Wildland Fuel Management Options for the Central Plains of Martha's Vineyard: Impacts on Fuel Loads, Fire Behavior and Rare Plant and Insect Species

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Front Cover: Intense surface fire in unmanaged barrens fuels (left; photo by A. Woolsey). Harrowed and mowed firelane (right; photo by G. Clarke). Massachusetts Department of Conservation and Recreation state forest lands - southeastern Massachusetts. For additional information and photographs see: www.umass.edu/nrc/nebarrensfuels/

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EXECUTIVE SUMMARY

One of the largest undeveloped sandplains in Massachusetts exists in the Manuel F. Correllus State Forest (MFCSF) on the island of Martha's Vineyard. Nearly 4000 acres (1670 ha) of barrens vegetation remain in an area currently recognized as critical habitat for a number of plant and animal species that are rare in the Commonwealth of Massachusetts. MFCSF has the state's highest concentration of state-listed terrestrial animals, some of which have been extirpated from mainland New England. Unique coppice-oak stands on the central plains are comprised of individual oaks that almost certainly predate the time of first European settlement in the early 17th century. These plants may be several hundred years old and collectively resemble British coppice woodlands that have been managed for centuries.

Sandplain vegetation can be highly flammable, and under dry, windy conditions it can support extreme fire behavior. In addition to its flammability, high fuel loading contributes to fire hazard in barrens vegetation. Scrub Oak stands, in particular, are highly flammable and support high litter and shrub fuel loads (1-hr plus 10-hr fuels = 14.3 t/acre (32 mt/ha) and fuel depths of 4-5 ft (1.3-1.5 m). Pitch Pine and Oak Woodland stands support lower surface fuel loads (10.9 and 10.2 t/acre; 24 and 23 mt/ha, respectively) and fuel depths of only 1.6 and 1.9 ft (0.5 and 0.6 m). Scrub Oak and Pitch Pine stands can support canopy fires with extreme fire behavior, whereas Oak Woodlands are inherently less flammable. Most rare plant species on MFCSF occur in culturally maintained grasslands. Previous work suggests that Scrub Oak is most important for rare Lepidoptera species.

MFCSF is currently surrounded by private land which would be threatened by wildfires spreading from the Forest. As an initial response to the inherent fire danger, a series of fuelbreaks was established around and throughout MFCSF in the early 20th century. These fuelbreaks can both slow the spread of fire and provide access for fire suppression personnel. Fuels management along the boundary of the Forest in conjunction with the maintenance of existing breaks could help reduce the intensity of fires and the threat to adjacent properties. In the past, fuelbreaks have been created and widened using harrows to clear away native vegetation, a procedure which has created "fire lanes" dominated by grasses and forbs. Although these lanes currently support populations of state-listed plants, the vegetation represents an artificially created state not natural to the central plain. It has been argued that alternative management practices could be used to both reduce fuels and maintain open sandplain habitats more typical of natural conditions.

This study examined the effectiveness of alternative methods for fuelbreak establishment and maintenance including thinning, mowing, grazing, and prescribed burning. Our goal was to evaluate ways to prevent wildfire escaping the boundary of MFCSF while at the same time conserving or enhancing the habitats of five rare plant species and 22 rare insect species. Here we report the results of our work and provide recommendations for future fire break creation and management. It is important to note that this report does not provide a "fire management plan" for the Forest as a whole; nor

does it assume that management techniques appropriate for the small portions of the Forest that might be managed as fire breaks would be appropriate if applied more widely as general vegetation management procedures. What we have learned could, however, serve as a guide to future efforts to develop management practices and plans for the Forest as a whole.

Treatments we evaluated reduced slash and shrub loads and heights in the first growing season after treatments. Scrub Oak plots showed the most pronounced change from pretreatment conditions (shrub heights were less than a quarter and loads were well under half their pretreatment values). Mowing in Pitch Pine and Scrub Oak reduced shrub loads to well under 50% of pretreatment values. Sheep will graze new woody shoots following mowing, effectively reducing shrub loads however the expense of this treatment (which is more than four times that of mowing) may be prohibitive. In mow/graze Scrub Oak plots post-treatment loads were <10% of pretreatment values. Effects of treatments in Oak Woodlands were less pronounced as they were more heterogeneously applied. Pile burning and mowing are comparable in cost, and both effectively remove slash in thinned Pitch Pine stands. Creating lanes using alternative techniques can be comparable in cost to harrowing (although grazing is more expensive). However, long-term maintenance costs may be more expensive in the Experimental Fuel Break (relative to the cost of mowing harrowed lanes).

Prior to treatments, average flame lengths [under moderate fire weather conditions of 3.5 mph (5.8 km/hr) midflame wind speeds and humidities of 65%] were more than 6.5 ft (2 m) in Pitch Pine and Scrub Oak and 3.5 ft (1.1 m) in Oak Woodlands. Untreated fuels supported rates of spread greater than 15 ft/min (4.6 m/min) in all three fuel types. Fire behavior in treated plots was greatly reduced with little difference between treatments and fuel types: average flame lengths were reduced to less than 2.1 ft (0.6 m) and rates of spread to less than 7 ft/min (2.1 m/min). Fire behavior in these treated plots is comparable to fire behavior expected in firelanes; predictions suggests that had prescribed burns been conducted on the driest windiest day of burning, flame lengths would have been 2.9 ft (0.9 m) and rates of spread of 59.4 feet/min (18.1 m/min) in firelanes. Custom fuel models performed well in predicting observed fire behavior and appear to be widely applicable across MFCSF.

The longevity of treatment effects is unclear. Fuel loads will probably take somewhat longer to recover in Scrub Oak plots. However, it may take less than five years without further treatments. Growing season treatments could deplete shrub root reserves and slow fuel load recovery. Patterson (unpublished data) found that five annual treatments virtually eliminated Huckleberry from Oak Woodlands on Cape Cod that are similar to those on MFCSF. Litter layer compaction may have a more lasting effect, especially in Scrub Oak and Pitch Pine mow plots where increases in litter load were greatest. Thinning of Pitch Pine stands increased the estimated wind speed at which crowning would occur from 21 to 62 mph, and this change will be long-lasting, especially where seedling recruitment is likely to be dominated by Oaks.

Harrowing, and thinning with a fellerbuncher, increased soil compaction significantly relative to controls, however the magnitude of the change was relatively small (maximum values in harrowed and thinned areas were 180 PSI (1241 KPa) whereas values of 150-160 KPa were not uncommon in control stands). The overall effect of soil compaction in sandy soils is somewhat unclear and has ranged from detrimental, to none, to positive in studies elsewhere.

The unique coppice structure appears to be common in Oak-dominated stands at MFCSF. Areas burned in fires in the 1930's and 1940's have more coppice Oak stems than stands not burned in the early 20th century. Management to preserve Oak stools will require either cutting followed by prescribed burning or cutting of stems near their base, because most Oak stems are >2.5 inches (6 cm) dbh and will not be topkilled by burning alone.

Repeated mowing of existing fuelbreaks has facilitated the development of large populations of several rare plant species. Harrowing can provide immediate habitat for rare plants. Colonization by grassland species (both common and rare) of newly harrowed areas is improved by the availability of nearby seed sources. Deep organic layers appear to inhibit the germination of rare plant and grassland-associated species, and presence of the more common species appears to be a good indicator of the presence of habitat requirements for rare plants. Off firelanes, at the landscape scale, grassland associates occur in untreated stands with thinner organic layers (generally Scrub Oak stands, including Scrub Oak bottoms). Experimental fuel treatments that we evaluated improved rare plant habitat, and two rare species appeared following their application. A number of grassland associated species and the state endangered Nut-sedge colonized small areas where bare soil was exposed by machinery and pile burning. Further research may be necessary to determine the range in variability of suitable seed beds for rare plant species. Low canopy cover may also characterize suitable habitat. Scrub Oak stands which supported grassland assocates at the landscape scale had minimal overstory cover and within treatment areas, colonization by grassland associated species was mainly in Pitch Pine and Scrub Oak stands, where overstory cover was either low prior to or as a result of treatments.

A number of invasive plant species were found within newly harrowed firelanes near the exterior of MFCSF. However the occurrence of invasive species in older firelanes and forested habitats, even if infrequent, suggests that these areas can be invaded as well. Treatments we evaluated as alternatives to harrowing did not result in the establishment of invasive species over three growing seasons, although our experiments were in areas where seed sources were not immediately available. Grazing increased establishment of non-native species, although most did not persist past the first growing season.

Larval Barrens Buckmoth habitat is found in areas with the highest Scrub Oak stem densities (20.2 ± 3.79) across MFCSF, such as is found in the untreated Scrub Oak and Grassland vegetation types. This habitat can be created by thinning and burning Pitch Pine stands and by burning or mowing and then burning in Oak Woodlands. All treatments in the Scrub Oak vegetation type produced Scrub Oak stem densities that were higher than those found at Buckmoth larvae locations elsewhere on MFCSF.

Based on information currently available for the other 21 rare insect species reported for MFCSF, these fuel reduction techniques could also be used to maintain or enhance the habitat of other rare insects. Nearly all of the 22 rare species at MFCSF are specialists of Pitch Pine-Scrub Oak barrens in the Northeast; and thinning, mowing, grazing and burning are all techniques that could be used to retain the open characteristics of sandplains ecosystems. Treatments, however, must be applied across the landscape in a mosaic pattern with respect to both space and time, as each of the 22 species has different natural history requirements, and no one treatment would directly benefit every species at any given time of the year. All species are vulnerable to direct mortality from these treatments at some time during the year, so untreated patches should be left as refugia for recolonization post treatment.

Our results generally support a fuel break management strategy that maximizes diversity in the seasonal timing and areal extent of individual management operations. We believe that creating spatial and temporal heterogeneity in fuel beds – with recently treated areas interspersed among less frequently treated areas - will effectively minimize the development and spread of wildfires under conditions that would support extreme fire behavior, while facilitating the conservation of rare species.

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TABLE OF ABBREVIATIONS

Abbreviation	Definition
B	Burn
C	Control
CFM	Custom fuel model
DCR	MA Department of Conservation and Recreation
DF&W	MA Division of Fisheries and Wildlife
DWF	Downed Woody Fuel Inventory
EFB	Experimental Fuels Break
FBPS	Fire Behavior Prediction System
FEIS	Fire Effects Information System (www.fs.fed.us/database/feis/)
G	Graze
GPS	Global Positioning System
IV	Importance Value
KPa	Kilopascal
M	Mow
MA	Massachusetts
MFCSF	Manuel F. Correllus State Forest
MT	Metric Ton
MV	Martha’s Vineyard
NHESP	MA Natural Heritage and Endangered Species Program
OW	Oak Woodland
P	Pile burn
PP	Pitch Pine
PSI	Pounds per Square Inch
SO	Scrub Oak
SFM	Standard Fuel Model
SW	Southwest
T	Ton
T	Thin
USFS	United States Forest Service
WTB	Willow Tree Bottom

Note: Abbreviations are used liberally in text, tables, and figures.

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INTRODUCTION

Within the forested landscapes of the northeastern United States, open early seral communities are rare and declining in size and number (Noss et al. 1995, Motzkin and Foster 2002). Most occur in areas of level topography and course-textured soils known as sandplains. They support a variety of plant communities including grasslands, heathlands, shrublands, oak savannas, and Pitch Pine-Scrub Oak barrens (Goldstein 1997). Sandplain soils, for the most part derived from outwash left by retreating ice lobes of the Wisconsin glacial stage, are well-drained and nutrient-poor. The unique physical and vegetative characteristics of sandplains combine to create ecosystems that are globally rare. Often referred to as “barrens”, they provide habitat for numerous rare plant and animal species, making them the focus of a number of land conservation efforts (Noss et al. 1995, Barbour et al. 1998, MNHESP 2001, Wagner et al. 2003).

Open or early seral ecosystems such as sandplains require frequent disturbance to keep them in an open state, or their grass, shrub and forb vegetation will be overgrown by taller, woody vegetation (Motzkin et al. 1996, Dunwiddie et al. 1997, Goldstein 1997, Motzkin and Foster 2002). Sandplains were historically maintained in an open condition through a variety of disturbances such as fire, grazing, and, near the coast, salt spray from ocean storms (Griffiths and Orians 2004), with mowing, timber cutting and plowing added to the list as Europeans settled the landscape. With farm abandonment in New England beginning in the 1800s and increased fire suppression efforts following catastrophic fires in the 19th and early 20th centuries, these disturbances were dramatically reduced (Pyne 1984). Fire-dependent systems have been lost through succession where fire suppression has been successful (Habeck 1992, Goldstein 1997, Finton 1998, Barbour et al. 1998, Panzer and Schwartz 2000). Without disturbance, these usually open areas with low-growing or sparse vegetation develop into dense shrub thickets or forests. Non-fire adapted species previously eliminated by frequent fires encroach and either outcompete the fire-adapted flora or simply add to the growing volume of fuel.

Barrens vegetation produces abundant, flammable fuel which decomposes slowly creating the potential for wildfires. Heavy fuel-loads increase the risk of intense fires which are difficult to control and threaten human resources. Flat, well-drained sandplain soils are easily developed for housing and light industry, which increases the need for fuels management to reduce the risk of damaging wildfires. Techniques such as thinning, mowing, grazing, and prescribed burning have been used to reduce fuels in order to restore naturally functioning ecosystems.

One of the largest undeveloped sandplains in Massachusetts exists in the Manuel F. Correllus State Forest (MFCSF) on the island of Martha’s Vineyard. Nearly 4000 acres (1670 ha) of barrens vegetation remain in an area currently recognized as critical habitat for a number of plant and animal species that are rare in the Commonwealth of Massachusetts. MFCSF has the Commonwealth’s highest concentration of state-listed terrestrial animals (Goldstein 1997, Foster and Motzkin 1999), some of which have been extirpated from mainland New England. Some represent the only New England populations ever recorded, possibly disjunct populations of prairie species more common to the Midwest (Goldstein 1997, Mehrhoff 1997). Martha's Vineyard was also the final home of the now extinct Heath Hen (*Tympanuchus cupido cupido)*, an eastern subspecies of prairie chicken (Dunwiddie 1994, Foster and Motzkin 1999), and was one of the last holdouts for a regionally extirpated butterfly, the Regal Fritillary (*Speyeria idalia*) (Goldstein 1997, Wagner et al. 1997b). Unique coppice-oak stands also exist in the central plain of Martha's Vineyard (Foster and Motzkin 1999). These multi-stemmed rings of widely spaced oaks were created when oaks resprouted after disturbances such as cutting and fire (Mouw 2002). The oak stools on MFCSF may be hundreds of years old, and their structure resembles that of oaks in British woodlands that have been managed as coppice for centuries (Foster and Motzkin 1999).

MFCSF is currently surrounded by private land which could be endangered if a wildfire were to begin on the Forest and escape the boundary. As an initial response to the inherent fire danger, a series of fuelbreaks was established around and throughout MFCSF in the early 20^{th} century (Foster and Motzkin 1999, Mouw 2002). These fuelbreaks can both slow the spread of fire and provide access for fire suppression personnel. Fuels management along the boundary of the Forest in conjunction with the maintenance of existing breaks could help reduce the intensity of fires and the threat to adjacent properties. Fire behavior modeling experiments based on MFCSF fuels suggest that the types of fuels upwind of a break influence the intensity of a fire (Mouw 2002). For a given set of weather conditions, fire intensity and the width of a break help determine the likelihood of a fire crossing the fuelbreak. In the past, fuelbreaks have been created and widened using harrows to clear away all native vegetation, a procedure which has created "fire lanes" dominated by grasses and forbs. Although these lanes currently support populations of state-listed plants, the vegetation as a whole is considered by some to be undesirable, because it is an artificially created state that is not natural to the sandplain. It has been argued that alternative management practices could be used to both reduce fuels and maintain open sandplain habitats more typical of natural conditions (Foster and Motzkin, 1990).

This study examined the effectiveness of alternative methods for fuelbreak maintenance and expansion including overstory thinning, understory mowing and grazing, and prescribed burning. The goal was to evaluate ways to prevent wildfire from escaping the boundary of MFCSF while at the same time conserving or enhancing the habitats of five rare plant species and 22 rare insect species (See Tables 1 and 2).

OBJECTIVES

Rare Plants

At the landscape scale, our objective was to obtain a better understanding of the distribution of rare plant species at MFCSF, both outside of firelanes and across firelane management types. By documenting environmental variables as well as the presence and

Table 1. Rare plants evaluated in this study. See Appendix C for explanation of ranks.

