables with each of the axes).

Table 9. Pearson correlation coefficients (r) for comparisons of vegetation/environmental variables and their scores on two axes for the NMS ordination of forest and shrubland plots (values > 0.40 are in bold; see Figure 9).

	Axis 1	Axis 2
canopy stratum cover	**0.559**	**0.624**
high shrub stratum cover	**-0.463**	-0.141
low shrub stratum cover	-0.096	0.122
herb stratum cover	**0.496**	-0.105
% bare soil cover	0.004	0.102
% litter cover	-0.045	-0.127
% moss cover	0.049	-0.008
% lichen cover	-0.186	-0.319
% coarse woody debris cover	0.122	0.144
% vegetative cover (0.5 m)	0.124	0.324
% vegetative cover (1.4 m)	**0.483**	**0.583**
ave. litter depth (cm)	-0.018	0.149
ave. duff depth (cm)	0.342	**0.687**
% graminoid cover	-0.073	-0.239
% herb cover	-0.379	-0.274
% woody cover	0.134	0.397

Table 10. Average values for environmental variables in forested/ shrubland plots with and without grassland associates with confidence interval half widths (p= 0.05) and associated p value (based on Kruskal-Wallis test).

	plots with grassland associates	plots without grassland associates	p value
% bare soil cover	0.1 ± 0.2	0.1 ± 0.1	0.6122
% litter cover	99.5 ± 0.6	99.5 ± 0.2	0.8111
% moss cover	0 ± 0	0.1 ± 0.1	0.3778
% lichen cover	1.3 ± 1.6	0 ± 0	< 0.0001
% coarse woody cover	0.8 ± 0.9	0.9 ± 0.5	0.8406
ave. litter depth (cm)	3.7 ± 0.9	3.7 ± 0.3	0.7183
ave. duff depth (cm)	2.5 ± 0.4	3.1 ± 0.2	0.0318
% graminoid cover	0.2 ± 0.5	0.1 ± 0.1	0.377
% herb cover	11.9 ± 9.3	4.3 ± 2.6	0.0058
% woody cover	90.3 ± 5.7	91.8 ± 1.8	0.6902
% vegetative cover (0.5 m)	70.2 ± 6.3	73.5 ± 1.5	0.1141
% vegetative cover (1.4 m)	32.2 ± 22.7	48.8 ± 5.8	0.0889

Table 11. Frequency of occurrence of common species (occurring in more than 33% of all plots sampled) in firelanes and forested/shrubland habitats. Significance was tested with G-test; test statistic (G) and p value are shown. Also shown is life form (grass, herbaceous or woody and annual or perennial). A G-test was not conducted for species with expected frequencies of <5 (Sokal and Rohlf 1995). Expanded table including all species is in Appendix E. Grassland associates (defined as occurring in > 80% of firelane plots and <20% forested/shrubland plots) are indicated by a "*".

a/p	life form	common name	scientific name	% firelane plots	% forest/ shrubland plots	G	p value
p	g	Forked Panic-grass	*Panicum dichotomum**	98	2	64.3	<.001
p	h	Cinquefoil	*Potentilla sp.**	96	2	63	<.001
p	g	Poverty-grass	*Danthonia spicata*	94	0		
p	h	Frostweed	*Helianthemum sp.**	98	5	53.8	<.001
p	h	Downey Goldenrod	*Solidago puberula*	89	0		
p	h	Sweet goldenrod	*Solidago odora**	91	3	53.3	<.001
p	h	Yellow Wild Indigo	*Baptisia tinctoria**	91	5	48.7	<.001
p	g	Bentgrass	*Agrostis sp.*	85	0		
p	h	Grass-leaf goldenrod	*Euthamia sp.*	85	0		
p	h	Thyme-leaf Pinweed	*Lechea minor*	85	0		
p	g	Little Bluestem	*Schizachyrium scoparium**	91	8	41.2	<.001
p	h	Bushy Aster	*Aster dumosus**	83	3	48.1	<.001
p	h	Whorled Loosestrife	*Lysimachia quadrifolia**	83	3	48.1	<.001
p	h	Round-headed Bush-clover	*Lespedeza capitata*	78	0		
p	h	Showy Aster	*Aster spectabilis*	72	0		
a	h	Orange Grass	*Hypericum gentianoides*	72	0		
p	w	Pitch Pine	*Pinus rigida*	89	38	8.1	0.005
p	g	Pennsylvania Sedge	*Carex pensylvanica*	91	41	7.1	0.01
p	w	Sweet Fern	*Comptonia peregrina*	91	42	6.4	0.025
p	w	Blackberry	*Rubus* sp.	69	22	10.7	<.001
			moss	87	55	1.8	
			lichen	78	52	1.1	
p	w	Post-oak	*Quercus stellata*	78	63		
p	w	Chokeberry	*Aronia* sp.	44	30	0.6	
p	h	Bracken	*Pteridium aquilinum*	80	66		
p	w	Trailing Arbutus	*Epigaea repens*	50	39	0.1	
a	h	Cow-wheat	*Melampyrum lineare*	43	42	0.3	
p	w	Scrub-oak	*Quercus ilicifolia*	98	100	1	
p	w	Late Sweet blueberry	*Vaccinium angustifolium*	93	95	1.1	
p	w	Early Sweet blueberry	*Vaccinium pallidum*	96	100	1.2	
p	w	White Oak	*Quercus alba*	61	72	2.1	
p	w	Sheep-laurel	*Kalmia angustifolia*	35	48	2.9	0.1
p	w	Black Huckleberry	*Gaylussacia baccata*	78	98	4.2	0.05
p	w	Dwarf Chinquapin-oak	*Quercus prinoides*	57	81	5.3	0.025
p	h	Pink Lady's Slipper	*Cypripedium acaule*	19	48	11.1	<.001
p	w	Black Oak	*Quercus velutina*	20	58	14.7	<.001

CHAPTER 6

DISCUSSION

Factors Affecting Rare Species Occurrence at MFCSF

Rare plant species are not found in the forests and shrublands of MFCSF, which have been largely undisturbed in the past half century. Rather they occur in firelanes harrowed in the early 1900s and mowed regularly since then. This finding is consistent with a large body of literature suggesting that coastal rare species are disturbance-adapted (e.g. Motzkin and Foster 2002, Zaremba 2004). Two rare species (*S. fuscatum* and *L. intercursum*) are occasionally found on well-worn trails in forested and shrubland habitats, also supporting the idea that these rare species occupy sites that are regularly disturbed.

Firelanes are characterized by environmental conditions typical of disturbed habitats. Rare species habitats, and firelanes in general, have significantly higher cover of bare soil, lower litter cover, lower litter and duff depths, higher grass cover, and lower woody and vegetative cover (measured at 0.5 m) compared to forests and shrublands. Floristically, rare species are associated with firelane vegetation with a high diversity of native sandplain grasslands by Dunwiddie et al. (1996; Clarke in prep).

The five rare species differ somewhat in their specific habitat requirements; the differences reflecting the disturbance history of sites they occupy. *Linum intercursum* and *Scleria pauciflora* are frequently found in recently harrowed areas. *Scleria* is associated with plots that are highly variable, whereas *Linum* is associated with particularly low duff depths and low vegetative cover (above 1.4 m). Conversely, *A. purpurascens*, *S. fuscatum* and *N. serpentarius* are infrequently found in newly harrowed lanes, and plots in old lanes occupied by these species are characterized by greater plant (especially grass) cover and cover/depth of litter/duff. Yet there are also differences among habitats occupied by these three species. *Nabalus serpentarius* has the most narrowly-defined habitat of the five rare species investigated, however its plots are the most likely to be spatially auto-correlated. *Nabalus*, unlike other rare species, is associated with somewhat greater (although not significantly different) woody cover than randomly located firelane plots. Compared to random plots, those occupied by *Nabalus* have significantly higher cover and depth of litter and lower lichen cover. *Aristida purpurascens* and *S. fuscatum* tend to occur in wide firelanes, in areas with high grass cover and low herb cover. *Sisyrinchium fuscatum* occurs in areas with high litter depth and low moss cover, whereas *A. purpurascens* occurs in plots with high cover of moss and lichen.

Linum intercursum and *S. pauciflora* are both frequent at MFCSF relative to the other rare species and readily colonized newly harrowed areas. Both are also conspicuous in their ability to colonize areas within a decade after they were harrowed (including in areas more than 1/3 km away from the nearest known occurrence for the species). They also appear to be most abundant in these recently harrowed areas. This is particularly interesting given that establishment in barrens soils for many common species may be limited more by recruitment than dispersal (Verheyen et al. 2003). Other studies have also found that *L. intercursum* and *S. pauciflora* can establish quickly following disturbances (Snyder 1994, Dunwiddie 1998, Clinton and Vose 2000, Zaremba 2003, Patterson and Clarke 2006), and *L. intercursum* has been associated with high cover of bare ground at Long Point on Martha’s Vineyard (Frey and Raleigh 1998). In New

England both species occur at sites with particularly recent and/or intense disturbances, such as sandpits (Appendix A).

That *Linum* and *Scleria* are able to readily colonize recently disturbed areas suggests that they may be characterized by prolific seed production, rapid dispersal and/or the capacity to bank seed. Zaremba (2004) notes, for example, that *S. pauciflora* plants may produce more seed in disturbed environments. Neither *Scleria* nor *Linum* appears to have adaptations for wind or animal dispersal, but both species produce abundant small seed, and it is possible that either one may have been dispersed to more remote areas by machinery or humans (bikers, pedestrians, and equestrians use firelanes). Several studies suggest that *S. pauciflora* may bank seeds (Oosting and Humphreys 1940, Clinton and Vose 2000, Zaremba 2004). *Scleria* also established in several small patches of bare soil within a year of being created by mechanical thinning in a pitch pine stand (more than 1/3 km from the nearest known occurrence for the species; Patterson and Clarke 2006). Some species of *Linum* bank seeds (Zaremba 2003), but it is not known whether *L. intercursum* does.