Scientific name	MA status	Global	National	NEPCoP division	MA	Other NE state listings
Aristida purpurascens	T	G5	N5	2	S2	RI=S1; CT=SU
Linum intercursum	SC	G4	N4		S3	RI=S1; CT=SH
Prenanthes serpentaria	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

Table 2. Rare insects evaluated in this study. See Appendix C for explanation of ranks.

Scientific name	MA status	Global	MA	Other NE state listings
Abagrotis nefascia benjamini	SC	G4	S3	CT=S1; RI=S1S2
Acronicta albarufa	T	G3G4	S2S3	CT=SH; NH=SNR
Anisota stigma	SC	G5	S3	CT=SH; NH=SH
Callophrys irus	SC	G3	S2S3	CT=S2S3; ME=SX; NH=S1; RI=S1
Catocala herodias	SC	G3T3	S3	CT=S1
Cicindela purpurea	SC	G5	S2S3	CT=SX; ME=SNR; NH=S5; RI=S1; VT=SU
Cicinnus melsheimeri	T	G4	S2S3	CT=SX
Cingilia catenaria	SC	G4	S2S3	CT=S1; NH=S4
Cycnia inopinatus	T	G4	S1S2	
Digrammia eremiata	T	G1	S1	
Eacles imperialis	T	G5	S1	CT=SH; ME=SX; NH=SX; RI=SH; VT=SH
Euchlaena madusaria	SC	G4	S2S3	NH=S1
Hemaris gracilis	SC	G3G4	S2S3	CT=S1; ME=SH; NH=S2S3
Hemileuca maia	SC	G5	S3	CT=S1; ME=S1; NH=SH; RI=SNR
Itame sp. 1 (near *inextricata*)	SC	G2G3	S2S3	CT=S1; ME=S1; NH=S1S2
Lycia ypsilon	T	G4	S1	
Metarranthis apiciaria	E	GU	S1	CT=SH; ME=SU; NH=S1
Metarranthis pilosaria	SC	G3G4	S2S3	
Psectraglaea carnosa	SC	G3	S2S3	CT=S1; ME=SH; NH=SH
Ptichodis bistrigata	T	G3	S1S2	
Stenoporpia polygrammaria	T	GU	S1	
Zale sp. 1 (near *lunifera)*	SC	G3G4	S2S3	CT=SU; ME=S1; NH=S1; RI=S1

abundance of common species at all sites we hoped to identify habitats that are more or less suitable for rare plants. Within experimental treatment plots, we sought to determine the effects of different management options on rare plant habitat. We also developed monitoring protocols to identify the effects of future treatments on rare plant habitat.

Invasive Plants

The objective of the invasive plant portion of this research was, at the landscape scale, to obtain better understanding of the distribution of invasive plant species at MFCSF. In particular, the goal was to provide an extensive characterization of the status of firelanes with respect to the frequency and abundance of invasive species. This information was used to assess whether past management has influenced the establishment of invasive plant species. At the experimental scale, we sought to evaluate the immediate effects of management on the establishment of invasive species. Sampling provided baseline data for the future monitoring of these areas.

Fuels and Fire Behavior

Our objective with respect to fire behavior and fuels was to demonstrate the extent to which alternative management techniques not employed on the forest in the recent past affect fuel loads and fire behavior in three sandplain vegetation types. To do this we compared fuel loads and prescribed fire behavior in treated and untreated (control) plots. We developed a fuels monitoring protocol to be used in future sampling as well as custom fuel models which can be used for planning future treatments.

Soil Compaction

Forest-wide, our objective was to determine if historical firelane creation techniques (harrowing) increased soil compaction compared to undisturbed areas. In the experimental area, our objective was to determine the extent to which alternative fuels manipulation treatments compacted soils.

Insects

The objectives of our insect work were to identify variables associated with rare species habitats and to determine the effects of various vegetation management practices including thinning, mowing, grazing, and prescribed fire, on those variables. The goal was to determine if these techniques could help to conserve and maintain rare insect habitats while at the same time reducing the risk of catastrophic wildfires.

The specific objectives of this portion of the study were: 1) to determine the abilities of various combinations of three fuelbreak creation techniques (thinning, mowing, and grazing) and two fuelbreak maintenance techniques (grazing and prescribed fire) to provide habitat for two locally common species, the Barrens Buckmoth (*Hemileuca maia*) and the Spiny Oakworm Moth (*Anisota stigma*) (Lepidoptera:

Saturniidae), as represented by the larval stage, in MFCSF; and 2) to examine the vegetative characteristics of existing and newly created fuelbreaks to assess their ability to provide habitat for as many of the 22 rare insect species as possible.

Ancient Oak Woodlands

The research objective was to identify silvicultural techniques which can be used to maintain coppice oak structure. This involved surveying stands to estimate the age of existing above-ground structures and identifying past disturbances and management activities which may have contributed to the development of oak stools.

STUDY SITE

Landscape Scale

Location, Geology, and Climate

Manuel F. Correllus State Forest (MFCSF; Figure1) is located at the center of the 100 mi^2 (256 km^2) island of Martha's Vineyard, which lies 6 miles (9.6 km) south of Cape Cod, and 4 miles (6.4 km) southeast of the Elizabeth Islands off of Massachusetts' south coast. The soils of MFCSF are derived from outwash, although at the northeastern corner of the Forest they are underlain by morainal deposits. All are characterized as having high permeability and low water-holding capacity (Fletcher and Roffinoli, 1986). The topography is relatively flat, with the elevation not varying more than 40 ft (12.2 m). Slopes > 5% occur only in the northeast corner of the Forest and within several north/south running depressions called frost bottoms. The climate of the island is humid continental with average monthly precipitation ranging from a high of 4.7 inches (12 cm) in November to a low of 2.9 (7.4 cm) inches in July (Stormfax, 1990). Although precipitation occurs evenly throughout the year, periods of drought lasting up to several weeks may occur. Humidity levels are typically high and temperatures are moderated by maritime influences. The 30-year average annual high temperature is 69.8° F (21° C) and the low 29.3° F (-1.5° C). Days with low humidities occur in the spring, often with high winds (Mouw, 2002). In the summer, winds are commonly from the southwest and in the winter from the northwest.

Within the flat, outwash plain exist minor depressions left by buried ice blocks or meltwater from the retreating glaciers. These depressions allow cold air to drain and/or pool, creating areas known as "frost bottoms" (or pockets) in which freezing temperatures can occur in any month of the year. Only a few frost tolerant plant species like shrub oaks (but also some grasses, sedges and blueberries) can survive in these areas, and some rare invertebrate species may depend upon them for their survival (Schlegel and Butch 1980, Aizen and Patterson 1995, Goldstein 1997, Barbour et al. 1998, Motzkin et al. 2002).

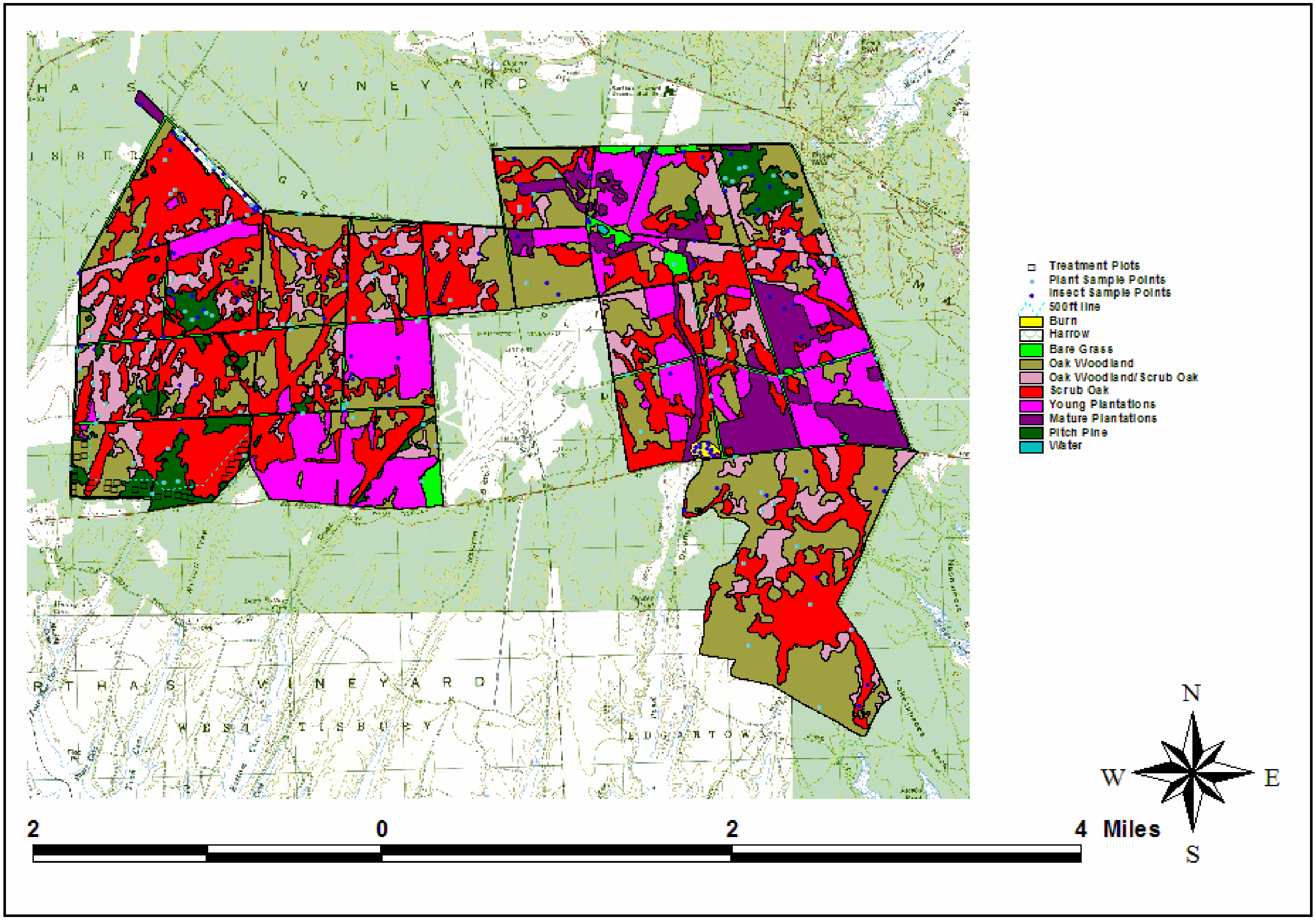

Figure 1. Map of MFCSF showing vegetation types, EFB, treatment plots, plant and insect sample plots.

Disturbance History

It remains unclear what the Martha's Vineyard landscape looked like prior to European settlement on the island (in the mid 1600s). Paleoecological evidence suggests that fire was more important in that period than after European colonization and that oaks dominated the outwash plain, although the structure and species composition of these woodlands are not known. Grasslands or open grassy areas within wooded vegetation probably existed near the shore or in areas frequented by Native American populations (Stevens 1996). It is likely that Native Americans ignited most fires, but their specific intent in doing so is unknown. A number of motives have been proposed [by Bromley (1935), Day (1953), Patterson and Sassaman (1988) and others].

In contrast to the perimeter of the island and many other New England barrens (Finton, 1998; Motzkin et al. 1999), the Vineyard's central outwash plain was little plowed for agriculture (Mouw 2002) and may have experienced little grazing during the Colonial period (Foster and Motzkin 1999). Elsewhere, tillage (i.e. agricultural plowing) caused few long-term changes in soil chemical or physical properties, although it altered plant species composition and vegetation structure in barrens vegetation of Massachusetts' Connecticut Valley (Motzkin, et al. 1996, Motzkin, et al. 2002b) and the Albany Pine Bush Preserve (Gebauer et al. 1995). Plowing at MFCSF was almost exclusively limited to areas adjacent to the Forest Headquarters and areas that are now firelanes (Mouw, 2002). The Forest has, however, had a long history of timber cutting and wildfire (Foster and Motzkin, 1999).

The earliest quantitative description of the Forest's vegetation comes from interpretation of aerial photos taken in the 1930s, over 250 years after European colonization (Mouw 2002). In the early 20th century, MFCSF was dominated by immature tree and shrub oaks – the product of many decades by cutting and wildfire (Foster and Motzkin 1999). Evidence today for the importance of young tree oaks in this vegetation is the existence of coppice oaks whose above-ground stems are frequently 50-80 years in age but whose underground root structures indicate that the plants may be centuries old (Mouw 2002). These structures appear to be the result of cutting and burning in the historic period. The existence of these coppice oaks and relatively little Pitch Pine at MFCSF suggest that fires of the early historic period did not kill underground plant structures (Mouw 2002).

By the early 19th century woodcutting began to decline throughout coastal New England as stems of sufficient size became scarce, and wood was replaced by coal and then oil for heating and cooking. But fires remained prevalent; only in the past five decades have efforts to suppress them been effective. The modern fire regime is now characterized by small (generally <10 acres, or 4 ha; infrequently >100 acres, or 45 ha) fires with return intervals of a decade or longer (Mouw 2002). Because of this dramatic change in disturbance regime, much of the vegetation of MFCSF has shifted from oak shrublands to less flammable oak woodlands, although extensive shrublands remain in some areas (Mouw 2002).

During the early to mid 20th century, especially, and continuing to a lesser extent until the 1970s, conifer plantations were established over about a quarter of MFCSF (Foster and Motzkin, 1999). Most plantations were established by mechanical planting in native vegetation, and where canopy closure has not occurred, many planted stands still support native understories. In areas where soil disturbance was common (i.e. plantations), nonnative and invasive species have established (Foster and Motzkin 1999;, Mouw 2002).

Some plantations were damaged by Hurricane Bob (in 1991) and salvaged. The Island's native vegetation is thought to be somewhat resistant to storm damage. Although more frequent along the coast than in other parts of New England (Boose et al. 2001), hurricanes may have had less impact on MFCSF vegetation before the existence of plantations.

Frost bottoms are particularly prone to frequent disturbance. They experience higher daytime and lower nighttime temperatures than the surrounding landscape. Frequent frosts and shorter growing seasons physiologically stress plants. These microclimatic effects are a result of cold air drainage patterns, increased insolation during the day, radiational cooling at night, and the short stature of the vegetation itself (Motzkin et al. 2002). Succession appears to occur more slowly in these areas which now support extensive Scrub Oak stands (Mouw 2002). Frost bottoms are more susceptible to fire than the surrounding landscape due to the high cover of flammable shrub fuels and high day-time temperatures during the fire season.

Firelane Management

A grid of firelanes was established in the 1920s and 1930s which dissects MFCSF into blocks ½ mile (0.8 km) on a side (Figure 2). These firelanes, created by clearing and plowing native vegetation, have been mowed regularly and now support grass and heathland vegetation (see Clarke, 2005 expected). Firelanes were initially 50 feet (15 m) wide including a vehicle road through the middle, but many have narrowed since their construction. In 1993 the two major east/west lanes (C and D) on the western side of the Forest were widened to 80 feet (24 m) and those on the northern edge of the Forest (1, A, and B) to 200 feet (61 m). Widening was done by clearing and harrowing. In the other lanes additional harrowing was done in 2000 or 2002. Management now calls for all lanes to be mowed annually.

Modern Vegetation Cover

Interpretation of 1:12,000 aerial photos taken in 1994 by Janice Stone of the University of Massachusetts Resource Mapping Lab (funded through a contract by the USFS to W. A. Patterson) identified 120 stand types within the boundaries of MFCSF. A composite vegetation map for the Forest was originally published by Foster and Motzkin (1999). Mouw (2002) sampled relevé plots in 110 of the 635 stands delineated by Stone and performed a cluster analysis enabling him to identify seven principal vegetation types

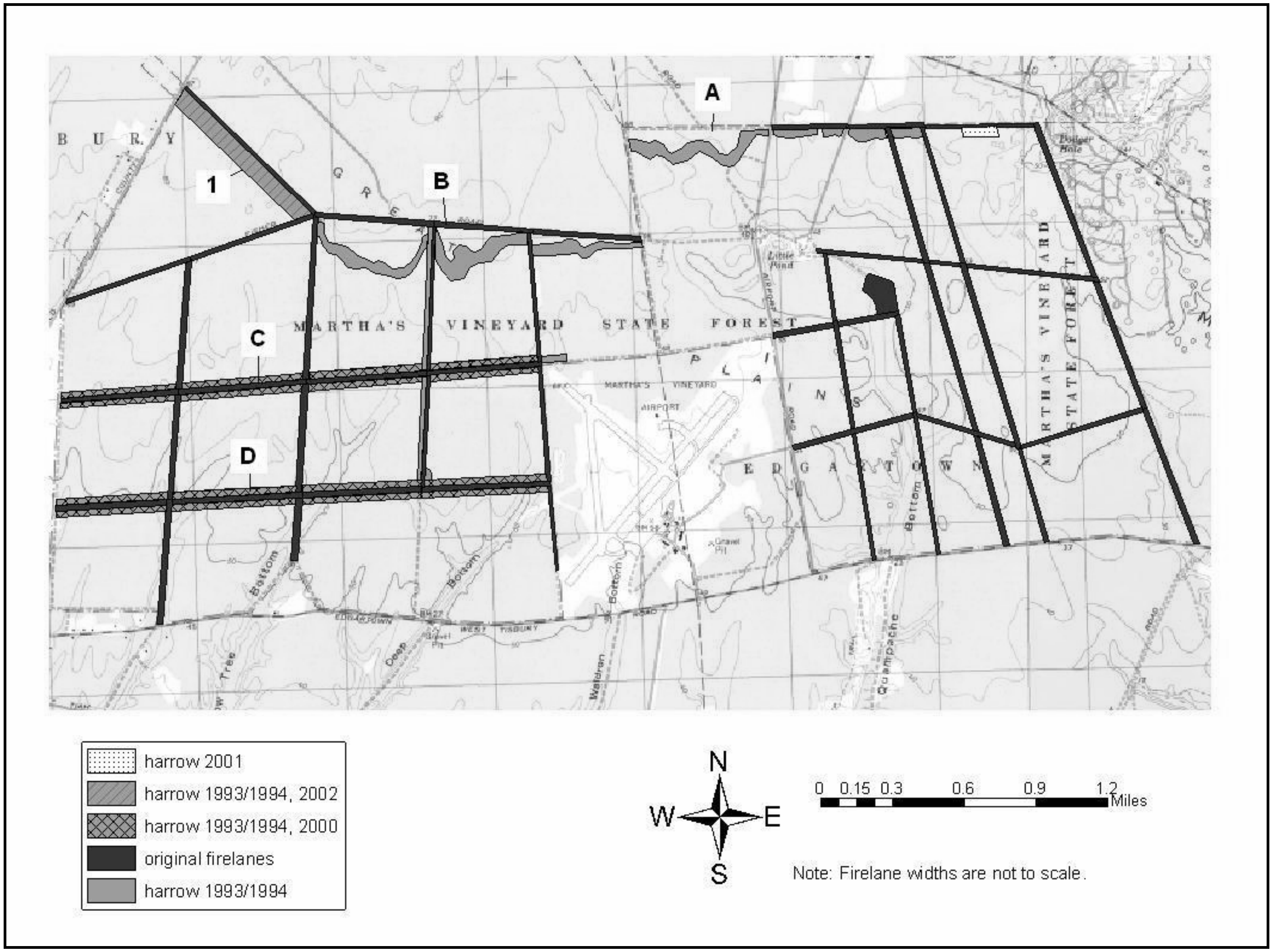

Figure 2. Map of MFCSF showing original firelanes ("old" lanes) in addition to areas which have been more recently managed under firelane expansion projects since 1993 ("new" lanes).

(depicted on a revised vegetation map – Figure 1). His types include: Pitch Pine, Oak Woodlands, Oak Woodland/Scrub Oak, Scrub Oak, Grassland, Young Plantations and Mature Plantations. All stands classified as Pitch Pine contained pitch pine with a cover of 5-25% or greater. Stands assigned to other vegetation types had covers of pitch pine of 5% or less. A successional gradient exists from Scrub Oak, Oak Woodland/Scrub Oak and Oak Woodlands, with canopy cover increasing from Scrub Oak (< 20% canopy cover) to Scrub Oak/Oak Woodland (20-50% cover) to Oak Woodland (> 50% cover). Conversely, average cover of shrub oak species decreases from Scrub Oak to Oak Woodland. Scrub Oak stands are dominated by Bear (*Quercus illicifolia*) and Dwarf Chinquapin Oak (*Q. prinoides*), with Huckleberry (*Gaylussacia baccata*) and Blueberry (*Vaccinium* spp.) less common. Patches of Heath contain Bearberry (*Arctostaphylos uva-ursi*), Golden Heather (*Hudsonia ericoides*) and other herbaceous and graminoid vegetation (Dunwiddie et al. 1996). With increasing canopy cover, the high shrub layer tends to be comprised of Huckleberry or Scrub Oaks, with Blueberries restricted to the low shrub layer.

The most abundant vegetation types at MFCSF are Scrub Oak (comprising 29% of the Forest), Oak Woodlands (26%), mixed Oak Woodland/ Scrub Oak (17%) and Plantations (16%) (Mouw 2002). Pitch Pine occupies <5% of MFCSF and is concentrated in a few areas in the western and northeastern parts of the Forest. Based upon his field sampling, Mouw reclassified, from Foster and Motzkin's (1999) original map, over 800 acres (324 hectares) of Oak Woodland/ Scrub Oak as Scrub Oak, more than 120 (49 hectares) acres in three Pitch Pine types as a single Pitch Pine type and over 1000 acres (405 hectares) of plantations as either old or new plantations (the latter supporting fires with higher rates of spread and understories more frequently dominated by native species).

Mouw (2002) extensively sampled fuels in 110 stands, and intensively sampled fuels in ten of these. He assessed variability in fuels across stand types and developed a fuels map. Classifications based on vegetative characteristics were suitable for describing the variability seen in fuels characteristics.

Southwest Experimental Fuel Break

Location and Justification

To evaluate the effects of different management practices on fuel loading, fire behavior and ecosystem properties, we established an experimental fuel break (EFB) within the Forest boundaries (Figure 3). Mouw's (2002) simulations showed that fires ignited in the southwestern corner of MFCSF have the greatest potential to burn large areas of MFCSF under average worst-case conditions. There, fires burning with a southwest wind can run for a mile (1.6 km) or more through largely untreated fuels before reaching the northern boundary of the Forest. Creating an EFB in this area thus provided both the opportunity to evaluate different fuel treatment techniques while at the same time protecting an area with potentially high fire hazard. Ultimately, a 500 foot-

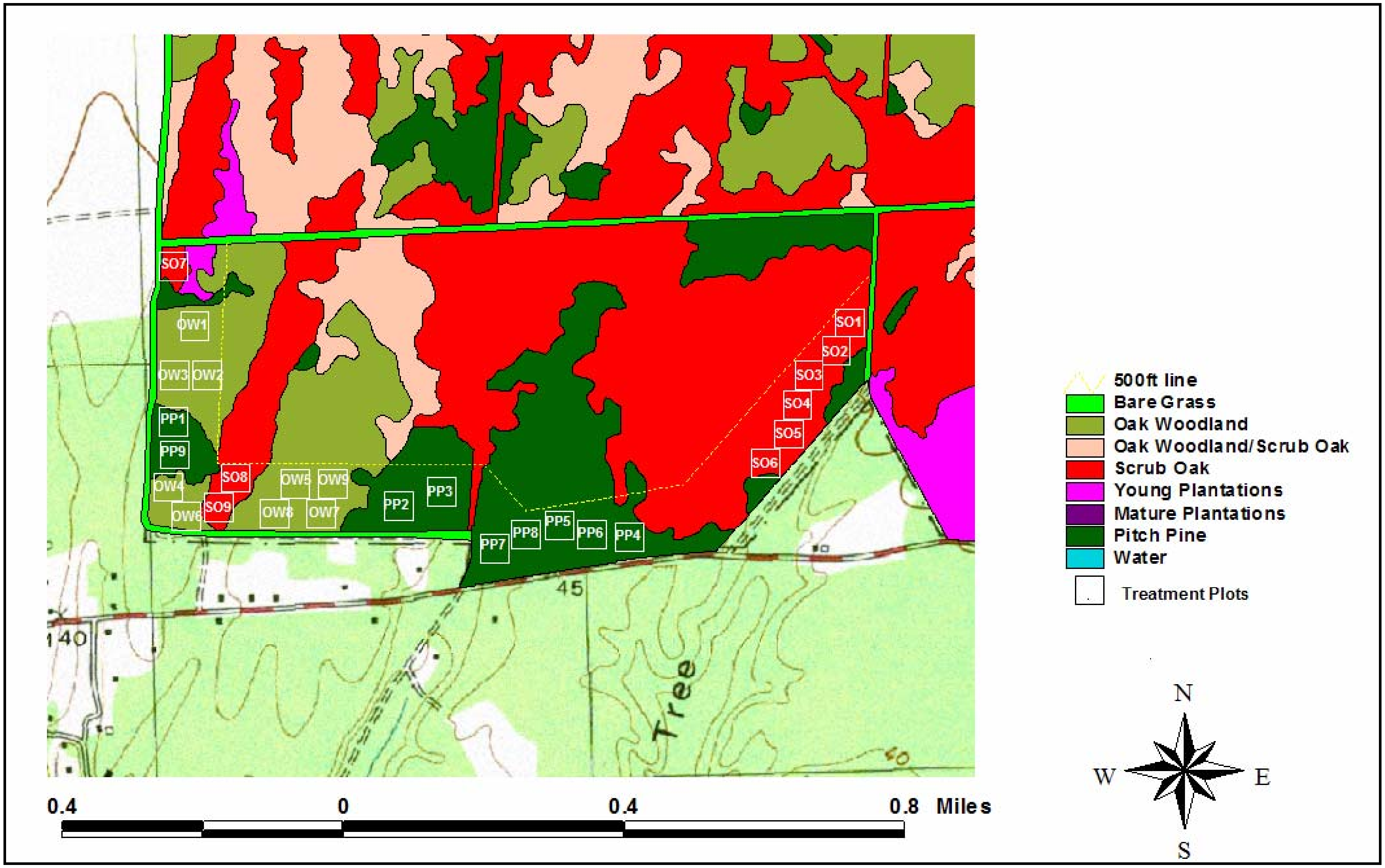

Figure 3. Map showing twenty-seven half-acre experimental fuel reduction plots in three vegetation types (PP, OW, SO) in SW corner of MFCSF. Vegetation types as described by Mouw (2002). See Table S2 for treatments.

wide (152 m) fuel break was established along a nearly 2-mile (3.2-km) segment of the Forest boundary.

Fuels and Vegetation

The 500-foot-wide (152-m) EFB contains extensive stands of Oak Woodland, Scrub Oak, and Pitch Pine – three of the fuel types of interest to DCR managers. Scrub Oak and Pitch Pine-dominated areas are among the Forests most flammable fuel types, whereas Oak Woodlands can slow a fire running through the canopies of adjacent Scrub Oak and Pitch Pine. Fuel management practices we evaluated (thinning of dense, mature Pitch Pine; cutting and grazing of Scrub Oak; and thinning shrub understories in Oak Woodlands) were expected to reduce the potential for wildfires to cross the break. Treatments were concentrated on replicated, 45 m by 45 m (0.2 ha, or 0.5 acre) research plots, but all fuels were treated within the 500-foot-wide (152-m) strip with at least prescribed fire.

METHODS

Landscape Scale

Plants

Rare Plants. Vegetation and environmental variable sampling was conducted where rare plant species occurred in order to characterize suitable habitat. Five rare species were included in the study (Table 1): Aristida purpurascens (Purple Needle-grass), *Linum intercursum* (Sandplain Flax), *Prenanthes serpentaria* (Lion's Foot; Figure 4a), *Scleria pauciflora* var. *caroliniana* (Papillose Nut-sedge), and *Sisyrinchium fuscatum* (Sandplain Blue-eyed Grass; Figure 4b). Several rare species were not included either because they were not located or were located only once [e.g. Barren's Adder's Mouth (*Malaxis bayardii*), and Spring Ladies' Tresses (*Spiranthes vernalis*)], or where their identification was problematic, especially because of the frequency of the genus as a whole [Bushy Rockrose (*Helianthemum dumosum*), and Nantucket Shadbush (*Amelanchier nantucketensis*)]. Sampling was also conducted at 15 randomly selected points in each of the five native cover types identified by Mouw (2002) (Pitch Pine, Oak Woodland, Oak Woodland/Scrub Oak, Scrub Oak, and Grasslands). Sampling resulted in extensive rare plant searches throughout the Forest. In order to better document the impacts of firelane management, additional plots were added to ensure thorough sampling within historically maintained firelanes. A total of 64 plots were sampled off firelanes, and 54 were sampled within firelanes during the 2003 and 2004 field seasons.

Vegetation was sampled on 10 m by 10 m ($100 m^2$, or $1076 ft^2$) relevé plots, which were large enough to adequately sample species diversity in grassland communities (Mueller-Dombois and Ellenberg 1974). All plant species were enumerated. When a species was found during relevé sampling that could not be identified, the plot was visited later that season and/or the following year to ensure a positive identification.

Within grassland plots this occurred regularly, and all grassland plots were visited both early and late in the season.

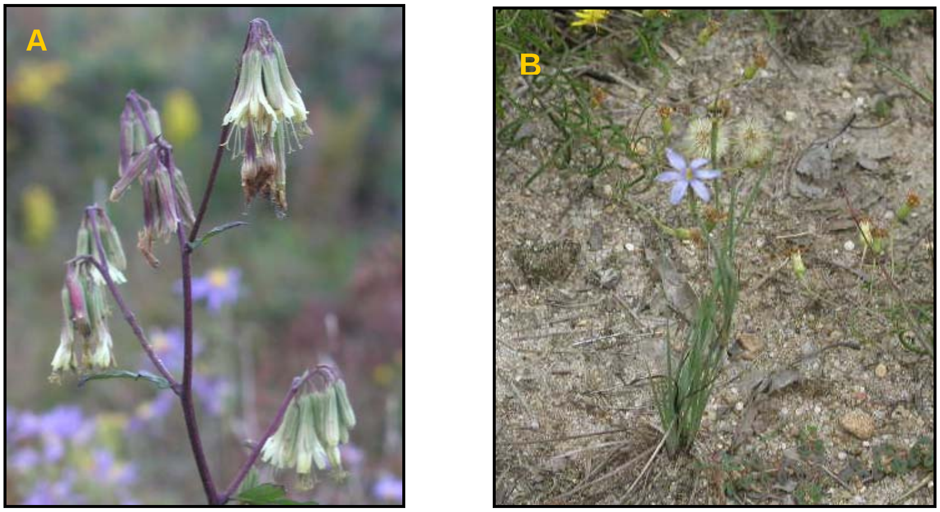

Figure 4. Rare plant photos: A) Lion's Foot (*Prenanthes serpentaria*) and B) Sandplain Blue-eyed Grass (*Sisyrinchium arenicola*). Photos by G. Clarke.

Basic habitat descriptors were measured at each relevé plot during the 2003 and 2004 field seasons. At a minimum of 100 evenly distributed points within each plot, ground cover type (bare soil, litter, lichen, etc.) and vegetative cover were assessed. Vegetative cover was tallied as the presence of graminoid, herbaceous, and woody vegetation in any of four height categories (0-0.5, 0.5-1, 1-1.5, and 1.5+m). Litter and duff depths were recorded at 15 evenly distributed points per plot. Canopy cover was sampled with a spherical densitometer at four evenly spaced locations in plots. At each location four readings were taken (in the cardinal directions) at breast height and at 0.5 m (1.6 ft) above the ground.

We attempted to determine if rare plant species occur outside of firelanes at MFCSF. Searches were made while traveling to plots, within open areas identified by aerial photos, and in areas burned by wildfires in the past 20 years. Extensive searches were also made within firelanes to assess the frequency with which rare plant species occur overall and across management types.

Importance values (IV) were computed for each species on each plot according to the following convention: we added the value one (1) to the cover value for each species, summed the cover values across strata by species, subtracted the number of strata the species occurred in, and added the value one (1) (Clark and Patterson, 1985). To classify vegetation, cluster analyses were run using PC-ORD version 4.0 and were based on the group average linkage method and Sorensen's distance measure. Species occurring in fewer than two plots were removed from the forested data set, and species occurring in only one plot (plus rare species) were removed from the grassland data set prior to analysis. Two-sample-tests of variances and t-tests were run using SAS v 9.1 (SAS Institute 2004) to evaluate the importance of environmental variables on the distribution of rare species and grassland associates.