Different conditions occupied by *A. purpurascens, S. fuscatum*, and *N. serpentarius* in old firelanes may reflect differences in habitat preferences or species biology. *Nabalus* may be able to persist in shrubby areas because it can grow to 2 m tall and overtop shrub vegetation. It is heavily browsed by deer (pers. obs, and Everett and Lepley 2002), and may avoid herbivory by growing amongst shrubs. *Aristida purpurascens* and *S. fuscatum* which are associated with wide grassy firelanes may be less shade-tolerant than *N. serpentarius*. *Sisyrinchium fuscatum* occurs at MFCSF in grasslands that may be particularly “old”. For example, this species occurs in a large field near the state forest headquarters. This was one of the first areas to be plowed at MFCSF in the late 1800s (Foster and Motzkin 1999). It also occurs in one of the first firelanes (Varkonda pers. com.) developed at the boundary of MFCSF. The deep litter layer in grassland plots with *Sisyrinchium* also supports this idea. The earliest plowing at MFCSF was associated with agriculture (Foster and Motzkin 1999), so the association of *S. fuscatum* with a number of weedy and agricultural species may also support this interpretation. Frey and Raleigh (1998) found that unlike other rare species, *Sisyrinchium fuscatum* was not found in more open sites but rather with higher grass cover at Wasque and Long Point.

Aristida, *Sisyrinchium* and *Nabalus* are found almost exclusively in old lanes where they tended to occur in large isolated patches. The maintenance of appropriate habitat over a long period of time may mitigate biological limitations (e.g. low survival or seed set) characterizing these three species, especially *Nabalus serpentarius*. In this sense they are similar to "old field" species and have been so characterized by several authors (*A. purpurascens*: Smith 1940, Hotchkiss and Stewart 1947, Evans and Dahl 1955, *S. fuscatum*: Greller 1989). The largest recorded *A. purpurascens* population in Massachusetts occurs in an area that has been pastured since the Colonial era (MNHESP). The absence of these species in areas harrowed in the last decade is not particularly unusual (with the possible exception of the near absence of *Nabalas* stems in a recently harrowed area which was in very close proximity to a large population of the species).

Current firelane conditions may be more important as indicators of past disturbances than as indicators of the modern suitability of the sites for rare species especially when one considers that older firelanes now supporting *Aristida*, *Sisyrinchium* and *Nabalus* were probably more like recently plowed lanes when these species established. Firelanes with especially high grass cover, like those supporting *Sisyrinchium* and *Aristida*, may have been more thoroughly plowed than other firelanes, thereby resulting in slower establishment by woody species. Some sites supporting *Sisyrinchium* may have a longer or more intensive history of anthropogenic disturbance, possibly pastorage as suggested by the presence of weedy species and the proximity of those sites to an old farmhouse (now MFCSF headquarters) and the exterior of MFCSF.

The responses of rare species to disturbance are not always what might be expected based on their life history characteristics (although comparisons among species are somewhat dubious, as all are likely to exhibit a number of different biological limitations). *Linum* and *Scleria* appear from this study to be the most likely of the five species to bank seeds. Their small seed sizes are consistent with this; small seed sizes have been correlated with seed bank longevity in several studies (Thompson et al. 1993, Verheyen et al. 2003). Existing data suggest that of the five species, *Scleria pauciflora* is most likely to reproduce vegetatively (Appendix A), yet this was one of the species which readily colonized remote, recently harrowed areas. This may be explained by the species' reported ability to sprout from root fragments (Zaremba 2004). *Sisyrinchium fuscatum* forms dense stands in old firelanes and thus appears to be capable of tillering, which may explain its positive response to repeated mowing. Yet, two species which behave more like old field species (*N. serpentarius* and *A. purpurascens*) are not thought to be capable of extensive vegetative growth.

There is little evidence to suggest that species identified as significant indicators of the presence of individual rare plant species at MFCSF indicate the presence of these species elsewhere in the region. In my analysis *S. fuscatum* is associated with a number of weedy and uncommon species at MFCSF. Although *S. fuscatum* occurs at Wasque and Long Point in floristically homogenous plots, it does not, with the exception of *Achillea millifolium* (Frey and Raleigh 1998) occur there with the weedy species it is associated with at MFCSF. Further, both *S. fuscatum* and *L. intercursum* occur at Wasque and Long Point with only a few species identified as significant indicators at MFCSF (however *Gaylussacia baccata*, *Toxicodendron radicans*, *Helianthemum* sp. occur with *S. fuscatum* there). It is likely that the association of indicator species with individual rare species is the result of ephemeral and geographically-narrow differences in communities as a result of individual life history characteristics (dispersal abilities and response to disturbance), stochastic establishment events, and spatial auto-correlation of the data.

The Manuel F. Correllus State Forest appears to support not only one of the largest occurrences in Massachusetts for each of the rare species but also more total rare species than many natural areas (MNHESP). Yet caution is warranted as comparable searches have not been made in many other preserves. Furthermore, a comparison of population sizes among different natural areas is also not possible without a consideration of the area of suitable habitat within each. However, initial conclusions appear to suggest that plowing followed by repeated mowing has been as successful, if not more so, than other management strategies conducted in grasslands and heathlands throughout New England (including grazing and prescribed fire), at least in supporting the five rare species investigated. At the same time, several rare species (e.g. *Agalinis acuta*, *Spiranthes tuberosa* and *Malaxis bayardii*) were very infrequent in firelanes and additional research on these species should be a priority.

Forests and Shrublands as Potential Rare Plant Habitat

The distribution of rare plants and grassland associates at MFCSF suggests that deep organic layers and low lichen cover may prevent the occurrence of these species in forests and shrublands. Although rare plants are not found outside plowed firelanes, grassland associates (grasses and herbs found in > 80% of firelane plots) occur occasionally in forests and shrublands (<10% plots), associated there with lower duff depths and higher lichen cover than are found in forest and shrublands where these species do not occur. Few grass or herb species occur in barrens forests and shrublands and the presence of grassland associates may, generally speaking, indicate areas that are more likely to provide suitable habitat for rare plants. Experimental evidence suggests that management which creates bare soil benefits rare plants and grassland associates (Patterson and Clarke 2006). Although rare species differ in terms of characteristics of suitable habitat, and several species (*Sisyrinchium and Nabalus*) are found in firelanes with high litter cover/depth (relative to average firelane plots), all rare species are found in firelanes which have significantly lower litter cover, litter and duff depth, and canopy cover than forests and shrublands.

Organic layers may inhibit germination or establishment by their influence on light, heat and available moisture. They may prevent seeds from reaching mineral soil, or, should a seed germinate, litter may smother young seedlings (Baskin and Baskin 1998). In the dry barrens environment, duff affects water availability. Humus is hard to rewet once dry, and is thus may be a poor substrate for germinating seedlings (also posited by Evans and Dahl 1955). Lichen may directly enhance germination or establishment of grassland associates, but the relationship could also be indirect - high lichen cover may simply reflect low surface organic cover.

Shading may not preclude the occurrence of rare plants or grassland associates in forests and shrublands. Grassland associates (including *Helianthemum* sp. and *Solidago odora*) are found in forested stands with well-developed overstories (vegetative cover above 1.4 m of 60-80%), and canopy cover shading is not different between forested/shrubland plots that were occupied versus not occupied by grassland associates. *Linum intercursum* occurs on paths in forested stands with high canopy cover, and *Helianthemum* sp. occurs under dense scrub oak in disturbed sites (pers. obs.). Patterson and Clarke (2006) found that following treatments, colonization rates were highest in stands with low canopy cover (scrub oak and thinned pitch pine stands), however the effects of canopy cover and soil disturbance can not be separated in that study (because plots with reduced canopy cover also had soil disturbance).

Scrub oak is more likely to support rare plants than other vegetation types. This is not surprising, as scrub oak stands themselves require disturbances for their perpetuation (Motzkin and Foster 2002). In comparison to other vegetation types, scrub oak has low duff depths (this study, and Mouw 2002). Lichen cover is significantly higher in scrub oak than the other vegetation types and is equivalent to that found in firelanes and in plots supporting several rare species. Average duff depth in scrub oak stands is 1.9 cm compared to 3.2 cm in other community types and 0.2 cm in plots supporting any of the rare species (lichen cover is 2% in scrub oak stands, 0% in other types, and 6% in plots with rare species).

As in firelanes, anthropogenic disturbances create habitat for rare plants and grassland associates in forests and shrublands, but scrub oak stands are one of the only vegetation types which support grassland associates and conditions more like those found in firelanes without anthropogenic disturbance. None of the scrub oak stands I sampled showed evidence of recent anthropogenic disturbance. Where grassland associates occurred in other vegetation types, they were associated with unusually low duff depths and generally with evidence of anthropogenic disturbance (roads, trails, and mechanical disturbance). Modern forested stands have deep organic layers, and substantial anthropogenic disturbances are generally required to create appropriate habitat there (Patterson and Clarke 2006). One natural disturbance which created habitat for a grassland associate (*Helianthemum* sp.) in a forested (pitch pine) stand was a blowdown. Although pitch pine stands have probably never been common on Martha's Vineyard (see Stevens 1996), it is possible that windstorms may have created rare plant habitat in the past.

Several potentially important natural disturbance mechanisms affect scrub oak. Scrub oak stands in depressions experience microclimatic disturbances related to high daytime and low nighttime temperatures due to, respectively, high solar radiation and radiational cooling (Aizen and Patterson 1995, Motzkin 2002). At MFCSF this effect is common in topographic depressions (known as frost bottoms) which accumulate cold air at night and heat rapidly during the day. This could have the direct effect of retarding shrub growth (by shortening growing seasons, increasing water stress, and causing frost kill) and slowing litter production and development of the duff layer. Indirectly it could increase the likelihood for fire by perpetuating flammable short stature shrubs, fostering high daytime temperatures, and causing growing season frost kill (which creates dead and potentially dry standing stems). The possibility for a positive feedback exists wherein scrub oak is perpetuated by the combined effect of these mechanisms. Over the last half century, scrub oak in frost bottoms have been replaced more slowly by woodlands compared to other scrub oak stands (Mouw 2002).

An important finding of my research is that at least certain rare species (and several grassland associates) can persist in frost bottoms. It might be presumed that rare species (and many grassland associates), which tend to be at the northern edge of their ranges, would be especially susceptible to cooler microclimates found in frost bottoms. *Sisyrinchium fuscatum* and *N. serpentarius* and several grassland associated species (*Aster dumosus* and *Schizachyrium scoparium*) are found in scrub oak frost bottoms. In addition, *L. intercursum*, *S. pauciflora* and *S. fuscatum* are found in firelanes running through frost bottoms, and limited data suggest that mowed firelanes in frost bottoms experience at least some of the microclimatic effects of other frost bottoms (unpublished data). It may be that rare species are at the northern edge of their ranges on the New England coastal plain not only as a result of climate but also the availability of suitable, disturbed habitats. Thus, rare species occur in frost bottoms which, although cooler than surrounding areas, may also be susceptible to more frequent disturbances. My findings also suggest that frost bottoms may not be floristically depauperate as suggested Barbour et al. (1998) and others.

A natural disturbance capable of creating and maintaining bare soil is fire (Motzkin and Foster 2002), although there is no clear evidence of fire in stands now supporting grassland associates. High severity ground fires occurring during extended periods of summer drought in the summer can consume duff. Lightning-ignited fires are uncommon in the Northeast, but Native Americans often ignited fires (Bromley 1935, Day 1953, Cronon 1983, Patterson and Sassaman 1988). They are reported to have “burned the wood in November, when the grasse is withered and leaves dryed” (Wood 1634), and at least some of these fires must have burned when duff was dry thereby exposing mineral soil. The possibility remains that under a different fire regime bare soil may have been maintained or created at a spatial and temporal scale permitting the occurrence of rare species on the central plain.

Although most evidence in New England comes from prescribed fires in grasslands and heathlands, there is some evidence that fires in forests and shrublands can favor the establishment and/or expansion of rare species. *Scleria pauciflora* appeared following the application of several summer burns at Ram Pasture on Nantucket, and *S. fuscatum* populations increased in frequency following summer burns in the same grassland, although another small population apparently declined or was lost following spring burns (Dunwiddie 1998). Patterson and Clarke (2006) found that several grassland associates established following burning in forested stands, including in areas where brush piles would have caused an intense heating of the organic layer. *Scleria pauciflora* appeared following fires in woodlands at MFCSF (Patterson and Clarke 2006) and in the southeastern U.S. (Clinton and Vose 2000). *Nabalus serpentarius* rapidly resprouted and flowered following burning in a shrubland at MFCSF (Patterson and Clarke 2006). This species also occurs in a hardwood forest in central Massachusetts that is suspected to have been periodically burned over the past several decades (Everett and Lepley 2002).

Characteristics of firelanes occupied by the five rare species may reflect conditions that would be required in forests and shrublands that would support them. *Nabalus* may be the most likely of the five species to be supported outside firelanes, because it is found with high shrub and organic layer cover in firelanes. *Scleria pauciflora* and *L. intercursum*, with their capacity for rapid dispersal and establishment, may be able to take advantage of small, short- lived openings, although *L. intercursum* may require especially open conditions which may be difficult to create in forests and shrublands. *Aristida* and *Sisyrinchium* are found as dense stands in fairly open, grass-dominated firelanes. It would be difficult to create conditions in forests and shrublands like those found in firelanes supporting these species. However, it should be kept in mind that any species that historically occurred in forests and shrublands may have undergone extreme genetic alteration attendant with the dramatic shift in the habitats they occupy. This could also complicate the recolonization of suitable habitat should it be created in forests and shrublands.

CHAPTER 7

MANAGEMENT RECOMMENDATIONS

Although firelane management may have no pre-colonial analog, it has permitted the development of large rare-plant populations at MFCSF, so grasslands now supported in firelanes should be conserved. Repeated fall mowing (following seed production by most species) has maintained habitat for five rare plant species for many decades and will presumably continue to do so. Prescribed burning and grazing are more expensive alternatives to mowing (Patterson and Clarke 2006), and my research suggests that mowing alone is sufficient. Yet rare plant populations should be monitored, as habitat quality could decline or rare species could be competitively excluded (in which case, prescribed fire could be used to reduce the organic layer or a series of summer treatments- including mowing, grazing or fire- can reduce woody cover). In addition, should suitable habitat be created in forests and shrublands of MFCSF, firelanes may provide a seed source for their colonization.

This research provides evidence that rare plants could have occurred on the central plain prior to the advent of European disturbances. At present, deep organic layers may be one of the main environmental conditions precluding their occurrence there. Yet high severity ground fires occurring during the growing season– particularly during extended periods of drought- can consume duff or maintain it at low levels (Patterson unpublished). Fire was more important on Martha’s Vineyard prior to, in comparison to after, the arrival of Europeans but the nature of the fire regime shaped by Native

Americans is unknown. The possibility remains that a pre-colonial fire regime may have permitted the occurrence of rare plants on the central plain.

Today, a number of management options exist for sandplain barrens depending on the goals for that management: conservation of rare species, restoration of natural processes, reduction of fire hazard, and/or research. In a number of respects prescribed fire may be the preferred option because if rare plants occurred on the central plain in the past, fire is a likely disturbance mechanism to have created suitable habitat. However, prescribed fire is difficult to apply under summer draught conditions- when it would be most favorable for the creation of rare plant habitat- particularly on a scale that is traditionally used for management. Mechanical treatments, such as mowing and thinning, are increasingly being used to reduce wildfire hazard (e.g. Patterson and Clarke 2006, Lezberg et al. in press). These treatments, when used alone or in combination with fire, offer a safer and quicker alternative to the use of prescribed fire alone. In general, any treatments which create bare soil (or are conducted in areas where it already exists- naturally or artificially) can create suitable habitat rapidly (Patterson and Clarke 2006). However, it may be desirable to restrict more intensive mechanical treatments to exterior firelanes as these treatments- which cause soil disturbance and compaction- may complicate our understanding of the interaction between more “natural” (pre-colonial) disturbances and habitat characteristics in the future.

Scrub oak stands are more likely to support conditions suitable for rare plants and grassland associates than other vegetation types. Research which involves prescribed fire in scrub oak stands (e.g. that initiated by Patterson and Clarke 2006, and Lezberg et al. in press), including in frost bottoms, could be particularly enlightening. However, sparse oak woodland and pitch pine stands might also provide suitable habitat. These stands are most likely to have experienced habitat decline resulting from four decades of fire suppression, because intact tree canopies accelerate litter deposition. In these stands, where deep organic layers have developed, more intensive (or longer duration) treatments are probably necessary to create suitable habitat.

Although fire can presumably create and maintain rare plant habitat in forests and shrublands of the central plain, it is unclear whether it could do so over a spatial and temporal scale to permit the occurrence of rare plant populations. Because there are many permutations to potential fire effects (influenced by vegetation type, time since fire, seasonality, and weather conditions -both before, during, and after a fire), any of which may combine to determine the types of habitats supported post fire, a long future is ensured for sandplain research.

APPENDIX A

SPECIES BIOLOGY LITERATURE REVIEW

Aristida purpurascens

Aristida purpurascens is a densely tufted perennial, non-rhizomatous bunchgrass of the Poaceae family (Barkworth, 2003). The grass is not noticeable until it produces flowering culms in August, but is most readily identified when seed is dispersing and the awns are extended, from August through late fall (pers. obs.). The seeds may be dispersed by wind, or possibly also by animals. The species exhibits a wide range in eastern North America, extending south to Florida and west to Kansas and Missouri, and has northern disjunct occurrences in Michigan and Wisconsin. The species has a global and national rank of G5 and N5 for “Secure” (NatureServe 2005). Coastal Massachusetts is the Northern edge of the range for the species, although there is at least one population in southern Ontario, Canada (Argus et al., 1982). There are 18 extant populations in Massachusetts where the species is listed as Threatened (MNHESP). Several historic records from the early 1900s appear to document several occurrences for the species in Connecticut however there is now only one known extant population in the state. In Rhode Island there are three extant occurrences (Brumback et al. 1996). At present, occurrences for this species in Massachusetts are found primarily on Cape Cod and the islands but historical records indicate that the species was more widespread in the mid 19th to early 20th century, with a number of occurrences in the eastern part of the state and a few as far west as the Connecticut valley (MNHESP).

Massachusetts extant occurrences have been reported from sandplain grasslands and heathlands but also from a railroad bed (MNHESP). One of the largest populations in the state is in an area that has been continuously grazed since the time of colonization, the landowners reporting that *Aristida* is not palatable to sheep (Sorrie, 1987). Three Massachusetts populations have persisted at the same location for more than 50 years, in habitat described in each case as sandplain grassland. It is not clear how large these populations were in historical times but recent surveys, where available, have characterized the populations as containing between 60 and 500+ stems. Of 18 extant populations, four have more than 300 stems, five have between 100-300 stems, five have 30-100 stems, and 4 have fewer than 30 stems (MNHESP). Herbarium labels suggest that in Massachusetts the species has historically occurred in grasslands and along railroad beds and one specimen indicated that the plant was collected in a "dry sandy Pitch Pine woods" and additional specimens were from a "swamp" and "pond". Bicknell described *Aristida purpurascens* on Nantucket as common on "dry levels and barrens" (Bicknell, 1908). Herbarium records for specimens collected in Connecticut suggest that the species was found predominantly in sandy grasslands one specifically listed as "an abandoned pasture near shore". There is also one historical record from a swamp (MNHESP).