Invasive Plants. Searches for invasive plant species were conducted within all plots sampled in 2003 and 2004, and firelanes were searched intensively in 2004. When invasive species were found, the location was permanently recorded by GPS and notes made regarding the population size and possible dispersal method (e.g., the presence of nearby perch trees). In the proposal we said that we would resurvey areas of firelanes sampled by Downey and Consentino (1999), but these plots could not be relocated. Instead a more extensive survey was conducted throughout all lanes.

Insects

Because the larval stage of an insect's life is usually the most sedentary stage and the stage in which most feeding and growth occur, impacts to the habitats of the larval stage would probably have the most immediate effect on the population. Therefore, surveys and habitat assessments were focused on this portion of the species' lifecycle. The limited duration of the study precluded full recolonization into treatment areas, so a direct study of the impacts of treatments on insect populations could not be undertaken. Instead, habitat variables were evaluated in order to determine how management activities altered larval habitats.

The larvae of many of the 22 rare species are so infrequently encountered in MFCSF that assessments of their habitats would be extremely difficult. The larvae of two species - the Barrens Buckmoth (Figure 5a) and the Spiny Oakworm Moth (Figure 5b) - are fairly common and easily sampled, so they were the main focus of this study. Both species are gregarious feeders on scrub oaks (Bear Oak and Dwarf Chinquapin Oak) in their early instar stages and should be easily found if present. Potential impacts on the habitats of the other 20 species were studied indirectly by reviewing available literature and evaluating the habitat requirements of each species compared to the vegetative outcomes of the various fuelbreak management techniques.

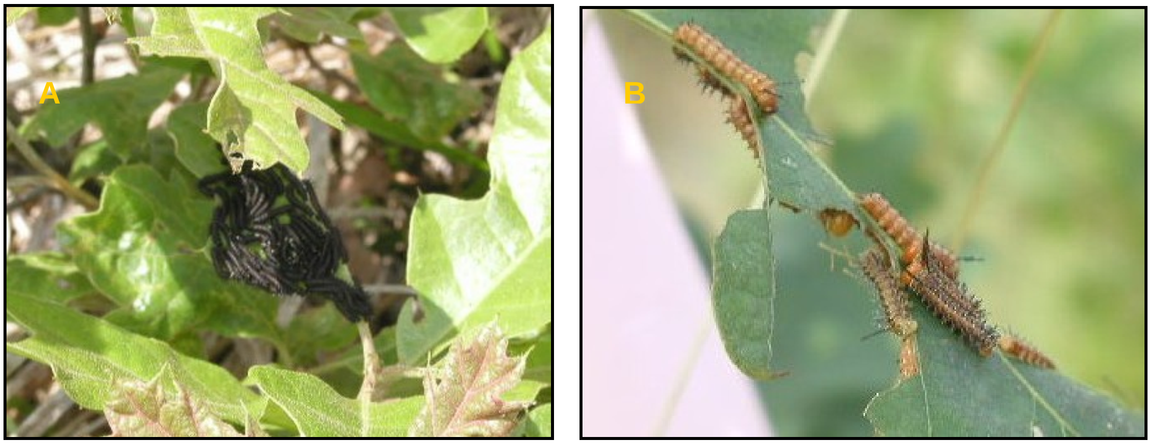

Figure 5. Rare insect photos: A) cluster of Barrens Buckmoth larvae feeding on Scrub Oak and B) cluster of Spiny Oakworm Moth larvae feeding on Scrub Oak. Photos by S. Haggerty.

Habitat assessments were based on larval locations identified through transect surveys. Previously documented locations were not necessarily based on systematic surveys and tended to be clustered along firelanes and trails rather than in unbroken vegetation. To remove potential observer bias, random transects were used to equally survey nine broad vegetation types. Twenty, 100-meter-long transects were randomly located within each of the seven vegetation types recognized by Mouw (2002) (Grassland, Oak Woodland, Oak Woodland/Scrub Oak, Scrub Oak, Pitch Pine, Young Plantation, Mature Plantation) and within two additional vegetation types - 19 acres (7.5 ha) harrowed during spring 2002 in the NW portion of MFCSF (Harrow), and 7 acres (2.9 ha) burned in summer 1999 in the SE part of MFCSF (Burn). Both of these areas represent disturbances expected to affect the habitats of rare insects. Surveys were conducted equally across all vegetation types, rather than according to their representation on the landscape. This was done for two reasons: 1) to determine if broad landscape-level characterizations of the vegetation could be used to delineate preferred habitats simply from aerial photographs; and 2) to avoid overlooking a correlation between larval presence and vegetation type in one of the less-well-represented vegetation types due to low sample sizes.

Surveys were conducted along transects in June and early July of 2003 for the Barrens Buckmoth, and in August of 2003 for the Spiny Oakworm. When a larval cluster was discovered, its location was recorded using GPS, and the habitat characteristics of the site were described later in the season. For the habitat characterization, a 225 m^2 (15 m x 15 m) plot was established, centered on the larval cluster (or egg ring, if found). This size plot should provide adequate representation of the plant species found in a temperate forest community (Barbour et al. 1980). Habitat characteristics noted included canopy cover, height and percent cover of each of four strata (overstory, understory, high shrub, low shrub/herb) (Mueller-Dombois and Ellenburg 2002); height and percent cover of each plant species within each strata; and size-class distribution and stem density of scrub oaks (Bear Oak and Dwarf Chinquapin Oak*)* stems on a 1m x 1m subplot located at the center of the larger plot. From the cover/abundance data, Importance Values (IV) were calculated for Bear Oak as described in Clark and Patterson (1985).   Variable means and standard errors are reported here.

Ten, 225-m^2 plots were also located randomly within each of the nine vegetation types throughout the forest for comparison with the larval sites. All of these plots were sampled as above.

Canopy cover, scrub oak stem density, and Bear Oak IV were used with SAS software (SAS Institute 2004) to develop logistic regression models of the vegetation characteristics at larval sites, compared to vegetation characteristics found at randomly selected sites.   The goal was to identify the preferred habitat characteristics of both Barrens Buckmoth and Spiny Oakworm Moth larval sites. The models developed could then be used to evaluate variables found in the treatment plots to assess their ability to provide habitat for these species.

Soil Compaction

Soil compaction was measured with a DICKEY-john Soil Compaction Tester to a depth of 10-15 cm (4-6 inches), and resistance recorded in pounds per square inch. Measurements were made every meter along 50-meter-long (165-ft) transects. Eight pairs of randomly located transects were sampled in firelanes and in adjacent unplowed forests and shrublands (for a total of 400 sampling points in both firelanes and undisturbed controls).

Ancient Oaks

During a site visit in August 2003, we inspected coppice oaks in hardwood stands on MFCSF. No new systematic sampling was carried out in these stands, many of which Mouw (2002) had sampled in 1997/98. Literature on the biology and management of coppice oak stands was reviewed.

Southwest Experimental Fuels Break

Treatment Descriptions

Our goal was to evaluate the effectiveness of fuel-reduction techniques other than harrowing in creating fuel breaks while retaining or enhancing the characteristics of the natural habitats upon which rare species depend. Twenty-seven treatment plots were created in three fuel types (Pitch Pine, Oak Woodland, and Scrub Oak), with three treatment combinations per fuel type (Table 3). When the treatment plots were established, assessments were made to ensure that vegetation within the plots matched the intended vegetation type, as defined by Mouw (2002). The canopies of Pitch Pine plots had no less than 25% cover of Pitch Pine. Tree oak cover in the canopy layer of Pitch Pine plots never exceeded 25%. The canopies of Oak Woodland plots were dominated by oak species with other species never exceeding 5%. Tree canopy cover within Scrub Oak plots was always less than 25%, whereas within Oak Woodland plots it was never less than 25%. Cover of scrub oak species was higher in Scrub Oak stands than under Oak Woodland canopies. Individual treatments – each replicated three times – were randomly assigned to the 27 plots. Treatments were as follows:

- CONTROL – No treatment.

- MOW – Shrub layers were mowed in all three types during summer 2002 to a height of approximately 10 cm using a Rayco FM 225 flail (Brushhog) mower (Figure 6a).

- MOW/GRAZE – At least two weeks after mowing (to allow for shrub and herb regeneration), Scrub Oak plots were grazed by sheep (Figure 6b) in summer 2002 and again in mid-to-late summer 2003. Oak Woodland plots were mowed in 2002 and grazed in late-summer 2003.

- THIN/MOW – Overstory Pitch Pines were thinned during 2002 to a density of 20-30 ft^2/acre (5-7 m^2/ha) using a feller-buncher (Figure 6c); then shrub layers were mowed to a height of approximately 10 cm using the Brushhog mower.

- THIN/GRAZE – After thinning, the shrub layer was grazed during summer 2002 on one Pitch Pine plot. Slash was piled and burned in the winter of 2002/2003.

- THIN/PILE BURN – When it became apparent that sheep would not feed on Pitch Pine needles, slash was piled after thinning two Pitch Pine plots in fall 2003. Slash was burned on these two plots in February 2004 (Figure 6d).

Following fuels-reduction, all 27 plots were burned (Figure 6e) to document differences in fire behavior between treated and untreated conditions, and to complete the fuels break (the area around the treatment plots was burned in the spring of 2004 in order to facilitate burning the experimental plots between April 29 and May 7, 2004). Prior to the creation of the EFB, this portion of the Forest boundary had a roughly 50-foot (15.3 m) wide fuel-free zone. The vegetation in the treatment plots was resampled in 2003 and 2004 to evaluate the effects of the treatments, including the burning.

Figure 6. Photos showing tools used in creating experimental fuel break: A) Brushhog (photo by J. Varkonda), B) sheep grazing in plot (photo by D. Brennan), C) fellerbuncher (photo by J. Varkonda), D) brush pile burning (photo by J. Carlson), E) prescribed burning in early spring around the outside of research plot (photo by G. Clarke).

Plants

Vegetation Sampling. Prior to treatments (between early July and mid August 2002), relevé sampling (encompassing the entire 0.5 acre, or 0.2 hectare, plot) was conducted. In the second season, between July and October 2003, relevé sampling was conducted in plots where treatments had occurred (mow/graze plots were sampled just before and just after grazing). At the end of the final field season (in August and September 2004), following the application of all treatments and prescribed burning, all treatment plots were sampled.

To illustrate the extent and direction of vegetation change following treatments, nonmetric multidimensional scaling (NMS) ordination was run using PC-ORD version 4.0 with Sorensen distance measure. Species occurring in fewer than two plots were removed from the dataset prior to analysis. Two-sample tests of variances and t-tests were run in SAS v 9.1 (SAS Institute 2004) to evaluate the effects of treatments on environmental variables.

Rare Plants. Surveys for rare species were conducted throughout the 500-foot-wide (152-m) EFB in early summer 2002 to document baseline conditions and in 2004 following the application of all treatments.

Invasive Plants. A survey for invasive plant species was conducted throughout the entire EFB over the course of several weeks in August and September 2004.

Insects

To evaluate the effects of treatments on habitat for rare insect species, vegetation was sampled on three randomly chosen 225 m^2 subplots from each of the experimental plots, and the means were used to represent each experimental plot. Subplots were used rather than entire plots to allow for direct comparisons with the smaller plots used to assess larval habitats. Small plots were also used because the insects in question may choose habitats in which to lay their eggs (and thus, habitats in which larvae would be feeding) based on the characteristics of small patches within the larger landscape. If so, these specific characteristics could be lost through the characterization of a larger area around the habitat patch if the surrounding vegetation differed from the habitat patch.

All subplots in the treatment area were sampled with the techniques described above for plots centered on larval locations and randomly located plots of the different vegetation types across MFCSF. Comparisons were then made between the variable means of the model and the variable means of the treatment sites.

Vegetation characteristics were sampled in the growing season following the treatments, after the vegetation had resprouted and attained its full growing season stature. Thus, vegetation characteristics measured in 2003 were the result of treatments in 2002, and the measurements taken in 2004 included the effects of the spring burning.

Table 3. Treatment history for SW EFB, grazing PP plots was abandoned after one unsuccessful plot*.

Fuel Type	Treatment	Plot	2002 Treatment	2003 Treatment	2004 Treatment
Pitch Pine	Control	1	--	--	Burn (April)
Pitch Pine	Control	5	--	--	Burn (May)
Pitch Pine	Control	9	--	--	Burn (April)
Pitch Pine	Thin/Mow	2	Thin (July)/Mow (July)	--	Burn (May)
Pitch Pine	Thin/Mow	3	Thin (July)/Mow (July)	--	Burn (May)
Pitch Pine	Thin/Mow	7	Thin (July)/Mow (July)	--	Burn (May)
Pitch Pine	*Thin/Graze/ Pile Burn	4	--	Thin (August)/pile burn (winter)	Burn (May)
Pitch Pine	*Thin/Graze/ Pile Burn	6	--	Thin (August)/pile burn (winter)	Burn (May)
Pitch Pine	*Thin/Graze/ Pile Burn	8	Thin/Graze (August)/pile burn (winter)	--	Burn (May)
Oak Woodland	Control	2	--	--	Burn (April)
Oak Woodland	Control	7	--	--	Burn (April)
Oak Woodland	Control	8	--	--	Burn (April)
Oak Woodland	Mow/Graze	1	Mow (July)	Graze (July)	Burn (April)
Oak Woodland	Mow/Graze	5	Mow (July)	Graze (June-July)	Burn (April)
Oak Woodland	Mow/Graze	9	Mow (July)	Graze (August)	Burn (April)
Oak Woodland	Mow	3	Mow (July)	--	Burn (April)
Oak Woodland	Mow	4	Mow (July)	--	Burn (April)
Oak Woodland	Mow	6	Mow (July)	--	Burn (April)
Scrub Oak	Control	4	--	--	Burn (May)
Scrub Oak	Control	5	--	--	Burn (May)
Scrub Oak	Control	8	--	--	Burn (May)
Scrub Oak	Mow/Graze	1	Mow (July)/Graze (August)	Graze (September)	Burn (May)
Scrub Oak	Mow/Graze	2	Mow (July)/Graze (September)	Graze (September)	Burn (May)
Scrub Oak	Mow/Graze	9	Mow (July)/Graze (September)	Graze (September)	Burn (May)
Scrub Oak	Mow	3	Mow (July)	--	Burn (May)
Scrub Oak	Mow	6	Mow (July)	--	Burn (May)
Scrub Oak	Mow	7	Mow (July)	--	Burn (April)

T-tests were used to compare the vegetation characteristics of the treatment subplots to those found to be important to larvae on the larval-location plots in order to estimate which treatments create habitats most similar to rare insect larval habitat.

Fuels and Fire Behavior

Once plots were established and prior to treatments, fuels were sampled in all plots except controls, during summer 2002. Sampling included downed woody fuels (Appendix M), point intercept lines for vegetation and ground cover, variable radius plots for tree basal area, canopy cover, 1-m^2 (10.8-ft^2) plot tallies of scrub oak stems by size class, and harvesting of 40 cm by 40 cm (1600 cm^2, or 1.72 ft^2) plots for litter, downed wood, and live and dead standing fuels. Between March and May 2004, after 2003 leaf-fall but before prescribed burning, fuels were sampled on all plots including controls (sampling on treatment plots did not include 1 m x1 m scrub oak plots or point intercept sampling, and used an abbreviated Brown's line –see Appendix M). Post-treatment sampling was conducted in August 2004. In 2004 a complete survey of all trees with diameter at breast heigh >1 inch (2.5 cm) included species, dbh, status (live or dead), degree of vigor, and sprouting.

BehavePlus 3.0 was used to develop custom fuel models for each vegetation and treatment type using fuel measurements from individual plots, averaged across replicates of treatment types within vegetation types (see www.umass.edu/nrc/nebarrensfuels/ for data summarization techniques). Day-of-burn wind speed and fuel moisture data were used with these custom fuel models to predict (using Nexus 2.0) fire behavior in each plot. Data for the driest, windiest day was used with standard fuel model 1 to predict fire behavior in firelanes. Pearson's product-moment correlation (Sokal and Rohlf 1995) was used to compare predicted and observed values on a plot-by-plot basis. Observed values were obtained from direct observation of flame length and rate of spread between reference polls, and by comparison of these values with observations recorded on video.