In the southern part of its range, *Aristida purpurascens* occurs in pine and oak savannahs (Allred, 1986; Hotchkiss and Stewart, 1947; Pessin, 1933), unplowed prairies including the tall-grass and mixed-grass prairies of Kansas and Oklahoma (Ray, 1959), abandoned fields (Evans and Dahl, 1955; Smith, 1940), glades (Baskin et al., 1995), rock outcrop communities (Mohlenbrock, 1959; Warner, 1926), and powerlines and roadsides (Diamond et al., 2002). The species has been reported from soils derived from limestone

(Baskin et al., 1995) and serpentine (Pohl, 1947) and sandstone (e.g. Mohlenbrock, 1959) bedrock. *Aristida purpurascens* can persist in extremely xeric habitats (e.g. Pessin, 1933; Mohlenbrock, 1959) however several reports suggest that the species can also be found in soils with high water holding capacity (Warner, 1926) or which experience frequent fall flooding (Baskin et al., 1995). It is interesting to note that in each of these more mesic habitats, occasional to frequent growing season droughts were also reported.

Aristida purpurascens is often referred to as being disturbance-adapted; suitable habitat reportedly being maintained by mowing (Diamond et al., 2002; Ray, 1959) and burning (Witsell, pers. comm.) and on occasion by human impacts such as car or foot traffic (Sorrie, pers. com). Where the species occurs in woodlands, disturbances such as fire may be necessary to maintain open conditions (Witsell, pers. com.) and other authors have suggested that the species' abundance in such environments is inversely proportional to the overstory cover (Pessin, 1933). Nicholson and Monk (1974) include *Aristida purpurascens* in a list of species that colonize sites within a few years of disturbance on the Georgia piedmont and its occurrence in areas recently disturbed by plowing or mechanical soil disturbance in Virginia also indicates its ability to rapidly colonize (Townsend, pers. com.). A number of other studies have reported that the species is not an early colonizer. In a field that had been abandoned for 50 years, *Aristida purpurascens* was most frequent and abundant on coarser textured soils which, unlike other areas, had not undergone erosion and were presumed to have been stable for much of the period (Evans and Dahl, 1955). Smith (1940) reported that *Aristida purpurascens* only came into farmland areas he studied in Oklahoma that had been abandoned for more than 30 years. There is also evidence that the species can persist for many decades after an initial disturbance, for example many decades after the abandonment of a pasture (Evans and Dahl, 1959) or in a pine stand that has regenerated on an old field (Hotchkiss and Stewart, 1947). These accounts suggest that the species is not necessarily an early colonizer, but rather a species that frequently takes longer to establish and once established can persist at one location for long periods if it is kept open (Witsell, pers. comm.; Sorrie, pers. com.).

Tyndall and Farr (1989) reported on the vegetation of Cherry Hill, an area on the Eastern Piedmont of Maryland with serpentine soils where *Aristida purpurascens* is one of the dominant herbaceous species in more open areas of the xeric, nutrient-poor soils. They suggest that although more open conditions supporting herbaceous species persist only on steep south-facing slopes in their study area, more of the landscape was in this condition prior to fire suppression. Historical and ecological lines of evidence (including tree cores and aerial photographs) do suggest that *Quercus marlandica* and *Quercus stellata* were dominant in the early 1900s, these areas now dominated by *Pinus virginiana* and *Juniperus virginiana*. In the more open oak savannahs where periodic fires occurred, herbaceous species may have been more common. Until the early 1900s, sheep grazing may also have influenced the open nature of the vegetation.

In the southern part of the range a pathogenic fungus of the Balansieae tribe has been found to infect *Aristida purpurascens* plants and cause stunted growth, and limited seed production (Phelps et al., 1993). Although it is known that infection can be transmitted through tillers to new vegetative plants, it is still not clear how new individuals are infected. Seed of infected plants did not contain fungal hyphae and attempts to inoculate uninfected plants, through a variety of mechanisms, were unsuccessful.

Linum intercursum

Linum intercursum is a perennial herb of the *Linaceae* family. Plants flower in July and August, although individual flowers may persist only one day (Knapp, pers. con.), and seed production occurs in August and September. In Massachusetts the species only occurs on Cape Cod and the islands. From Massachusetts, its range extends south along the coastal plain to North Carolina and extends inland to northwestern Georgia, northern Alabama, and eastern Tennessee with disjunct occurrences in Indiana. In New England, the species was historically known from only one other state, Connecticut, where it is now thought to be extirpated (NatureServe 2005). In inland locations occurrences can be found in serpentine barrens (Snyder, 1994) and the piedmont (Sorrie, pers.com). A number of states track the species, suggesting that it may be rare throughout its range (Snyder, 1994). The species global and national ranks are G4 and N4 meaning “apparently secure” (NatureServe 2005).

In Massachusetts, there are 41 extant populations seen since 1980 and the species is ranked “Special Concern”. Extant populations generally occur in sandplain grasslands but other habitats include cemeteries, powerlines, heathlands and pine/oak barrens in addition to several occurrences on coastal plain pond shores (MNHESP). Of the 41 extant populations, 2 have more than 300 stems, nine have 100-300 stems, eighteen have 30-100 stems and 12 have fewer than 30 stems. Four populations have persisted in the same location for at least 25 years; three in sandplain grasslands, one of reported at the same location for almost a century, and another on a coastal plain pondshore, persisting at the same site for over 50 years despite occasional years where plants were not present. Each of these populations contains at least 50 individuals, but there are as many as hundreds in one of the more recently reported populations (MNHESP). If historical records, derived largely from herbarium specimens, present an unbiased record of the distribution of *Linum intercursum*, it has always been restricted to Cape Cod and the islands in Massachusetts. Habitats that were associated with these historical occurrences again included pine/oak barrens and other wooded habitats but also ponds, swamps and bogs, in one case the habitat was listed as a cranberry bog (MNHESP). A specimen collected in Connecticut apparently occurred on a “gravelly shore of a river”. Two historic populations were supported in pine/oak barrens for several decades to more than 50 years; one was last seen in the early 1900s and the other in the 1970s.

In the southern part of its range, historical records also suggest that the species was supported in forested areas. Rodgers (1963) describes its habitat as “dry or more commonly moist soil, sometimes in the open, but usually in the semi-shade of oak or pine woods” and Snyder (1994) states that many specimens record the habitat as “dry sandy woods or dry oak and pine scrub”. Snyder (1994) also noted “an unusual record” of a “sandy, clayey border of an intermittent pond”. The species continues to be supported within open areas, grasslands and forested habitats (Gleason and Cronquist, 1991). Examples of the latter include recently burned pitch pine forest (Snyder, 1994) and longleaf pine-oak communities undergoing prescribed burning (Sorrie, pers. comm.). Furthermore, it has been suggested that fire suppression has resulted in this species decline throughout the eastern part of its range (e.g. Snyder, 1994).

Based on the results of two ex-situ germination experiments, the species may be best characterized as a short-lived perennial. After a period of cold storage, plants germinated and flowered in the next growing season, persisting at most only one additional growing season (Brumback, pers. com). Other members of the *Linum* genus have been shown to exhibit self-compatibility but information on *Linum intercursum* is lacking. Some evidence supporting the possibility that *Linum intercursum* may be self-compatible is derived from the fact that individual flowers persist only one day and also the fact that the plants do not display heterostyly (differentiation of style length between the flowers of different plants), which in has been shown to be linked to self-incompatibility in the genus (Nicholls, 1985). *Linum intercursum* plants may be unpalatable to grazing animals; all members of the genus produce compounds that can be acidic or toxic (Zaremba, 2003).

Nabalus serpentarius

Nabalus serpentarius is an herbaceous, taprooted plant of the family Asteraceae, tribe Lactuceae. The plant is considered to be perennial but field observations on Nantucket suggest that plants may be biennial and monocarpic, flowering only once in a lifetime. Its flowers, produced in August and September, are thought to be insect-pollinated and seeds, produced in September and October, are wind-dispersed. Several observations in New England and in the southeast suggest that plants may flower only when in open sunny conditions (Everett and Lepley 2002).

Nabalus serpentarius is found in the Eastern US, and its range extends south to Florida and Mississippi, west to Tennessee and Ohio and North to New York and Massachusetts. The species is considered secure in the mid-Atlantic and Southeast and as a result is ranked G5 and N5 (NatureServe 2005). In New England, herbarium records indicate that the species historically occurred in Massachusetts, Connecticut, Rhode Island and New Hampshire but extant occurrences are known only from Massachusetts and Connecticut (Brumback et al. 2006). This suggests that the species may have been more frequent on the landscape in the recent historical past, including into more inland locations. Many suspect that the regional decline of this and other early successional species is related to the widespread loss of open habitat which has followed the abandonment of agricultural land over the past two centuries.

In Massachusetts the species is ranked endangered and S1, critically imperiled. Of the seven populations that have been located in the past 25 years, one appears secure with about 50 plants. Two other populations contain between 10 and 20 plants. However, the remaining four populations in Massachusetts have fewer than 6 plants and of these, three have not been found in recent surveys (MNHESP). Some evidence suggests that *Nabalus serpantaria* may also occur in small populations in the southern part of its range and if this is true the species may possess adaptations which allow plants to persist with minimal outcrossed reproduction.

In New England, there are ten extant populations, half of which occur on the islands off Massachusetts and the other half are scattered inland occurrences in Massachusetts and Connecticut (Everett and Lepley 2002). Extant occurrences are mostly from grasslands and heathlands, powerlines and along trails but also occur at several locations in open woods and one is on an eroding coastal cliff. The largest population in Massachusetts has been maintained by mowing (MNHESP). Historic records suggest that the species was more widespread in the late 19th and early to mid 20th century. Herbarium specimens document the species in numerous locations in eastern Massachusetts, scattered throughout Connecticut and Rhode Island and an additional location in inland New Hampshire (Everett and Lepley 2002). The associated habitat for these historic locations was frequently described as wooded but clearings, roadsides and railroads were also noted. The habitat that supports this species in the southern part of its range has been described as open woods, thickets, fields, powerlines, and roadsides in both mesic and xeric conditions.

Although members of the Aster family are frequently self-incompatible, when in small populations, some have been found to exhibit self-compatibility. Although many *Nabalus serpentarius* populations are small, possibly throughout the species' range, there has been no research undertaken to determine if this species might be self-compatible. For self-compatible species, small populations may exhibit diminished compatibility from outcrossed reproductive events than larger populations. Several members of the tribe Lactuceae have the ability to produce seed without fertilization or meiosis by apomixis and this may also be possible for *Nabalus serpentarius* (Everett and Lepley 2002). Although *Nabalus trifoliolatus* and *N. serpentarius* have been found growing together, there is no evidence of hybridization between the two. It is not known whether, or to what extent, *Nabalus serpentarius* may spread vegetatively, however the fact that many populations throughout its range are small, suggest that it may not spread readily by vegetative growth. Seeds produced by a species of *Lactuca* were found to have a half-life of 1.5 to 3 years in the soil, however germination experiments conducted at the New England Wild Flower Society with *N. serpentarius* seeds have been largely unsuccessful (Brumback pers. com.).

Several early botanists suspected that the North American, African and East Asian *Prenanthes* should be in a separate genus or subgenus from their European, Japanese and Chinese counterparts. A genetic investigation confirmed that a North American species of *Prenanthes* was sufficiently different from a European congener (relative to its similarities with a North American *Taraxacum* species) to warrant placing the former in a separate, paraphyletic genus *Nabalus* (Everett and Lepley 2002).

Scleria pauciflora var. caroliniana

Scleria pauciflora var. caroliniana is a monoecious and perennial member of the Cyperaceae or sedge family. As with other sedges, *Scleria pauciflora* pollen is wind dispersed and despite adaptations which probably promote outcrossing, namely the separation of unisexual spikelets on the stem and disynchrony in development of male and female flowers, the species is probably self-compatible (Reznicek et al. 2002, Fairey 1967, summarized by Zaremba 2004). Seeds are produced between July and September. Some reports suggest that *Scleria* may only produce a few seeds per plant. If this is so, individual plant longevity and vegetative reproduction may be important to the persistence of many populations. However, other observations suggest that following disturbances plants may produce abundant seed, which would change the picture of population dynamics in those situations considerably. Seeds seem to require a cold treatment in order to germinate and field observations lend support to the idea that seeds may be viable in the soil for long periods (Zaremba 2004). The plant has thick rhizomes and following management, plants have been found to successfully establish from root fragments.

The range for *Scleria pauciflora* var. *caroliniana* extends from southern coastal New England in the North to Florida and Texas in the south and west to Kansas, Illinois and Michigan. Herbarium records indicate that the species once occurred in Maryland but otherwise the species is extant in all other states with historic locations (NatureServe 2005). In New England there are sixteen extant occurrences: 12 in Massachusetts, three in Rhode Island (1 additional historic location), and 1 in Connecticut (3 additional historic locations). The species is listed as Endangered (S1) in Massachusetts, Threatened (S1) in Rhode Island, and Endangered (S1) in Connecticut. *Scleria pauciflora* var *pauciflora*, which interbreeds with *Scleria pauciflora* var. *caroliniana* (Fairey, 1967) extends into Ontario, Canada and occurs at one location in Massachusetts with one additional historic location from New Hampshire. Because there are only a few extant occurrences in Massachusetts, it is considered Endangered in the state. Of the extant populations in Massachusetts, three of these appear to have more than 100 plants, three have between 25 and 50, and the remaining 6 populations have fewer than 10 plants. The population in Connecticut has about 25 plants whereas in Rhode Island populations contain only a few individuals. The population at MFCSF appears to be the largest in the state although this may be due in part to more thorough sampling. Most *Scleria pauciflora* populations, including those of both varieties, were first reported in 1980 or later. The species may be in the process of migrating northward and may have become more common recent times as a result. Earliest New England records include one from Massachusetts which dates to the mid 1800s (population is still extant) and three from Connecticut which date to the early 1900s. One historic record for *Scleria pauciflora* var *pauciflora* in New Hampshire dates to the early 1800s (Zaremba 2004).

In Massachusetts, *Scleria pauciflora* var. *caroliniana* is found in dry, open grassy areas, in a sandpit and in a "scrub-Pitch Pine ecotone bordering a sandplain grassland" (Schall and Digregorio, 1998). Human related disturbances including mowing, bulldozing, plowing, sandmining and prescribed burning have each been associated with different sites that currently support *Scleria* in New England (Zaremba, 2004). Historic habitats may have included shrublands; the habitat from an 1846 specimen was described as "a dry hill among scrub oaks". In the southern part of its range the species is found not only in sandy soils of the coastal plain but also in soils derived from serpentine, and limestone. In the southeast *Scleria pauciflora* occupies not only prairies and pinelands such as the long-leaf pine savannahs, and pine barrens, woodlands but also "seepage slopes and swamps" (Godfrey and Wooten, 2004).

Fire has apparently created appropriate habitat for *Scleria pauciflora* in both the southern part of the range (e.g. Clinton and Vose, 2000) as well as in New England (Zaremba, 2004). Following the application of summer thinning and fall burning treatments in a pine-hardwood stand in the southern Appalachians, *Scleria pauciflora* established within research plots where is did not occur previously in the third growing season following treatments (Clinton and Vose, 2000). There are two documented instances of populations establishing or re-establishing following fire in New England. In Ram Pasture on Nantucket, *Scleria pauciflora* plants became established following several summer burns where they were not known to occur previously (Dunwiddie, 1998). Another Massachusetts population re-appeared in 1989 about five years following prescribed burn, the last sighting having been 143 years earlier, in 1846. The latter example suggests that the *Scleria* seed may remain viable in the soil for decades, their hard seed coat being consistent with this (Zaremba, 2004). In a study in North Carolina of seed viability, which used a sampling of stands of different ages to evaluate changes that might be expected over time, surreptitiously, a single *Scleria pauciflora* seedling germinated from soil collected within a forested stand aged at 112 years (Oosting and Humphreys, 1940). The habitat presumably became unsuitable for *Scleria* soon after canopy closure and as it is unlikely that the seed would have been deposited after that time this suggests that the seed retained viability for many decades, since *Scleria* last occurred at that location. It has also been suggested that variability in seed coat strength may provide for variability in length of the seed storage period (Zaremba, 2004).

Sisyrinchium fuscatum

Sisyrinchium fuscatum is a perennial herb of the Iridaceae family. Plants flower from June to July and occasionally into August and disperse fruit from July to as late as October (Bicknell, 1899). Some members of the genus reproduce vegetatively from perennating buds at the base of the plant (Cholewa and Henderson, 1984). Along the coastal plain the species extends in the North to Massachusetts with disjunct occurrences in Nova Scotia, and in the south to Florida and Louisiana. The species is considered extirpated or endangered in Pennsylvania and Maryland and is listed as Historic in Rhode Island but its global rank is G5 or “Secure” (NatureServe 2005).

In Massachusetts the species is restricted to the islands and is listed as “Special Concern”. Habitats in which extant populations occur are generally described as sandplain grasslands and heathlands but the species is also reported from old fields, and roadsides. There are also individual records from a cemetery, coastal rocky bluffs, and a woodland and shrubland (MNHESP). Of the extant occurrences, four populations have more than 300 plants, eleven have 100-300 plants, thirteen have between 30- 100 stems, and six contain fewer than 30 stems. Five extant populations have apparently been supported at the same location for more than 50 years, their habitats being described as grasslands and in one case as heathland. One population has persisted in a cemetery for two decades. There are fourteen populations containing more than 100 individuals the majority of which occur in grasslands, but other habitats include an old pasture, a rocky coastal bluff and a roadside (MNHESP). Prescribed burning has been conducted in areas of Ram Pasture and Sanford Farm on Nantucket and somewhat conflicting results emerge in terms of its impacts on *Sisyrinchium arenicola*. Between the early 1980s and the mid

1990s seven biennial summer burns at Ram Pasture between and five spring burns and three late summer/fall mowings resulted in the increase in size of *Sisyrinchium fuscatum* populations. However over the same period biennial spring burning resulted in the loss of one preexisting *Sisyrinchium fuscatum* population (Dunwiddie, 1998).

Mowing also apparently created appropriate habitat for *Sisyrinchium fuscatum* which became established in a research plot at Ram Pasture on Nantucket following biennial summer mowing carried out there between 1983 and 1995. However, the species was supported at a low cover and frequency at the end of the period (Dunwiddie, 1998). Historic occurrences in Massachusetts are recorded only from heathlands and sandplain grasslands and are nearly all from the islands excepting individual records from Cape Cod and Norfolk County (MNHESP). For the past century or more, this species may have been consistently restricted to Cape Cod and islands and to open, unforested habitats, but caution is warranted as historical records can often be biased. In a floristic inventory of a property on Long Island, Greller (1989) reported that *Sisyrinchium fuscatum* was common only in old fields, and absent from young or mature woods, shrublands, lawns, recently fallowed fields, pond shores and disturbed areas. This quote also suggests that the species may not rapidly colonize disturbed areas. In Virginia, more recent observations of the species' absence in newly disturbed areas have prompted similar assessments (Townsend, pers. com.).

In the South, the taxonomy of the genus *Sisyrinchium* is in question as several species share the feature considered to be diagnostic for the species in the north (Bicknell 1899). This makes assessments of the habitat or species biology for *S. fuscatum* in the south difficult. In North Carolina, the larger taxonomic group that includes *Sisyrinchium* *fuscatum* and possibly also *S. rufipes* and *S. tenellum* is limited to the sandy coastal plain but also occurs outside the state in the piedmont region (Sorrie, pers. comm.). Plants from this group occur in somewhat mesic but usually xeric habitats. On the coastal plain the most common habitat for the group is in fire-maintained Longleaf Pine-Oak communities including occasionally along roadsides in such habitat. Plants can be found in powerlines but not in areas of recently plowed or scarified soil (Sorrie, pers.com.). In North Carolina, Bruce Sorrie (pers. com.) has generally seen plants occurring as scattered individual stems or in small populations.

Members of the *Sisyrinchium* genus have been found to display polyploidy and self-compatibility (Cholewa and Henderson, 1984). A better understanding of the breeding system of *Sisyrinchium fuscatum* would be necessary in order to better evaluate the biological limitations facing the species. If the species is capable of apomixis, for example, it may be able to persist in small populations whereas if hybridization is occurring the species may be facing a loss of genetic diversity. There is evidence that other members of the genus are heavily infested with VAM fungi (Trufem et al., 1990), are toxic to herbivores (Mendez et al., 1993), and contain allelopathic chemicals capable of suppressing growth of neighboring plants (Takahashi et al., 1995) but information on *Sisyrinchium fuscatum* is lacking.