Soil Compaction

Transects were sampled in thinned Pitch Pine plots where the fellerbuncher and bushhog were used (8 transects, 400 points), in one plot thinned and mowed with only a bushhog (5 transects, 250 points), and in an untreated Pitch Pine stand outside of the fuelbreak (8 transects, 400 points). A mowed and grazed Scrub Oak plot (4 transects, 200 points) and an untreated Scrub Oak stand outside of the fuelbreak (4 transects, 200 points) were also sampled.

RESULTS

Landscape Scale

Plants

Plant Communities. Cluster analysis (based on IVs and Sorensen distance, Figure 7) of relevé plots sampled off firelanes resulted in a community classification not unlike that of Mouw (2002), having a major division between closed-forest plots (groups 1 and 2, Pitch Pine and Oak Woodland; ave. canopy cover 57%) and more open ones (group 3, Scrub Oak/Oak Woodland; ave. canopy cover 46%). The major difference between this and Mouw's cluster analysis is that here a few very open Scrub Oak plots (average canopy cover 2%; group 4) cluster separately, whereas in Mouw's analysis Scrub Oak and Oak Woodland plots group together. Scrub Oak plots had little Blueberry and Huckleberry but group separately due to the almost exclusive occurrence of species such as Bearberry, Little Bluestem (*Schizachyrium scoparium*), Rockrose sp., and Whorled Loosestrife (*Lysimachia quadrifolia*) in this group. Mouw classifed a similar small set of plots as heathland (these plots were characterized by many of the same species and also grouped separately from other plots). For the purposes of Mouw's anaylsis, heathland plots were combined with scrub oak plots.

Despite intensive searches, rare plants were found outside of firelanes only along paths where frequent disturbance had occurred (but see results for the EFB below). There is, however, a set of grass and herb species, grassland associates, which occur frequently (>80%) in grassland plots and infrequently in forested and shrubland plots (<10% of plots). These grass and herb species (Table 4) occur in plots characterized as Scrub Oak (4 of 7 plots), Oak Woodland/ Scrub Oak (3 of 29 plots), Pitch Pine (2 of 15 plots), and Oak Woodland (1 of 12 plot), but occur in plots with significantly lower duff depths and ground cover of moss (Table 5) than is found on average.

Cluster analysis of relevé plots sampled within firelanes resulted in a community classification which was largely structured by management type (Figure 8). Lanes harrowed in 1993 and 1994 (herein refered to as new lanes) were classified apart from other lanes when they were at the exterior of the Forest (lanes 1, A and B; groups 3 and 4). These exterior new lanes were generally more isolated with respect to grassland seed sources and are characterized by lower frequencies and abundances of species otherwise common in firelanes. They also contain a number of unique species, including several non-native and invasive species. Eight of nine invasive and 11 of 19 non-native species occurrences were in exterior firelanes. New lanes in the interior of the Forest were grouped with old lanes (group 1).

Rare Plants. Each of the five rare species investigated was found to be locally abundant in at least an individual section of an old firelane. Each of the rare species was also found to have established within new firelanes since their creation in 1993. Species which more frequently colonized new lanes (Sandplain Flax and Papillose Nut-sedge) were also more frequent in old lanes. For other species, colonization in new lanes appeared to be more influenced by the proximity of existing populations. Sandplain Flax occurred frequently in new lanes and occupied firelane plots with significantly lower duff depths than were found in randomly located plots (Table 6). Sandplain Blue-eyed Grass was associated with higher moss and litter cover and greater duff depths than found in average firelane plots and was also associated with floristically unusual plots in group 5 of the cluster analysis (Figure 8). Lion's Foot was associated with subgroups (not shown) with a greater frequency and abundance of shrub species, higher litter and lower lichen cover (Table 6). Although little is known about the scale at which individuals of these species pollinate or disperse, Purple Needle-grass seems to be the most spatially restricted of the five rare plant species investigated. The species is very abundant within one firelane but has only a few other small occurrences, each separated from all others by more than 1.5 miles (2.4 km). This species occurs in firelane plots characterized by higher than average herbaceous cover (Table 6). Papillose Nut-sedge occurred relatively frequently in firelanes and established within newly harrowed lanes readily. There were no significant differences found in environmental characteristics between occupied and unoccupied plots for this species.

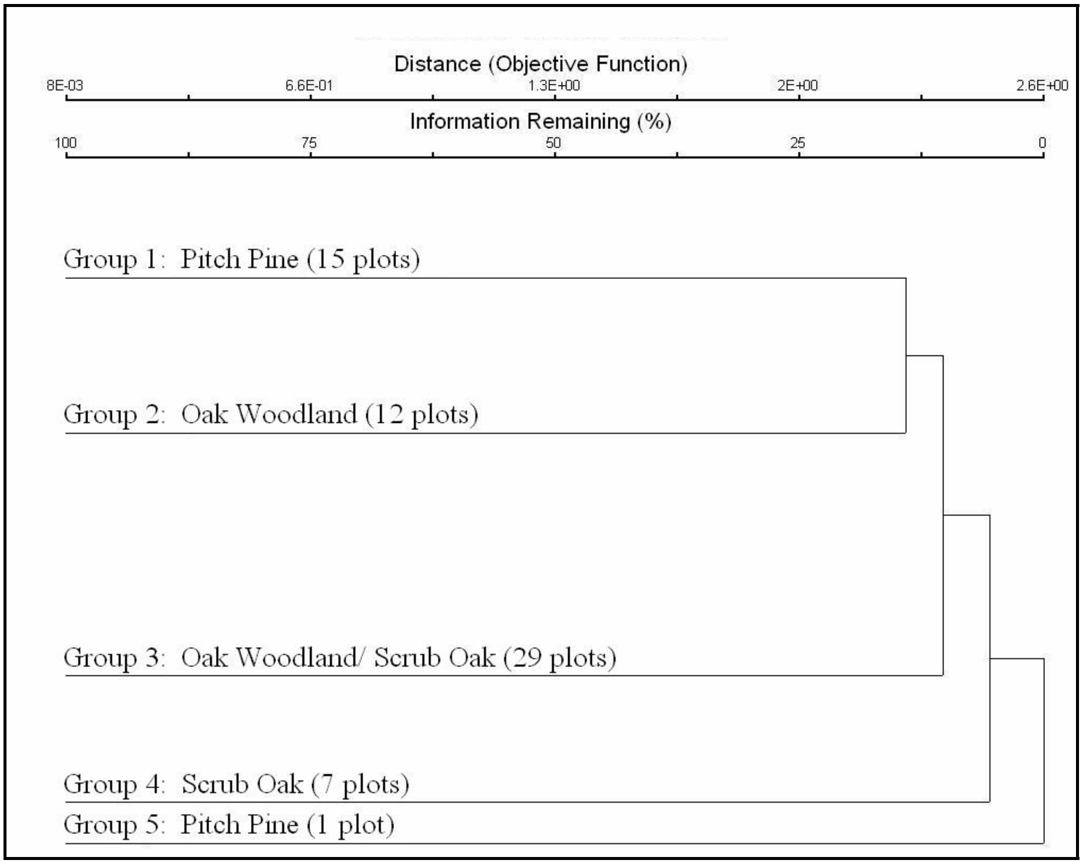

Figure 7. Cluster analysis based on 64 plots sampled off firelanes (species in less than 2 plots removed) showing the four vegetation types identified and the number of plots classified into each. One Pitch Pine plot with a unique species assemblage comprises the last cluster.

Invasive Plants. Invasive species occur both in firelanes that have not undergone recent management and forested areas near the perimeter, especially at points of entry to the Forest (i.e. along roads and bike paths, and near the Forest headquarters). Most occurrences were restricted to firelane 1 (Figures 2 and 9) and included Multiflora Rose (*Rosa multiflora*), Honeysuckle (*Lonicera* sp.), Oriental Bittersweet (*Celastrus* *orbiculata*), Autumn-olive (*Elaeagnus umbellata*), and Black Locust (*Robinia pseudoacacia*). Lane 1, created at the boundary of MFCSF, was harrowed in 1993 and 2002 but has not been mowed since. Within the new sections of lanes A and B, also near the exterior of MFCSF, four occurrences of Multiflora Rose were found. Multiflora Rose established in one interior firelane, in an area harrowed in 1993. In only one instance was an invasive species occurrence located under a tree, suggesting that perch trees did not facilitate their invasion.

Table 4. List of grassland associated species occurring in >75% of firelane plots and in <20% of forested/ shrubland plots sampled off firelanes (h=herbaceous and g=graminoid; p=perennial).

annual/ perennial	life form	Common name	scientific name	% grass plots	% forested plots
P	h	Bushy Rockrose	*Helianthemum sp.*	98	5
P	g	Forked Panic-grass	*Dichanthelium dichotomum*	98	2
P	h	Cinquefoil	*Potentilla sp.*	96	2
P	g	Little Bluestem	*Schizachyrium scoparium*	91	8
P	h	Yellow Wild Indigo	*Baptisia tinctoria*	91	5
P	h	Sweet Goldenrod	*Solidago odora*	91	3
P	h	Bushy Aster	*Aster dumosus*	83	3
P	h	Whorled Loosestrife	*Lysimachia quadrifolia*	83	3

Table 5. Environmental variables in forested/shrubland plots with and without grassland associates. Confidence intervals (p= 0.1) and level of significance (based on t tests).

	plots with grassland associates	plots without grassland associates	
	confidence interval (p=.1)	confidence interval (p=.1)	level of significance
% cover moss	**0 – 0**	**0- 0.1**	0.05
% cover lichen	0 - 2.6	0 – 0	-
% cover bare soil	0 - 0.3	0 - 0.2	-
average litter depth	3.0 - 4.4	3.5 - 4.0	-
average duff depth	**2.1 - 2.8**	**2.9 - 3.3**	0.05
canopy cover	1.3 - 4.7	4.3 - 5.2	-
Average cover @ 0.25 m	65.1 - 75.2	72.2 - 74.7	-

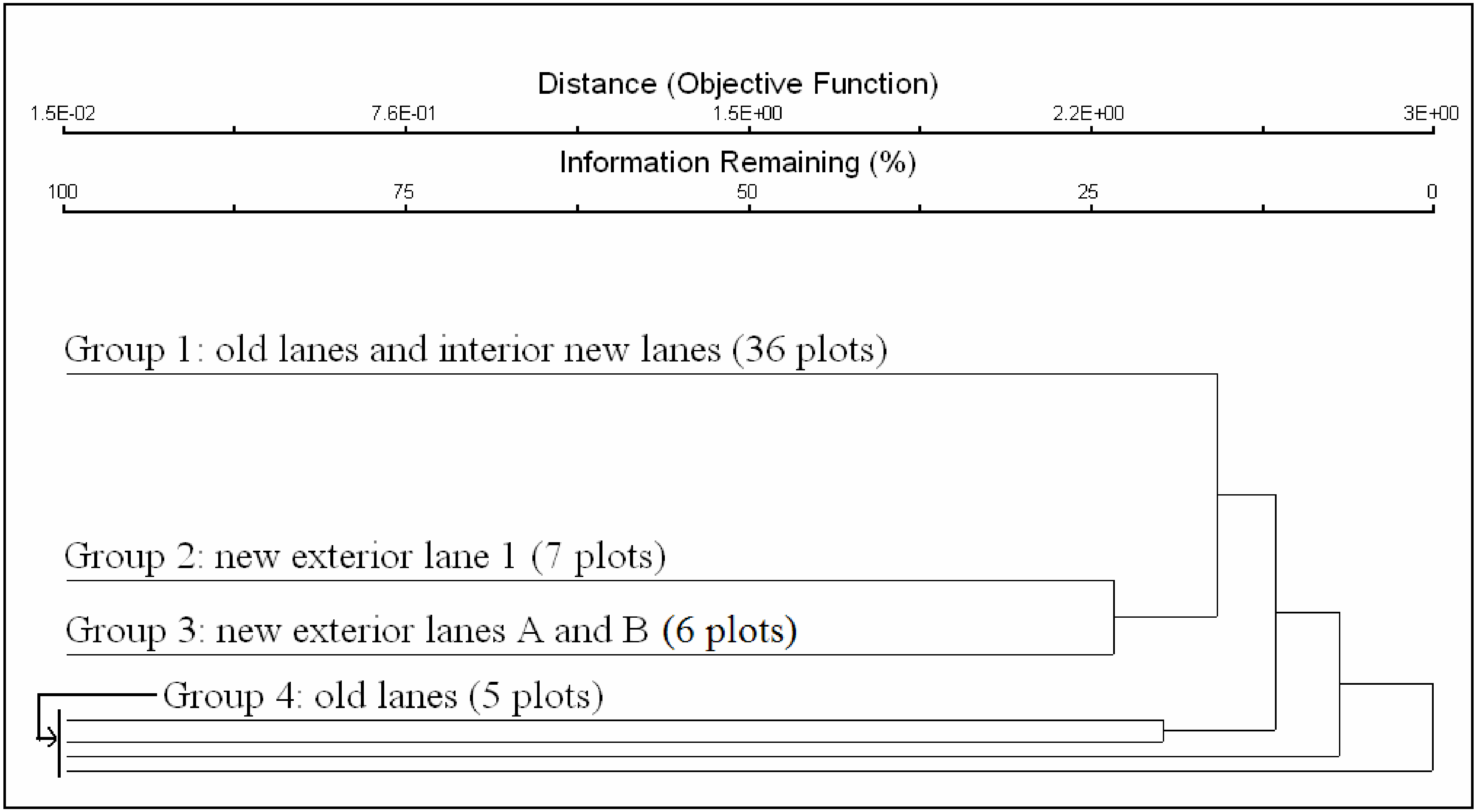

Figure 8. Cluster analysis based on 54 plots sampled in firelanes (rare species not included) showing five types identified and the number of plots classified in each.

Table 6. Environmental variables in firelane plots with and without rare plant species. Table shows confidence intervals (p= 0.1) and level of significance (based on t test).

A	Plots with Purple Needle- grass	Plots without Purple Needle-grass	
	confidence interval (p=.1)	confidence interval (p=.1)	level of significance
Average cover @ 0.25 m.	7.0 - 14.0	20.5 – 27.7	0.0001
% points with herbaceous veg	5.5 - 16.4	20.6 – 27.3	0.05

B	Plots with Sandplain Flax	Plots without Sandplain Flax	
	confidence interval (p=.1)	confidence interval (p=.1)	level of significance
average duff depth (inches)	0.0 - 0.0	0.0 - 0.1	0.01

C	Plots with Lion's Foot	Plots without Lion's Foot	
	confidence interval (p=.1)	confidence interval (p=.1)	level of significance
% cover of litter	87.5 - 98.0	70.1 - 81.0	0.005
% cover of lichen	0.0 - 0.4	3.8 - 11.0	0.005

D	Plots with Blue-eyed Grass	Plots without Blue-eyed Grass	
	confidence interval (p=.1)	confidence interval (p=.1)	level of significance
% cover of litter	83.0 - 97.7	71.2 - 81.9	0.05
% cover of moss	0.0 - 3.0	3.8 - 6.0	0.1
average litter depth (inches)	0.5 - 0.9	0.4 - 0.5	0.05

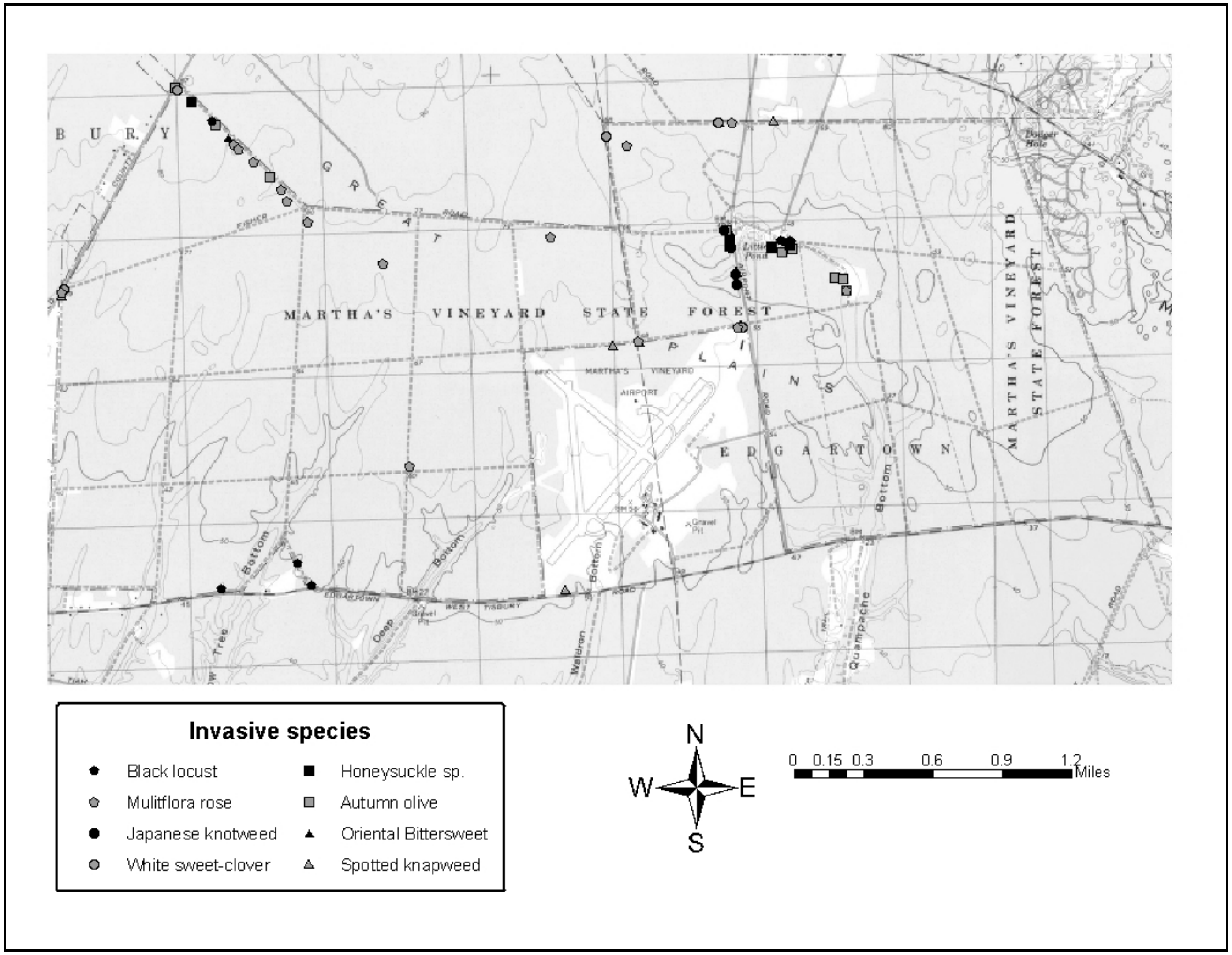

Figure 9. Map of MFCSF showing the locations of invasive plant occurrences found during searches conducted in 2004.