APPENDIX B

DETAILED FIRELANE MANAGEMENT HISTORY

Initial firelane construction was carried out in the first three decades of the 20th century (see Figure 2). The intention was to harrow a strip 10 feet wide on either side of a dirt road all along the network of lanes throughout MFCSF. Many of the lanes were- although some were not- widened to this extent and many others have since receded in width due to encroachment at the edges (Varkonda, pers. comm.). Below I have used terminology in the following manner: fuelbreak refers to the low, managed vegetation generally on either side of a dirt road, while firelane is used to refer to both the dirt road and the (generally grassy) fuelbreak on either side of it. Below I have noted the approximate width of the fuelbreaks on either side of the firelanes, assessed in the summer of 2002. During the process of widening lanes (initiated in 1993) pre-existing fuelbreaks were avoided so that they could provide a seed source to the newly cleared areas adjacent to them. In those cases, I note the approximate width of the pre-existing fuelbreaks and then the extent to which they were widened on either side. This management history below is current through June 2004. Mowing was with a standard mower unless otherwise noted, and since 1987 mowing has been conducted in the fall to accommodate native plant phenology.

East/west running lanes

1A: Original narrow fuelbreaks existed on both the southwest (about 10 ft wide) and northeast side (about 4 ft wide) of this firelane in 1993, before expansion was undertaken. The southwest (state forest) side of this firelane was expanded to a width of 200 feet through clearing, harrowing, and rootraking (to remove stumps) in the winter of 1993/1994. This new lane was mowed in the fall of 1997 and in the summer of 2001 it was grazed by a flock of 390 sheep. In the spring of 2002 the new lane was again harrowed, however equipment problems prevented successive passes from being completed and the lane is not level enough to mow, and as such has not been mowed since that time.

A8E: Unlike most of firelanes where old fuelbreaks were present prior to widening, there was no original firelane in this location prior to 1993. This lane, about 200 feet wide, was created by clearing, harrowing, and rootraking to remove stumps in the winter of 1993/1994. In 2002 the lane was mowed with a brushhog. In 2003 the lane was mowed with a standard mower.

A9: Original narrow fuelbreaks existed on both the north (about 5 feet wide) and south (about 3 feet wide) side of this firelane prior to widening in 1993. The southern (state forest) side of the lane was widened to about 200 feet in the winter of 1993/1994 by clearing and subsequent harrowing. The eastern 1/3 of this newly widened area has been re-harrowed a number of times in the intervening years.

A10: Original narrow fuelbreaks existed on both the north (about 5 feet wide) and south side (3 feet wide) of this firelane prior to widening in 1993. The southern side of the lane was widened to about 200 feet by clearing and harrowing in the winter of 1993/1994. In 1997 the lane was mowed which has continued annually since that time.

A11: Original narrow fuelbreaks existed on both the N (about 7 feet wide) and S side (about 3 feet wide) of this firelane prior to widening in 2002. The south side of the lane was widened to about 200 feet by mowing with the brushhog.

A12: Original narrow fuelbreaks existed on both the north (about 5 feet wide) and south side (about 4 feet wide) of this firelane prior to widening in 2001. The south side of the lane was widened to about 200 feet by mowing with the brushhog in 2001. The central 1/3 portion of the lane, on the south side of the lane, was also harrowed prior to mowing with the brushhog in 2001.

B3,B4: Original narrow fuelbreaks exist on both the north (about 6 feet wide) and south (about 3 feet wide) sides of the firelane.

B5,B6,B7: Original narrow fuelbreaks exist on both the north (about 4-6 feet wide) and south (about 4-6 feet wide) sides of the firelane.

B5E, B6E: Unlike most of the firelanes where narrow fuelbreaks were present prior to widening, no original firelane occurred in this location prior to 1993. The lane was expanded to about 200 feet by clearing, harrowing, and rootraking to remove stumps in the winter of 1993/1994. In 2002 the new lane was mowed with a brushhog. In 2003 the lane was mowed with a standard mower and will be maintained in this way in the future.

B7E: Unlike most of the firelanes where narrow fuelbreaks were present prior to widening, no original firelane occurred in this location prior to widening in 1993. The lane was expanded to about 200 feet by clearing, harrowing, and rootraking to remove stumps in the winter of 1993/1994. In 2002 the new lane was mowed with a brushhog. In 2003 the lane was mowed using a standard mower. One section of this new lane, comprising about 1/3 its length (located near the center of the firelane) was harrowed again in the fall of 1994. This section was mowed with a standard mower in the fall of 1995 as has been done annually since that time.

B10,B11,B12: Original narrow fuelbreaks exist on both the north (about 3 feet wide) and south (about 4 feet wide) sides of the firelane.

C3,C4,C5,C6: Narrow fuelbreaks existed on both the north (about 4 ft wide) and south side (about 4 ft wide) of this firelane in 1993, before expansion was undertaken. Both the south and north side of the firebreak were widened about 25 feet (the entire width of the firelane now being almost 80 feet) by clearing, harrowing and rootraking in the winter of 1993/1994. The new sections of firelane on both the north and south side of the lane were harrowed again (only one pass with the harrow) in the spring of 2000. These new sections of the lane have not been mowed since with the exception of the far western end, lane C1, which was mowed in 2001.

C7,C7A: Original narrow fuelbreaks exist on both the north (about 2 feet wide) and south (about 15 feet wide) sides of the firelane.

D3,D4,D5,D6: Narrow fuelbreaks existed on both the north (about 4 ft wide) and south side (about 4 ft wide) of this firelane in 1993, before expansion was undertaken. Both the south and north side of the firebreak were widened about 25 feet (the entire width of the firelane now being almost 80 feet) by clearing, harrowing and rootraking in the winter of 1993/1994. The new sections of firelane, on both the north and south side of the lane, were harrowed again (three passes with the harrow) in the spring of 2000. These new sections have been mowed twice since then.

D8,D9,D10,D11,D12: Original narrow fuelbreaks exist on both the north (about 2 feet wide) and south (about 6 feet wide) sides of the firelane.

North/south running lanes

3B,3C,3D: Original narrow fuelbreaks exist on both the west (2-4 feet wide) and east (about 15-20 feet wide) sides of the firelane.

4B,4C,4D: Original fuelbreaks exist on both the west (15-20 feet wide) and east (about 2-3 feet wide) sides of the firelane.

5B, 5C: A narrow fuelbreak existed on the east side (about 4 ft wide) of this firelane prior to widening in 1993. A fuelbreak, about 15 feet wide, was created on the west side of the firelane, and this area has been mowed annually since.

5D: Original narrow fuelbreaks exist on both the west (2-3 feet wide) and east (about 2-3 feet wide) sides of the firelane.

6B: Original fuelbreaks exist on both the west (about 20 feet wide) and east (about 5 feet wide) sides of the firelane.

8B, 8C, 8D: Original fuelbreaks exist on both the west (about 2 feet wide) and east (about 2 feet wide) sides of the firelane.

9C,9D: Original fuelbreaks exist on both the west (about 12-15 feet wide) and east (about 2-3 feet wide) sides of the firelane.

10A, 10B: Original fuelbreaks exist on both the west (about 2 feet wide) and east (about 2 feet wide) sides of the firelane.

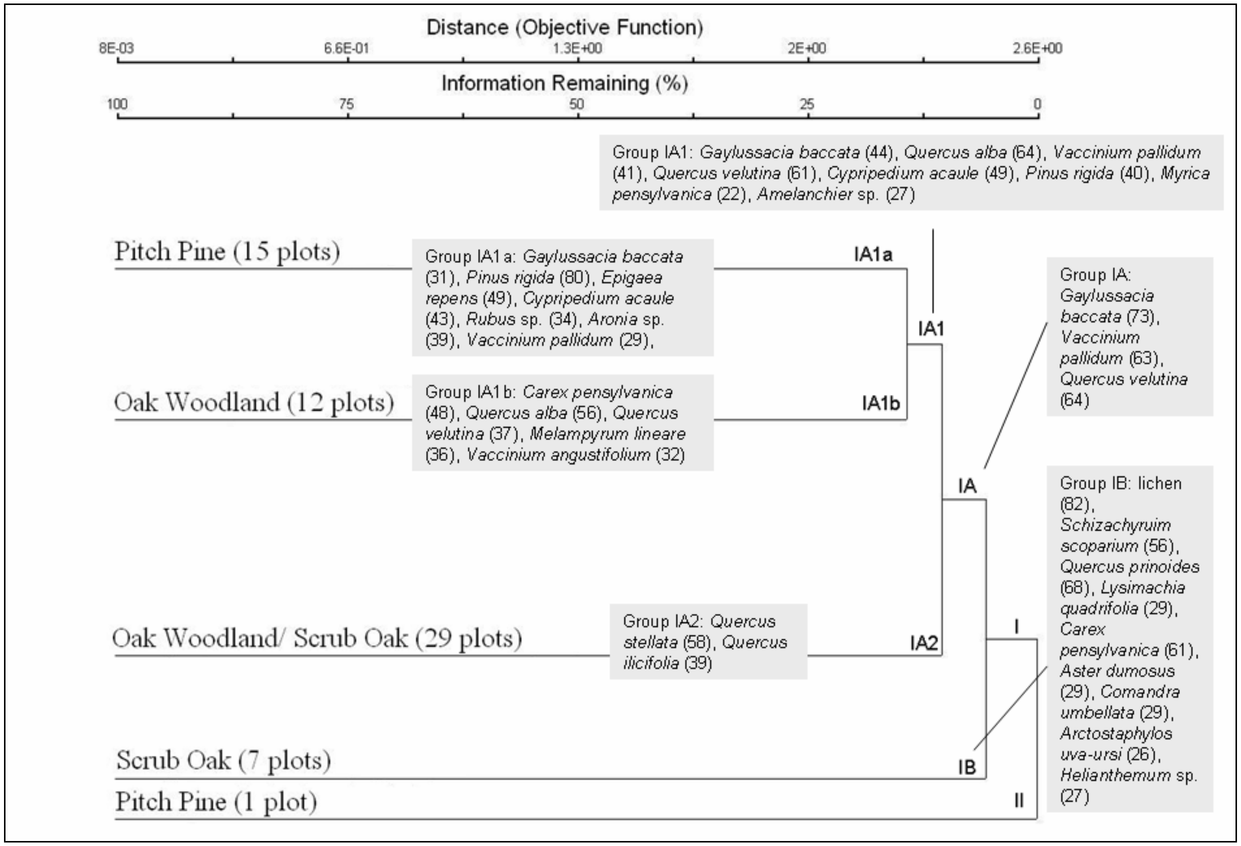
11A, 11B: Original fuelbreaks exist on both the west (about 5-7 feet wide) and east (about 2 feet wide) sides of the firelane.