Insects

Larvae of the Barrens Buckmoth were found at 11 sites based on 180 transects across MFCSF. These larval locations were distributed across seven of the nine vegetation types, suggesting that broadly classified vegetation types are not useful for identifying potential Barrens Buckmoth larval locations (Table 7). However, the two vegetation types in which larvae were not found (Pitch Pine and Mature Plantation) were the two types with the least Scrub Oak (the larval food plant).

Table 7. Number of larval locations found within each vegetation type, based on 20 100m transects surveyed within each vegetation type in the appropriate season.

Vegetation Type	# Barrens Buckmoth Sites per Vegetation Type	# Spiny Oakworm Sites per Vegetation Type
Grassland	2	1
Oak Woodland	1	3
OW/SO	2	0
Scrub Oak	2	1
Young Plantation	1	0
Mature Plantation	0	0
Pitch Pine	0	0
Harrow	2	0
Burn	1	0

Habitat characteristics measured at each of the larval sites for comparison with random points within the different vegetation types included canopy cover, scrub oak stem density, and Bear Oak IVs. Barrens Buckmoth larvae were found in areas with fairly open canopy closure (27.0 $\pm$ 7.11%), high scrub oak stem densities (20.2 $\pm$ 3.79 stems/m^2), and moderately high Bear Oak IVs (4.45 $\pm$ 0.72) (Table 8). Of the three habitat variables analyzed, only scrub oak stem density was statistically significant (p=0.032) for Barrens Buckmoth larval habitat (logistic regression, see Table 9). The mean scrub oak stem density at the Buckmoth larvae sites was higher than the average stem densities found in all of the other types, although not significantly higher (based on t-tests) than either the Scrub Oak type (18.3 $\pm$ 6.13; P=0.79) or the Grassland vegetation type (9.20 $\pm$ 4.55; P=0.08) (Table 10 and Figure 10). This preference for higher scrub oak stem densities suggests that recently disturbed scrub oak could provide habitat for Barrens Buckmoth larvae, since disturbance causes scrub oaks to resprout vigorously leading to higher stem densities. The Scrub Oak and Grassland vegetation types both experience periodic disturbance; the Scrub Oak vegetation type includes large areas within frost bottoms where frost acts to prune the scrub oak, and the Grassland vegetation type is mowed annually. The disturbance at the recently harrowed sites (Harrow cover type) caused the removal of much of the scrub oak root stocks. The Burn cover type was disturbed in 1999 and is dominated by vigorously resprouting tree oak species which were the dominant oaks prior to the burn.

Table 8. Mean ± standard error for variables by vegetation type . Values in **bold** are statistically significant at $p<0.05$ (logistic regression, see Table 9). Scrub Oak stem density was statistically significant for Barrens Buckmoth sites. *Italics* indicate larval sites.

Site Type	Canopy Closure (% closure)	Scrub Oak Stem Density (#/m^2)	Bear Oak Importance Value
Spiny Oakworm Habitat	*61.40 ± 16.79*	*0.60 ± 0.40*	*3.00 ± 1.38*
Barrens Buckmoth Habitat	*27.00 ± 7.11*	***20.18 ± 3.83***	*4.45 ± 0.72*
Grassland	37.27 ± 7.34	9.20 ± 4.55	1.30 ± 0.40
Oak Woodland	75.85 ± 5.24	1.70 ± 0.60	3.40 ± 0.31
OW/SO	59.45 ± 5.51	6.90 ± 1.60	5.80 ± 0.33
Scrub Oak	26.56 ± 8.55	18.30 ± 6.13	5.40 ± 0.56
Young Plantation	74.84 ± 7.64	5.40 ± 3.47	2.90 ± 0.84
Mature Plantation	86.24 ± 3.66	0.10 ± 0.10	0.60 ± 0.31
Pitch Pine	81.51 ± 3.38	1.00 ± 0.67	2.40 ± 0.69
Harrow	9.68 ± 3.83	5.50 ± 2.30	0.90 ± 0.31
Burn	20.11 ± 3.11	3.70 ± 0.47	6.70 ± 3.11

Table 9. Logistic regression results for Barrens Buckmoth larval habitat characteristics. p-values in **bold** are statistically significant at $p <0.05$. Scrub oak stem density was statistically significant.

Parameter	df	Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square
Intercept	1	-2.654	0.892	8.865	0.003
Canopy closure	1	-0.022	0.014	2.408	0.121
Scrub oak importance value	1	0.199	0.158	1.575	0.210
Scrub oak stem density	1	0.052	0.024	4.599	**0.032**

Table 10. T-test comparisons between scrub oak stem densities found at Buckmoth larvae sites and those found at different vegetation types across MFCSF. P-values in **bold** are <0.05 and denote scrub oak stem densities that are significantly different from those found at Barrens Buckmoth sites. Scrub oak stem densities of the Grassland and Scrub Oak vegetation types were not statistically different from those found at Barrens Buckmoth sites.

Site Type	N	Mean	Std Error	Variance	t-statistic	df	p-value
Barrens Buckmoth	*11*	*20.18*	*3.83*	*161.36*	--	--	--
Grassland	10	9.20	4.55	206.61	-1.86	19	0.079
Oak Woodland	10	1.70	0.60	3.57	4.77	10.49	**0.001**
OW/SO	10	6.90	1.60	25.66	3.20	13.35	**0.007**
Scrub Oak	10	18.30	6.13	375.78	0.27	19	0.793
Young Plantation	10	5.40	3.47	119.62	2.82	19	**0.011**
Mature Plantation	10	0.10	0.10	0.10	5.24	10.01	**0.000**
Pitch Pine	10	1.00	0.67	4.44	4.93	10.60	**0.001**
Harrow	10	5.50	2.30	52.94	3.29	16.18	**0.005**
Burn	10	3.70	0.47	96.46	-2.70	19	**0.014**

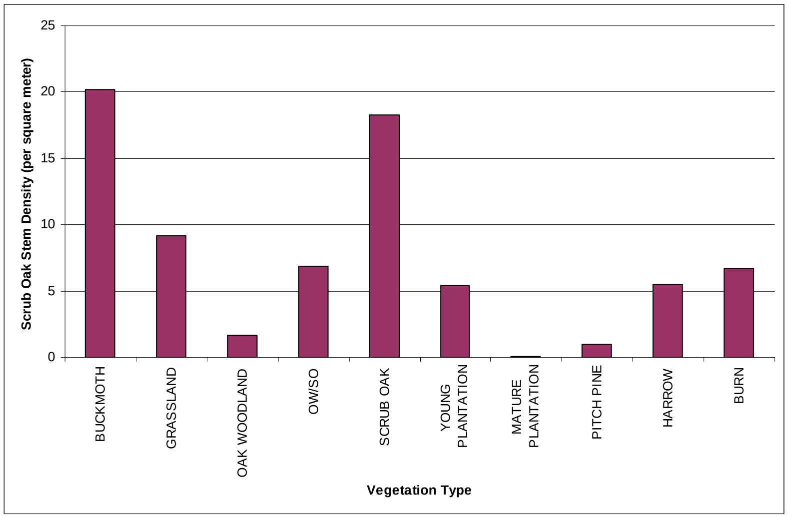

Figure 10. Mean scrub oak stem densities found on nine vegetation types compared to Buckmoth larvae sites, 2003. Scrub oak stem density is statistically significant from logistic regression model for Buckmoth habitat compared to random points (p=0.032). Note similarities between scrub oak stem densities of Buckmoth larval sites and Scrub Oak vegetation type

Scrub oak stem densities found in the Scrub Oak and Grassland vegetation types were not statistically different from those found at Barrens Buckmoth larval locations, but the larval locations were not found exclusively in these two vegetation types, as classified on a broad landscape level. In fact, the Barrens Buckmoth larval sites met the criteria for the Scrub Oak vegetation type with their open canopy and dominance of Bear Oak and Dwarf Chinquapin Oak, rather than the Grassland vegetation type which is defined by the dominance of short grasses. This suggests that the moths were selecting smaller patches of Scrub Oak within the larger landscape-level vegetation classifications.

Larvae of the Spiny Oakworm Moth were located along five of 180 transects. These five sites were in three vegetation types - Oak Woodland (3 locations), Scrub Oak (1), and Grasslands (1) - but the small sample size precludes making inferences about landscape-level habitat selection criteria (Table 7). As oak-feeders, Spiny Oakworm Moths were found most frequently in oak-dominated habitats. Using logistic regression, none of the three habitat variables were statistically significant (Table 11), but this may be due to low statistical power. The areas where Spiny Oakworms were found had moderate canopy closure ($61.4 \pm 16.8\%$), very low scrub oak stem densities (0.60 ± 0.40 stems/m^2), and moderate Bear Oak IVs (3.00 ± 1.38) compared to the averages of the variables found in the other vegetation types (Table 8).

Table 11. Logistic regression results for Spiny Oakworm Moth larval habitat characteristics. No variables showed statistical significance (p=0.05).

Parameter	df	Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square
Intercept	1	-3.095	1.382	5.015	0.025
Canopy closure	1	0.0028	0.016	0.031	0.860
Scrub oak importance value	1	0.263	0.236	1.243	0.265
Scrub oak stem density	1	-0.463	0.369	1.570	0.210

Soil Compaction

Soils in firelanes are significantly more compacted than in neighboring unharrowed areas (ave. compactions of 85 and 89 PSI (586 and 614 KPa) respectively (Figure 11).

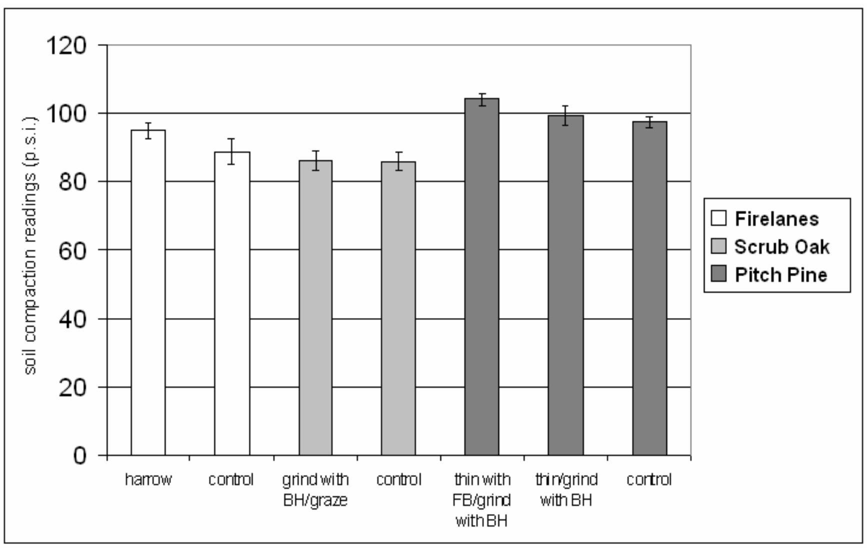

Figure 11. Average soil compaction in firelanes and adjacent unharrowed (control) vegetation sampled at the landscape scale, in treated Scrub Oak/Pitch Pine plots in the experimental area, and in untreated Scrub Oak and Pitch Pine stands (controls) just outside the EFB. Error bars depict confidence intervals (p=0.1). BH refers to brushhog and FB refers to fellerbuncher.

Ancient Oaks

Coppice oaks were observed in mature stands classified in the Oak Woodland or Oak Woodland/Scrub Oak cover types. Many of these sprout clumps had individual stems of 10-20 cm (3.9 – 7.9 inches) diameter at breast height (dbh), with no above-ground coppice stool visible (Figure 12). A younger stand was also inspected to examine the coppice structure in an earlier stage of development. The recent history of this stand (from incomplete management records) indicates that it was cut and then burned in a wildfire ca. 1950, cut again for cordwood ca. 1980, and burned in 1985 or 1987. In this younger stand, the burned stumps were still visible, and stems varied in size from 2 to 10 cm (0.8 – 3.9 inches) stump diameter and in number from 5 to 20 sprouts/stump (Figures 10 and 11).

Results from the tree survey conducted in the EFB control plots following prescribed burning show that larger oaks are resistant to moderate intensity prescribed burns. Mortality for stems < 2.5 inch diameter was less than 35% in Oak Woodland plots, less than 45% in Pitch Pine plots (Figure 15). Although there were fewer oak stems (> 1 in.) overall in Scrub Oak plots mortality in the smallest diameter class was high. Mortality was 67% in the control (n=3), 91% in the mow plot (n=11), and only one stem occurred in mow/graze plots and was not killed. Mortality was less than 20% for stems 2.5-5 inch (6.4-12.7 cm) diameter in all vegetation types and including in control plots.

Figure 12. Three black oak coppice sprouts growing around a 60-cm diameter belowground coppice stool, in the southwest section of MFCSF. Photo by M. Kelty.

Figure 13. Black oak coppice sprouts around a partially decayed coppice stool 35 cm in diameter, in a stand in the northeast section of MCFSF. The stand had been cut and then burned approximately 17 years before the photograph was taken. Photo by M. Kelty.

Figure 14. Black oak coppice sprouts in same stand as Figure 12. Many of the smaller diameter sprouts have died, presumably from competition within the dense sprout clump. Photo by M. Kelty.

Southwest Experimental Fuels Break

Plants

Vegetation Change. An ordination (Nonmetric Multidimensional Scaling – NMS) of experimental plots based on 2002 and 2004 vegetation data (IVs derived from relevé sampling; Figure 25) shows that the three habitats are easily distinguished and although the treatments altered vegetation within plots (Figures 16-21), changes do not warrant their reclassification to a different vegetation type. However, even before treatments Scrub Oak plots from the eastern branch of Willow Tree Bottom (WTB, SO1 through SO6) were floristically different from the three Scrub Oak plots to the west. When canopies were present in the WTB plots they tended to be dominated by Pitch Pine, whereas canopies of the other Scrub Oak plots (7-9) tended to be dominated by tree oaks. Extensive stands of Pitch Pine occupy the uplands surrounding WTB. The WTB plots contained grass and herb species (e.g., Rockrose, Bearberry, and Little Bluestem) which rarely occurred in plots SO7-9. Prior to treatments, 30% of duff depths in the WTB plots were < 0.25 inch (0.6 cm) - equivalent to the average found in rare plant plots (0.3 inch or 0.8 cm), whereas no values that low were found in the other Scrub Oak plots.