11D: Original fuelbreaks exist on both the west (about 2 feet wide) and east (about 4 feet wide) sides of the firelane.

12A, 12B, 12D: Original fuelbreaks in this lane are substantially wider than in other lanes, the west side being about 30 feet wide and east about 20 feet wide. The lane has been maintained at this width because it is partially in a powerline right-of-way.

APPENDIX C

CLUSTER ANALYSIS OF FOREST AND SHRUBALND PLOTS



Group IA1: *Gaylussacia baccata* (44), *Quercus alba* (64), *Vaccinium pallidum* (41), *Quercus velutina* (61), *Cypripedium acaule* (49), *Pinus rigida* (40), *Myrica pensylvanica* (22), *Amelanchier* sp. (27)

Group IA1a: *Gaylussacia baccata* (31), *Pinus rigida* (80), *Epigaea repens* (49), *Cypripedium acaule* (43), *Rubus* sp. (34), *Aronia* sp. (39), *Vaccinium pallidum* (29),

Group IA1b: *Carex pensylvanica* (48), *Quercus alba* (56), *Quercus velutina* (37), *Melampyrum lineare* (36), *Vaccinium angustifolium* (32)

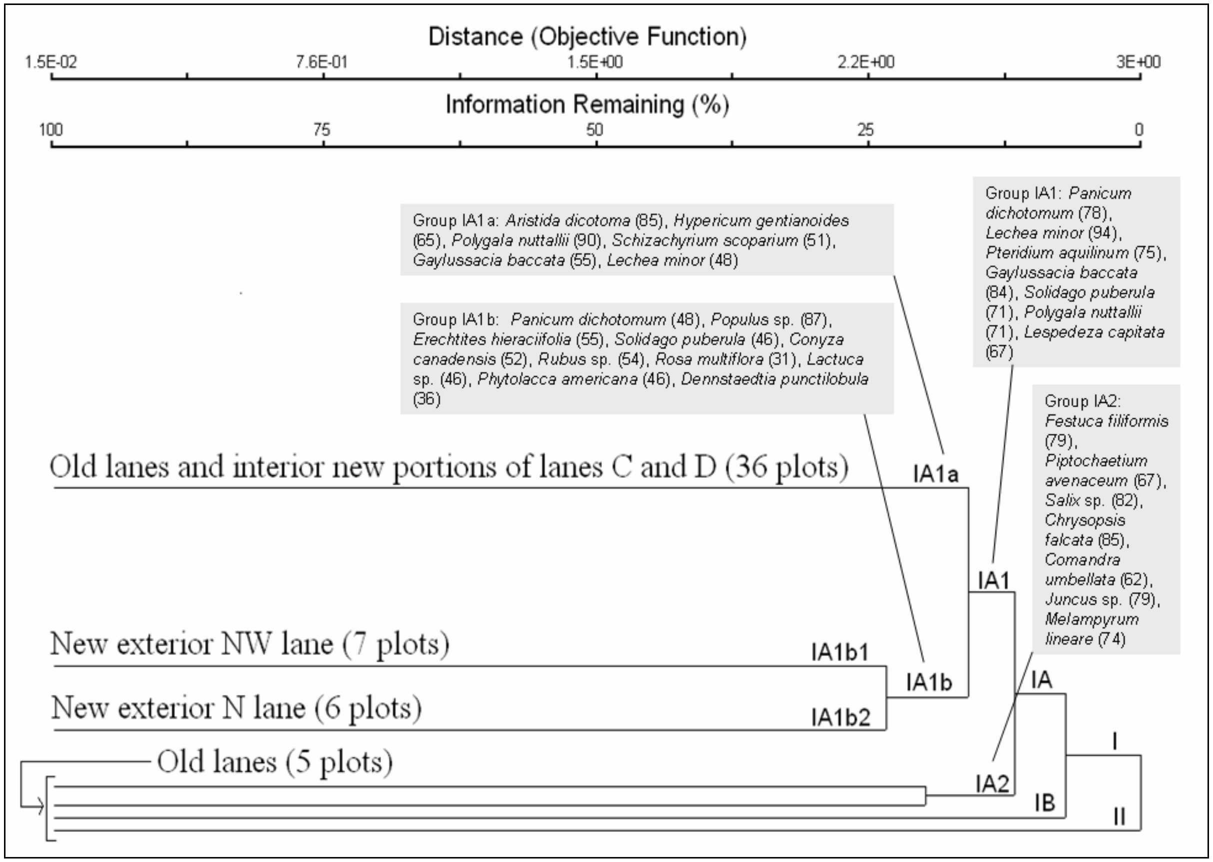
Group IA2: *Quercus stellata* (58), *Quercus ilicifolia* (39)

Group IA: *Gaylussacia baccata* (73), *Vaccinium pallidum* (63), *Quercus velutina* (64)

Group IB: lichen (82), *Schizachyruim scoparium* (56), *Quercus prinoides* (68), *Lysimachia quadrifolia* (29), *Carex pensylvanica* (61), *Aster dumosus* (29), *Comandra umbellata* (29), *Arctostaphylos uva-ursi* (26), *Helianthemum* sp. (27)

APPENDIX D

CLUSTER ANALYSIS OF FIRELANE PLOTS



Group IA1a: *Aristida dicotoma* (85), *Hypericum gentianoides* (65), *Polygala nuttallii* (90), *Schizachyrium scoparium* (51), *Gaylussacia baccata* (55), *Lechea minor* (48)

Group IA1b: *Panicum dichotomum* (48), *Populus* sp. (87), *Erechtites hieraciifolia* (55), *Solidago puberula* (46), *Conyza canadensis* (52), *Rubus* sp. (54), *Rosa multiflora* (31), *Lactuca* sp. (46), *Phytolacca americana* (46), *Dennstaedtia punctilobula* (36)

Group IA1: *Panicum dichotomum* (78), *Lechea minor* (94), *Pteridium aquilinum* (75), *Gaylussacia baccata* (84), *Solidago puberula* (71), *Polygala nuttallii* (71), *Lespedeza capitata* (67)

Group IA2: *Festuca filiformis* (79), *Piptochaetium avenaceum* (67), *Salix* sp. (82), *Chrysopsis falcata* (85), *Comandra umbellata* (62), *Juncus* sp. (79), *Melampyrum lineare* (74)

APPENDIX E

LIST OF ALL SPECIES SAMPLED

Frequency of occurrence of all species sampled in firelanes and forested/shrubland habitats. Significance was tested with G-test; test statistic (G) and p value are shown. Also shown is life form (grass, herbaceous or woody and annual or perennial). A G-test was not conducted for species with expected frequencies of <5 (Sokal and Rohlf 1995). Grassland associates (defined as occurring in > 75% of firelane plots and <20% forested/shrubland plots) are indicated by a "*".

a/p	life form	common name	scientific name	% firelane plots	% forested/ shrubland plots	G	p value
p	g	_Forked Panic-grass_	_Panicum dichotomum*_	98	2	64.3	<.001
p	h	Cinquefoil	Potentilla sp.*	96	2	63	<.001
p	g	_Poverty-grass_	_Danthonia spicata_	94	0	0	
p	h	_Frostweed_	Helianthemum sp.*	98	5	53.8	<.001
p	h	_Downey Goldenrod_	_Solidago puberula_	89	0	0	
p	h	Sweet goldenrod	_Solidago odora*_	91	3	53.3	<.001
p	h	Yellow Wild Indigo	_Baptisia tinctoria*_	91	5	48.7	<.001
p	g	_Bentgrass_	Agrostis sp.	85	0	0	
p	h	_Grass-leaf goldenrod_	Euthamia sp.	85	0	0	
p	h	_Thyme-leaf Pinweed_	_Lechea minor_	85	0	0	
p	g	_Little Bluestem_	_Schizachyrium scoparium*_	91	8	41.2	<.001
p	h	_Bushy Aster_	_Aster dumosus*_	83	3	48.1	<.001
p	h	_Whorled Loosestrife_	_Lysimachia quadrifolia*_	83	3	48.1	<.001
p	h	_Round-headed Bush-clover_	_Lespedeza capitata_	78	0	0	
p	h	_Showy Aster_	_Aster spectabilis_	72	0	0	
a	h	_Orange Grass_	_Hypericum gentianoides_	72	0	0	
p	h	_Rough goldenrod_	_Solidago rugosa_	69	0	0	
p	g	_Depauperate Panic-grass_	_Panicum depauperatum_	67	0	0	
a	h	_Nuttall's Milkwort_	_Polygala nuttallii_	65	0	0	
A	g	_Church-mouse Three-awn_	_Aristida dichotoma_	61	0	0	
p	h	_Pearly Everlasting_	_Anaphalis margaritacea_	57	0	0	
p	w	_Winged Sumac_	_Rhus copallinum_	57	0	0	
p	g	_Hair-fescue_	_Festuca filiformis_	54	0	0	
p	h	_Bird's Foot Violet_	_Viola pedata_	54	0	0	
p	w	_Pitch Pine_	_Pinus rigida_	89	38	8.1	0.005
p	g	_Pennsylvania Sedge_	_Carex pensylvanica_	91	41	7.1	0.01
p	h	_Toothed White-topped Aster_	_Aster paternus_	50	0	0	

a/p	life form	common name	scientific name	% firelane plots	% forested/ shrubland plots	G	p value
p	w	*Sweet Fern*	*Comptonia peregrina*	91	42	6.4	0.025
p	h	Beach-pinweed	*Lechea maritima*	48	0	0	
p	g	*Common Hairgrass*	*Deschampsia flexuosa*	50	3	25.2	<.001
p	w	Blackberry	Rubus sp.	69	22	10.7	<.001
p	h	*Narrow-leaved White-topped Aster*	*Aster solidagineus*	46	0	0	
p?	h	*Violet*	Viola sp.	46	0	0	
p	h	*Goat's Rue*	*Tephrosia virginiana*	44	3	21.5	<.001
p	w	*Golden Heather*	*Hudsonia ericoides*	41	0	0	
p	h	*Sandplain Flax*	*Linum intercursum*	41	0	0	
p	w	Dewberry	Rubus sp.2	43	5	17.1	<.001
			moss sp.	87	55	1.8	
p	w	Cherry	Prunus sp.	43	11	8.8	0.005
p	h	*Wavy-leaved Aster*	*Aster undulatus*	30	0	0	
p	w	Willow	Salix sp.	30	0	0	
p	g	*Rush*	*Juncus sp*	28	0	0	
p	w	*Bearberry*	*Arctostaphylos uva-ursi*	37	9	7.8	0.01
			lichen	78	52	1.1	
p	h	*Stiff-leaved Aster*	*Aster linariifolius*	26	0	0	
p	w	*Aspen*	Populus sp.	26	0	0	
a/wa	h	*Blue Toadflax*	*Linaria canadensis*	24	0	0	
p	h	Gray goldenrod	*Solidago nemoralis*	24	0	0	
a	h	*Pilewort*	*Erechtites hieraciifolia*	22	0	0	
a	h	*Horseweed*	*Conyza canadensis*	20	0	0	
p	h	*Sickle-leaved Golden-aster*	*Chrysopsis falcata*	19	0	0	
p	g	*Papillose Nut-sedge*	*Scleria pauciflora var. caroliniana*	19	0	0	
p	w	*Birch*	Betula sp.	17	0	0	
p	w	*Post-oak*	*Quercus stellata*	78	63	0	
p	h	*Lion's Foot*	*Prenanthes serpentaria*	15	0	0	
p	w	*Chokeberry*	Aronia sp.	44	30	0.6	
p	h	*Bracken*	*Pteridium aquilinum*	80	66	0	
p	w	*Northern Arrow-wood*	*Viburnum dentatum*	22	9	2	
p	h	*Dogbane*	Apocynum sp.	13	2	4.8	
p	g	*Purple Needle-grass*	*Aristida purpurascens*	11	0	0	
p	h	*Hay-scented fern*	*Dennstaedtia punctilobula*	11	0	0	
p	h	*Hyssop-leaved Boneset*	*Eupatorium hyssopifolium*	11	0	0	
a/b	h	Lettuce	Lactuca sp.	11	0	0	
p	h	Wand Bush-clover	*Lespedeza intermedia*	11	0	0	
p	h	Pokeweed	*Phytolacca americana*	11	0	0	
p	h	Sandplain Blue-eyed Grass	*Sisyrinchium fuscatum*	11	0	0	
p	w	*Trailing Arbutus*	*Epigaea repens*	50	39	0.1	
p	w	Juniper	Juniperus sp.	13	3	2.8	
p	w	*Sawbrier*	*Smilax glauca*	20	11	0.9	
p	h	Colic-root	*Aletris farinosa*	9	0	0	
p	h	Sheepsorrel	*Rumex acetosella*	9	0	0	

a/p	life form	common name	scientific name	% firelane plots	% forested/ shrubland plots	G	p value
p	w	*Bayberry*	*Myrica pensylvanica*	19	9	1	
p	w	*Wintergreen*	*Gaultheria procumbens*	28	19	0.3	
p	w	*Poison-ivy*	*Toxicodendron radicans*	11	3	2	
b	h	*Racemed Milkwort*	*Polygala polygama*	7	0	0	
p	h	*Winged Bindweed*	*Polygonum scandens*	7	0	0	
p	w	*Mulitflora Rose*	*Rosa multiflora*	7	0	0	
p	g	*Indian Grass*	*Sorghastrum nutans*	7	0	0	
p	h	*Bastard-toadflax*	*Comandra umbellata*	9	3	1.2	
p	h	*Yarrow*	*Achillea millefolium*	6	0	0	
p	w	*Oriental Bittersweet*	*Celastrus orbiculata*	6	0	0	
p	g	Switchgrass	*Panicum virgatum*	6	0	0	
a	h	*Jointweed*	*Polygonella articulata*	6	0	0	
a	h	Lady's Thumb	*Polygonum persicaria*	6	0	0	
p	w	Rose	Rosa sp.	6	2	0.9	
p	g	*Sweet Vernalgrass*	*Anthoxanthum odoratum*	4	0	0	
p/b	h	*Thistle*	Cirsium sp.	4	0	0	
p	w	*Hawthorn*	Crataegus sp.	4	0	0	
p	g	*Purple Lovegrass*	*Eragrostis spectabilis*	4	0	0	
p	h	*Wild Strawberry*	*Fragaria virginiana*	4	0	0	
p	g	*Velvet-grass*	*Holcus lanatus*	4	0	0	
p?	g	*Bulbous Wood-rush*	*Luzula bulbosa*	4	0	0	
p	h	*Hickey's Clubmoss*	*Lycopodium hickeyi*	4	0	0	
p	w	*Virginia Creeper*	*Parthenocissus quinquefoilia*	4	0	0	
p	g	*Black Oatgrass*	*Piptochaetium avenaceum*	4	0	0	
p	w	Sassafras	*Sassafras albidum*	4	0	0	
p	h	*Wild Sarsaparilla*	*Aralia nudicaulis*	6	3	0.2	
A	h	*Ragweed*	*Ambrosia artemisiifolia*	2	0	0	
p	h	*Milkweed*	Asclepias sp.	2	0	0	
p	h	*Clasping Aster*	*Aster patens*	2	0	0	
p	h	Cut-leaved Grape-fern	*Botrychium dissectum*	2	0	0	
p	g	*Feathertop*	*Calamagrostis epigeios*	2	0	0	
a	h	*Pigweed*	*Chenopodium album*	2	0	0	
p?	g	*Flatsedge*	Cyperus sp.	2	0	0	
p	h	Hairy Boneset	*Eupatorium rotundifolium var. ovatum*	2	0	0	
p	h	*Canada Mayflower*	*Maianthemum canadense*	2	0	0	
p	h	*Barrens Adder's Mouth*	*Malaxis bayardii*	2	0	0	
p	w	*Crabapple*	Malus sp.	2	0	0	
p	h	*Yellow Wood-sorrel*	*Oxalis dillenii*	2	0	0	
p	g	*Kentucky Bluegrass*	*Poa pratensis*	2	0	0	
p	h	*Gall-of-the-earth*	*Prenanthes trifoliolata*	2	0	0	
p	h	*Slender-leaved Mountain-mint*	*Pycnanthemum tenuifolium*	2	0	0	
p	w	*Staghorn-sumac*	*Rhus typhina*	2	0	0	
p	g	*Wool-grass*	*Scirpus cyperinus*	2	0	0	
a	g	*Green Foxtail*	*Setaria viridis*	2	0	0	

a/p	life form	common name	scientific name	% firelane plots	% forested/ shrubland plots	G	p value
p	h	*False Solomon's Seal*	*Smilacina racemosa*	2	0	0	
a	h	*European Black Nightshade*	*Solanum nigrum*	2	0	0	
p	h	*White Goldenrod*	*Solidago bicolor*	2	0	0	
p	h	*Canada goldenrod*	*Solidago canadensis var. scabra*	2	0	0	
p	h	*Elliott's goldenrod*	*Solidago latissimifolia*	2	0	0	
p	w	Steeple-bush	*Spiraea tomentosa*	2	0	0	
p	h	White Clover	*Trifolium repens*	2	0	0	
a	h	*Venus's Looking-glass*	*Triodanis perfoliata*	2	0	0	
p	w	*Grape*	Vitis sp.	2	0	0	
p	w	*Shadbush*	Amelanchier sp.	20	19	0	
p	w	White Pine	*Pinus strobus*	6	5	0	
p	h	*Elliptic Shinleaf*	*Pyrola elliptica*	6	5	0	
p	w	*Holly*	Ilex sp.	4	3	0	
a	h	Cow-wheat	*Melampyrum lineare*	43	42	0.3	
p	w	Scotch Pine	*Pinus sylvestris*	2	2	0	
p	w	*Spruce*	Picea sp.	0	2	0	
p	w	*High-bush blueberry*	*Vaccinium corymbosum*	0	2	0	
p	w	*Scrub-oak*	*Quercus ilicifolia*	98	100	1	
p	w	*Common Greenbrier*	*Smilax rotundifolia*	4	6	0.6	
p	w	*Late Sweet blueberry*	*Vaccinium angustifolium*	93	95	1.1	
p	w	*Red Pine*	*Pinus resinosa*	0	3	0	
p	w	*Early Sweet blueberry*	*Vaccinium pallidum*	96	100	1.2	
p	w	*Spotted Wintergreen*	*Chimaphila maculata*	4	8	1.2	
p	w	*White Oak*	*Quercus alba*	61	72	2.1	
p	w	*Sheep-laurel*	*Kalmia angustifolia*	35	48	2.9	0.1
p	w	Black Huckleberry	*Gaylussacia baccata*	78	98	4.2	0.05
p	w	*Dwarf Chinquapin-oak*	*Quercus prinoides*	57	81	5.3	0.025
p	h	*Pink Lady's Slipper*	*Cypripedium acaule*	19	48	11.1	<.001
p	w	Black Oak	*Quercus velutina*	20	58	14.7	<.001

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