Following treatments, a number of plots shifted in the ordination with treated plots (especially Pitch Pine plots) moving to the right towards increased importance of Scrub Oak. Yet most species on these plots resprouted and by 2004 many had IVs which equaled or exceeded pretreatment values. Grazing was a somewhat variable treatment, as a result of the browse preferences of the sheep, but generally when sheep were removed from plots only woody species remained. In the first few plots grazed in 2003 sheep ate all Bear Oak, Dwarf Chinquapin Oak, and Blueberry sprouts, yet later in the summer they would not completely graze these species. In the first plot they were introduced to in 2002, the sheep grazed only occasionally on Pitch Pine slash, yet in other plots where pitch pine occurred as young stems or low branches of trees sheep ate Pitch Pine. Sheep generally ate all grass and herb stems in plots yet these species were generally found again in the final year of sampling. Sheep were responsible for the introduction of a number of grass and herb species (Table 12) directly from grain feed and through

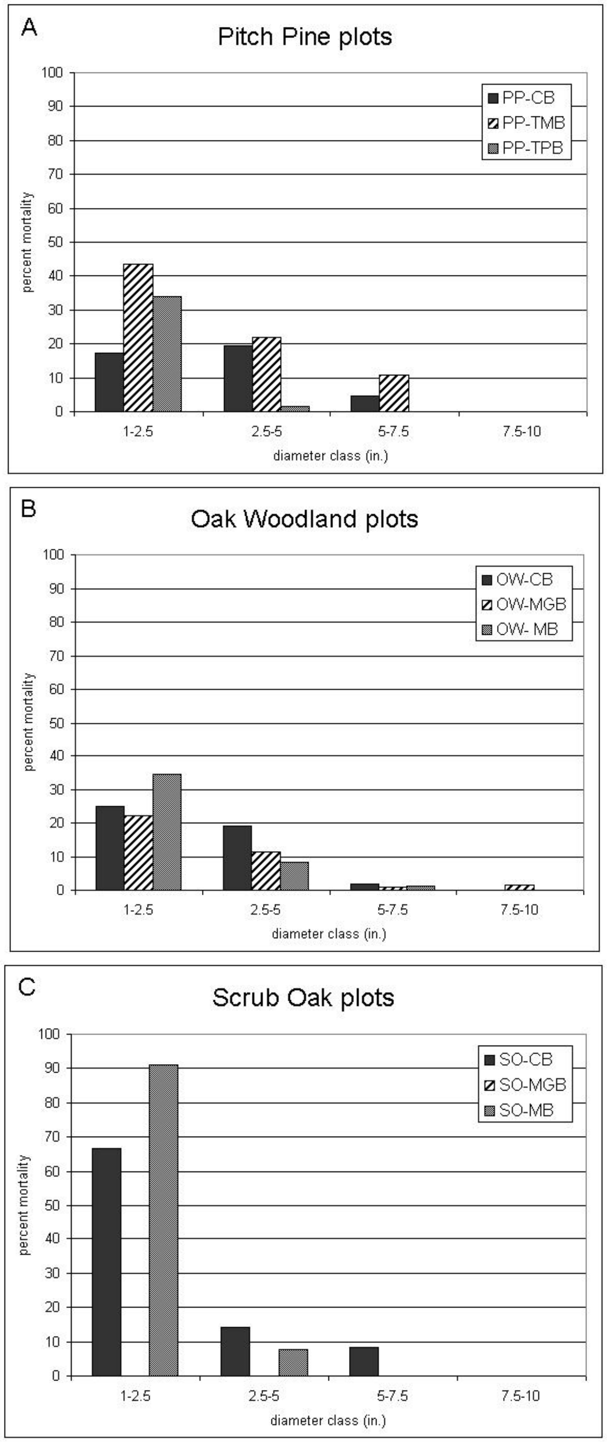

Figure 15. Percent mortality of stems (all oak species combined) by diameter class in Pitch Pine (A), Oak Woodland (B) and Scrub Oak (C) plots.

Figure 16. Photo series from Pitch Pine plot A) taken 7/12/02 prior to treatments (photo by D. Brennan), B) taken 7/17/03 following thinning and mowing (conducted in mid-July 2002; photo by C. Wood), and C) taken 7/29/04 following thinning, mowing, and burning (burning conducted 5/7/04; photo by B. Cotton).

Figure 17. Photo series from Pitch Pine plot A) taken 7/16/02 prior to treatments (photo by S. Haggerty), B) taken 7/22/03 following thinning and grazing (conducted early-mid August 2002; photo by C. Wood) and pile burning (conducted winter 2002/2003), C) taken 9/8/04 following thinning, grazing, pile burning and prescribed burning (burning conducted 5/5/04; photo by B. Cotton).

Figure 18. Photo series from Oak Woodland plot A) taken 7/11/02 prior to treatments (photo by D. Brennan), B) taken 8/20/03 following mowing (conducted mid-July 2002; photo by C. Wood), C) taken 7/30/04 following mowing and burning (burning conducted 4/29/04; photo by B. Cotton). Photos taken at different locations in plot.

Figure 19. Photo series from Oak Woodland plot A) taken 7/11/02 prior to treatments (photo by D. Brennan), B) taken 8/19/03 following mowing and grazing (conducted mid-July to mid-August 2003; photo by C. Wood), C) taken 7/26/04 following mowing, grazing, and burning (burning conducted 4/29/04; photo by B. Cotton)

Figure 20. Photo series from Scrub Oak plot A) taken 7/7/02 prior to treatments (photo by D. Brennan), B) taken 7/17/03 following mowing (mid-July 2002; photo by C. Wood), C) taken 9/8/04 following mowing and burning (burning conducted 4/30/04; photo by B. Cotton).

Figure 21. Photo series from Scrub Oak plot A) taken 7/18/02 prior to treatments (photo by D. Brennan), B) taken 7/16/03 following mowing (mid-July 2002) and grazing (September 2002; photo by C. Wood), C) taken 7/29/04 following mowing, grazing (grazed again in September 2003), and burning (burning conducted 5/6/04; photo by B. Cotton). Photos taken at different locations in plot.

Figure 22. Photo series in Pitch Pine control plot A) taken 7/8/02 (photo by D. Brennan) and B) taken 7/20/04 following burning (conducted 4/30/04; photo by B. Cotton).

Figure 23. Photo series in Oak Woodland control plot A) taken 7/11/02 (Photo by D. Brennan) and B) taken 7/26/04 following burning (conducted 4/29/04; photo by B. Cotton).

Figure 24. Photo series in Scrub Oak in control plot A) taken 8/28/02 (photo by D. Brennan), and B) taken 9/8/04 following burning (conducted 5/6/04; photo by B. Cotton).

their feces, particularly evident in the first plot they were introduced to each year (PP8 in 2002 and OW5 in 2003). Many of these species, particularly agricultural grasses, did not persist beyond a growing season and were not found during 2004 sampling (analyses based on pretreatment and 2004 sampling).

A number of grassland associated species colonized experimental plots (Appendix D), and those plots colonized by more species (Table 13) tended to shift to the right along Axis 1 (towards the Scrub Oak plots) in the ordination (e.g. PP8). Species which were identified as occurring in the plots following treatments did not necessarily represent new colonizations. Treatments, for example, may have stimulated flowering thereby enabling the identification of species.

Table 12. Nonnative plant species established in research plots in EFB (not present during initial pretreatment sampling and present in final sampling of plots in the summer of 2004). Table shows which plots each species occurs in and what treatment was applied there.

Common name	scientific name	PP8 (TGP)	SO9 (MG)	OW1 (MG)
Sweet Vernalgrass	*Anthoxanthum odoratum*	X		
Orchard-grass	*Dactylis glomerata*	X		
Velvet-grass	*Holcus lanatus*	X		X
Timothy	*Phleum pretense*		X	
Sheep-Sorrel	*Rumex acetosella*	X		
Clover	*Trifolium sp.*		X	
White Clover	*Trifolium repens*	X		

Rare Plants. During pre-treatment sampling, only one stem of one rare plant species (Sandplain Blue-eyed Grass) was found in the EFB (along a bridle path). Following treatments, Papillose Nut-sedge established at two sites in areas where bare soil was exposed (by machinery in Pitch Pine stands), and Lion’s Foot was found in a Scrub Oak stand treated with mowing and burning.

Because rare species were generally found and only sampled in firelanes, low canopy cover is associated with rare plants (Table 14). Canopy cover in Scrub Oak plots prior to (and following) treatments was equivalent to that found on rare plant plots. Canopy cover was significantly higher both before and after treatments in Pitch Pine and Oak Woodland plots compared to rare plant plots, despite a significant reduction in cover following thinning in Pitch Pine plots. Although percent woody cover was reduced (frequently significantly) and graminoid cover increased as a result of treatments, all plots had significantly greater woody cover and significantly less herbaceous and graminoid cover than rare plant plots following treatments; one exception was woody cover in Pitch Pine thin/pile burn plots which was equivalent to rare plant plots.

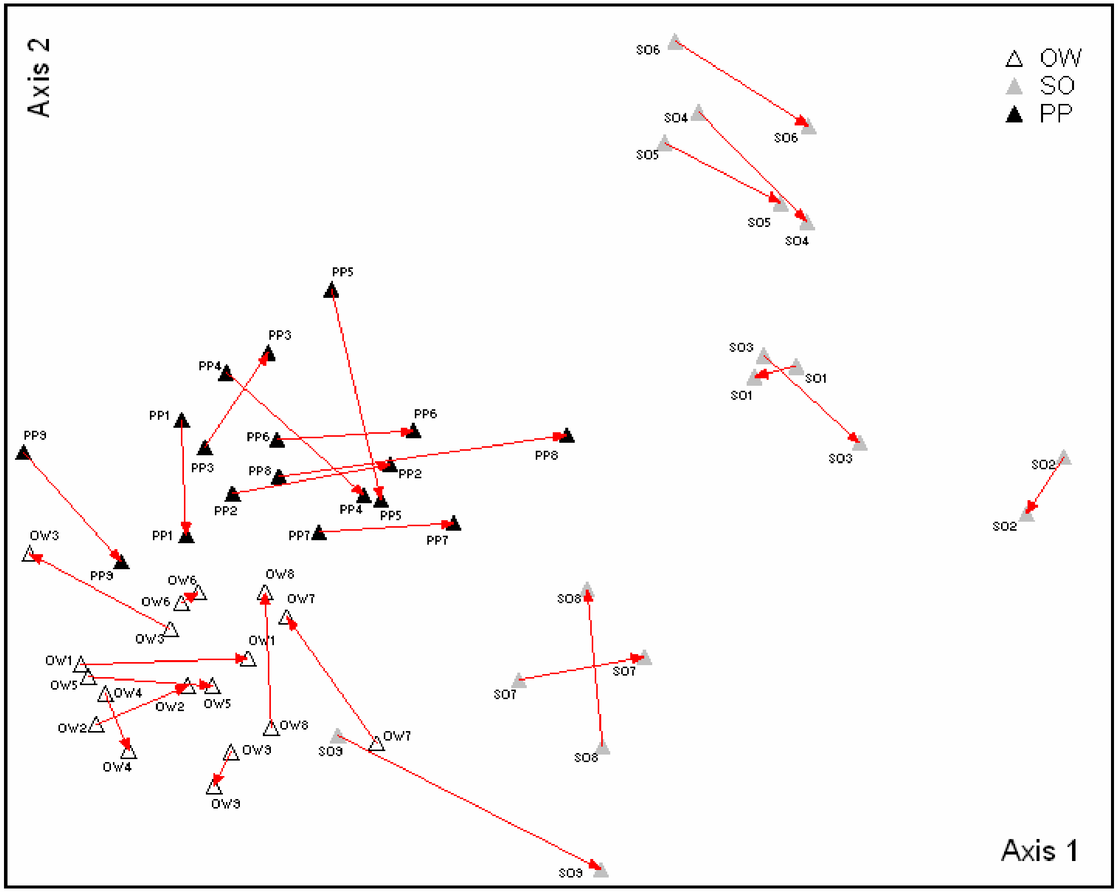

Figure 25. Ordination (NMS) of 27 EFB plots in space defined by species abundances (IVs) in 2002 and 2004 (arrows point toward the latter). Grassland associated species have high axis I scores and intermediate axis II scores. Treatments generally shifted Scrub Oak (SO) and Pitch Pine (PP) plots toward increasing importance of grassland associates, with no consistent trends identified in the movement of Oak Woodland (OW) plots.

Table 13. Number of grassland associated species that established in research plots in the EFB following treatment (i.e., they were found in plots in August 2004 but were not present in 2002).

Plot	treatment	# "established" grassland associates
PP1	C	0
PP5	C	0
PP9	C	1
PP2	T/M	3
PP3	T/M	4
PP7	T/M	6
PP8	T/G/P	15
PP4	T/P	3
PP6	T/P	8
OW2	C	2
OW7	C	2
OW8	C	1
OW1	M/G	3
OW5	M/G	4
OW9	M/G	1
OW3	M	0
OW4	M	0
OW6	M	0
SO4	C	1
SO5	C	1
SO8	C	0
SO1	M/G	7
SO2	M/G	14
SO9	M/G	13
SO3	M	5
SO6	M	10
SO7	M	13

Table 14. Ninety percent confidence intervals for environmental characteristics measured in research plots in the EFB and in plots containing any of five rare plant species, by cover type. Pretreatment values are the average of six plots sampled in 2002. Treatment values are averages of three plots sampled in the spring of 2004, after treatments but before prescribed burns. Duff depths and densiometer readings are from summer of 2004. Values for research plots are bold when statistically different from plots with rare plants (based on t test).

A Pitch Pine	pretreatment	post TM (thin/mow)	post TP (thin/pile burn)	rare plant plots
	confidence interval(p=.1)	Confidence interval(p=.1)	confidence interval (p=.1)	confidence interval (p=.1)
ave. litter depth (inches)	**3.4 - 5.0**	**1.1 - 2.5**	**1.8 - 2.9**	0.4 - 0.6
ave. duff depth (inches)	**2.2 - 3.4**	**2.6 - 2.7**	**1.6 - 2.5**	0 - 0.1
% bare soil	**0 - 1**	**0 - 0**	**0 – 3**	6 – 14
% graminoid	**0 - 0**	**0 - 0**	**0 – 6**	52 – 64
% herbaceous	**0 - 0**	**0 – 0**	**0 – 1**	18 – 25
% woody	**98- 100**	**51 – 65**	35 – 80	34 – 44
densiometer (% cover)	**58 - 71**	**35 – 59**	**36 – 59**	16 – 24

B Oak Woodland	pretreatment	post MG (mow/graze)	post M (mow)	rare plant plots
	confidence interval(p=.1)	confidence interval (p=.1)	confidence interval (p=.1)	confidence interval (p=.1)
ave. litter depth (inches)	**1.9 - 3.0**	**1.6 - 3.2**	**2.4 - 3.5**	0.4 - 0.6
ave. duff depth (inches)	**1.9 - 2.5**	**1.3 - 2.2**	**0.4 - 5.2**	0 - 0.1
% bare soil	**0 - 0**	**0 – 0**	**0 – 0**	6 – 14
% graminoid	**0 - 0**	**0 – 0**	**0 – 1**	52 – 64
% herbaceous	**0 - 0**	**0 – 0**	**0 - 0**	18 – 25
% woody	**98 - 100**	**66 - 99**	**83 – 93**	34 – 44
densiometer (% cover)	**46 - 57**	**54 - 77**	**48 – 58**	16 – 24

C Scrub Oak	pretreatment	Post MG (mow/graze)	post M (mow)	rare plant plots
	confidence interval(p=.1)	Confidence interval (p=.1)	confidence interval (p=.1)	confidence interval (p=.1)
ave litter depth (inches)	**2.3 - 3.2**	**1.3 - 2.2**	**1.6 - 2.5**	0.4 - 0.6
ave duff depth (inches)	**0.6 - 1.2**	**0.4 - 0.9**	**0.4 - 0.8**	0 - 0.1
% bare soil	**0 - 2**	**0 – 2**	**0 – 1**	6 – 14
% graminoid	**0 - 3**	**0 – 5**	**0 – 11**	52 – 64
% herbaceous	**0 - 1**	**0 – 0**	**0 – 1**	18 – 25
% woody	**97 - 99**	**60 – 77**	**65 – 81**	34 – 44
densiometer (% cover)	6 - 25	0 – 29	**0 – 17**	16 – 24

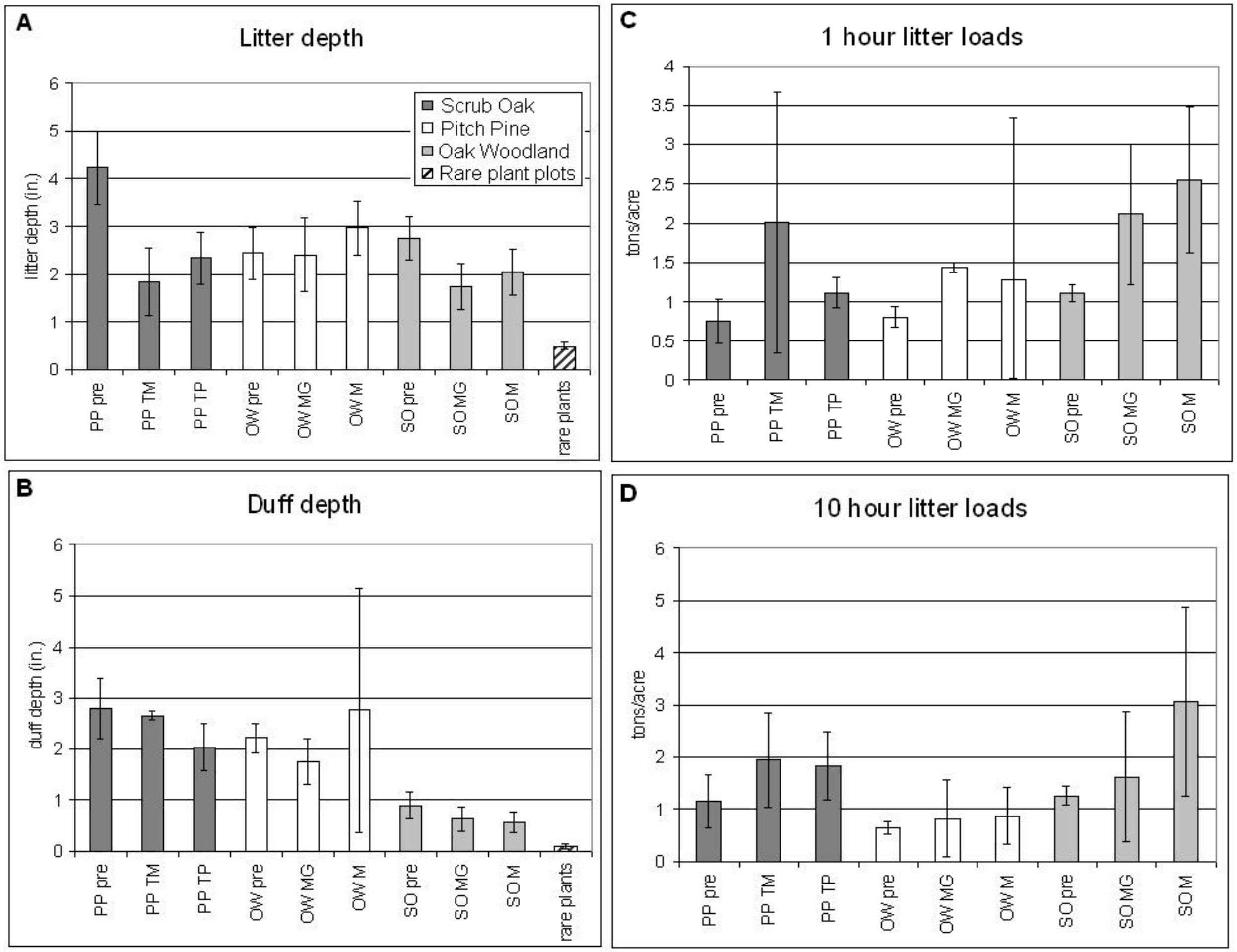

Figure 26. Average litter (A) and duff (B) depths and 1- (C) and 10- (D) hour litter loads in research plots in EFB. Error bars indicate confidence intervals (p=0.1). Pretreatment is an average of six plots sampled in 2002. Treatments are averages of three plots sampled in the spring of 2004 after treatments but before prescribed burns (however duff depths and densiometer readings are from spring of 2004). Figures 26 A and B include averages for plots containing one or more of the five rare plant species.

Average litter and duff depths were significantly higher in all experimental plots than in rare plant plots both before and after treatments (Table 14, Figure 26). Prior to treatments litter depths were highest in Pitch Pine (average depth 4.2 inches; 11 cm) and lowest in Scrub Oak (2.8 inches; 7 cm) plots. Treatments minimally impacted duff depths but generally reduced average litter depth (significantly in SO-MG and PP treated plots). However, treatments often resulted in an increase, frequently significant, in litter mass – the result of the addition of shredded shrub stems to the litter layer (Figure 26). The impact of treatments may be best understood not in terms of average depths and loads but rather their variability. In Pitch Pine plots where the fellerbuncher was used to thin trees, 5-to-10% of the sampled duff depths were less than 0.25 inch (0.6 cm). The average found in rare plant plots was 0.3 inch (0.8 cm). Similar values were not found in Pitch Pine prior to treatments, in control plots following burning, or in the plot thinned without the fellerbuncher following burning (PP7). In both treated and control Scrub Oak plots following burning, 30% of sample points were <0.25 inch vs. 20% in pretreatment Scrub Oak. Comparable values were not found in Oak Woodland plots before or after treatments.

Invasive Plants. In only one instance was an invasive plant species found outside firelanes at MFCSF. A number of stems of Black Locust were found prior to the application of treatments within the EFB and within 100 meters (328 ft) of Edgartown West Tisbury Road.

Insects

T-test comparisons between the mean scrub oak stem density of the Barrens Buckmoth larval habitat and those of the habitats created by the experimental fuel-reduction techniques suggest that three of the treatment combinations of 2002 and seven of the burn treatments of 2004 produced scrub oak stem densities similar to those found at Barrens Buckmoth larval sites (Tables 15 and 16, Figures 27 and 28).

The 2002 treatment combinations most closely mimicking scrub oak densities of the larval sites were OW-M, SO-M/G, and SO-C (Table 15 and Figure 27). The last of these is untreated Scrub Oak kept as a control for comparison with the fuel reduction techniques being examined. It is not surprising that this "treatment type" had scrub oak stem densities similar to larval sites, as the Scrub Oak vegetation type generally has densities similar to Buckmoth sites (Table 10).

The treatment combinations culminating in the burning of all the experimental plots in 2004 produced mean scrub oak stem densities not significantly different from those found at Barrens Buckmoth sites for nearly every treatment/vegetation type combination. Only the mean scrub oak stem densities of the Pitch Pine "control" plots—even after burning—were significantly different (lower) from those of the Barrens Buckmoth sites (Table 16 and Figure 28). The OW-M/G/B treatment produced only marginally similar stem densities (p=0.06). The 2004 burning of the Scrub Oak

Table 15. T-test comparison between scrub oak stem densities found at Buckmoth larvae sites and those found at experimental plots, post-treatment 2002 with measurements taken in 2003. P-values in **bold** are <0.05 and denote scrub oak stem densities that are significantly different from those found at Barrens Buckmoth sites. Scrub oak stem densities of the OW-M, SO-C, and SO-M/G treatments were not statistically different from those found at Barrens Buckmoth sites.

Site Type	N	Mean	Std Error	Variance	t-statistic	Df	P-value
Barrens Buckmoth	*11*	*20.18*	*3.83*	*161.36*	--	--	--
PP-C	3	4.89	2.28	15.59	3.43	11.27	**0.005**
PP-T/M	3	5.22	1.39	5.81	3.67	11.79	**0.003**
PP-T/G	3	NA	NA	NA	NA	NA	NA
OW-C	3	3.11	1.56	7.26	4.13	11.95	**0.001**
OW-M/G	3	NA	NA	NA	NA	NA	NA
OW-M	3	9.67	4.19	52.78	1.85	5.90	0.114
SO-C	3	20.67	5.55	92.33	-0.06	12	0.953
SO-M/G	3	35.33	12.68	482.11	-1.59	12	0.139
SO-M	3	62.89	10.28	316.93	-4.79	12	**0.000**

Table 16. T-test comparison between scrub oak stem densities found at Buckmoth larvae sites and those found at experimental plots, post-burn 2004, with measurements taken in 2004. P-values in **bold** are <0.05 and denote scrub oak stem densities that are significantly different from those found at Barrens Buckmoth sites. Scrub oak stem densities of the all treatments except the PP-C/B treatment were not statistically different from those found at Barrens Buckmoth sites.

Site Type	N	Mean	Std Error	Variance	t-statistic	Df	P-value
Barrens Buckmoth	*11*	*20.18*	*3.83*	*161.36*	--	--	--
PP-C/B	3	4.67	2.91	25.44	3.23	9.32	**0.010**
PP-T/M/B	3	12.22	7.02	148.04	0.97	12	0.352
OW-C/B	3	18.33	11.10	369.44	0.20	12	0.843
OW-M/G/B	3	9.00	3.47	36.11	2.16	7.59	0.064
OW-M/B	3	13.11	7.31	160.48	0.86	12	0.409
SO-C/B	3	66.33	23.86	1707.44	-1.91	2.10	0.190
SO-M/G/B	3	61.33	15.07	681.33	-2.65	2.26	0.104
SO-M/B	3	36.11	11.84	420.26	-1.71	12	0.113

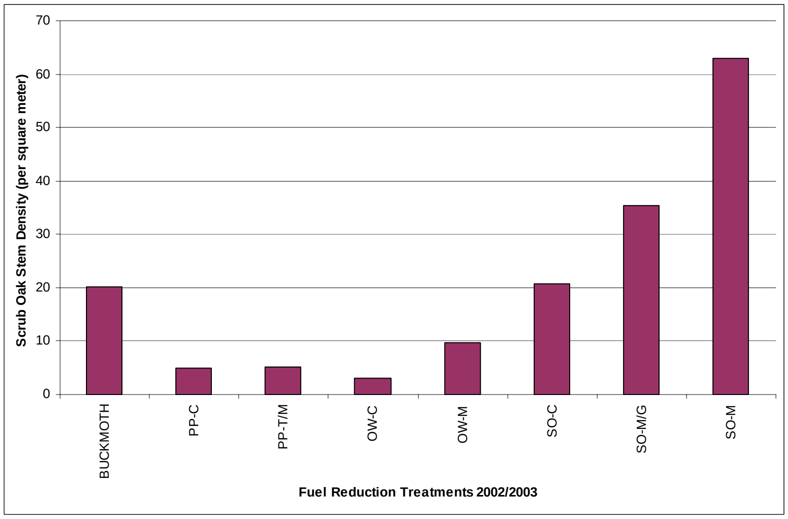

Figure 27. Mean scrub oak stem densities in SW EFB plots treated in 2002/2003, compared to Buckmoth larval sites. Scrub oak stem densities found at SO-C, SO-M/G, and OW-M plots were not statistically different from those found at Buckmoth sites using two-sample t-test (p>0.05).

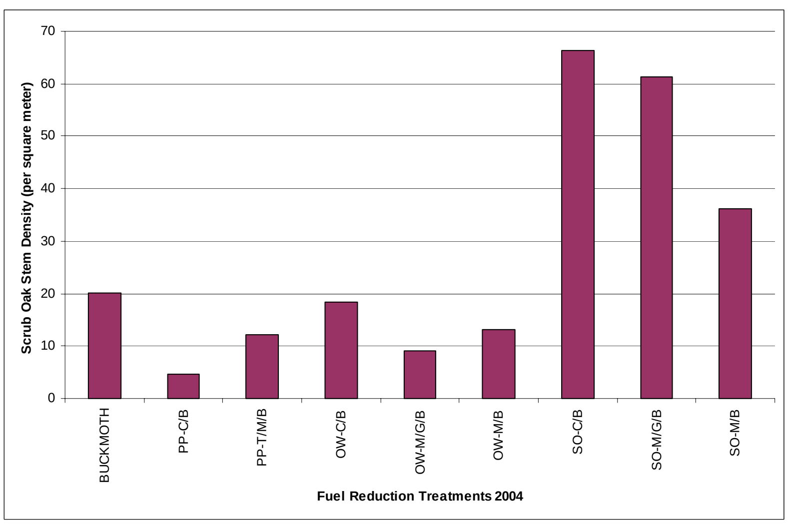

Figure 28. Mean scrub oak stem densities in SW EFB plots burned in 2004, compared to Buckmoth larval sites. Scrub oak stem densities found at all treatment plots except PP-C/B plots were not statistically different from those found at Buckmoth sites (p>0.05).

treatment plots produced scrub oak stem densities much higher than those found at Barrens Buckmoth larval sites (Table 16).

Overall, the experimental plots which had mean scrub oak stem densities closest to those found at Barrens Buckmoth larval sites were the SO-C plots, which had no treatments applied to them. This mirrors the finding that Scrub Oak plots randomly located across the Forest were most similar to Buckmoth larval sites in mean scrub oak density (Table 10). The actual treatments which created mean scrub oak stem densities comparable to those found at Buckmoth larval sites were OW-B, OW-M/B, and PP-T/M/B. Several other treatments created mean scrub oak stem densities not significantly different from those found at Buckmoth sites, but the p-values were low and the variances high (Tables 15 and 16). Variances were generally higher in the treated plots than in the untreated plots. P-values developed from such small treatment sample sizes (N=3) and from means with such large variances should be interpreted with caution, as a small sample size could result in a lack of power to distinguish a difference between the treatments and the larval habitats. This could lead to the assumption that the two entities are not different, when in fact we simply may not be able to detect the differences with only three treatment plots. Using an effect size of 12 (the difference in stem density needed to find statistical significance between the Buckmoth sites and the different vegetation types using a t-test), power of 0.8 by convention, and the smallest variance found in the treatment plots not significantly different from Buckmoth sites (36.1) a power analysis for two-sample t-tests determined that a minimum sample size of five would be necessary for sufficient power to detect a significant scrub oak stem density difference. Implementing up to 45 treatment plots would not have been practical.

Because the logistic regression analysis of three habitat variables showed none that were statistically significant for the Spiny Oakworm, no assessments could be made of the ability of the treatments to create habitat for the larvae of this species. These habitat variables may be important, but we were unable to detect significance with a small sample size. Variables not measured in this study could also play a role in creating ideal Spiny Oakworm habitat. It seems likely that they would be found most commonly where their food sources were most abundant (e.g. in Oak Woodlands, where three of the five locations were found) and in Scrub Oak (where one of the five locations was found), but also in the Scrub Oak/Oak Woodland type where we did not find them.

Fuels and Fire Behavior

Without treatment, observed fire behavior in both Scrub Oak (Figure 24) and Pitch Pine plots (Figure 22) was extreme. With moderate weather conditions (average wind speed = 3.6 mph - 5.8 km/h - and relative humidities = 65%) flame lengths averaged 7 to 10 feet (2 to 3 m) and rates of spread 15 to 23 ft/min (4.6 to 7 m/min; Figures 29 and 30; Table 17). In untreated OW-C plots, flame lengths averaged 7 feet (2.4 m) and rates of spread 16 ft/min (4.9 m/min; Figure 23). Because fuels, unlike observed fire behavior, are influenced by treatments but not variable weather conditions, they are useful in making comparisons between plots. Scrub Oak had higher one- and 10-hour fuel loads [litter plus live and dead woody material <1" (2.5 cm) diameter; 14.3 tons/acre (32 mt/ha)] than Pitch Pine [10.9 tons/acre (24 mt/ha)] or Oak Woodland plots [10.2 tons/acre (23 mt/ acre; Table 18; Figures 16-24)]. In Scrub Oak, fine (1-hour) slash loads averaged 2.5 tons/acre (6 mt/ha) and shrub loads averaged 1.5 tons/acre (3.4 mt/ha), whereas Pitch Pine (0.7 and 0.9 tons/acre for slash and shrubs) and Oak Woodlands (1.3 and 1.1 tons/acre for slash and shrubs) had lower loads (Table 18). Scrub Oak plots also had the highest shrub depths due to the dense scrub oak stems in these plots. Pitch Pine plots tended to have lower fine slash and live shrub loads than Oak Woodland plots but generally greater litter loads prior to treatments.

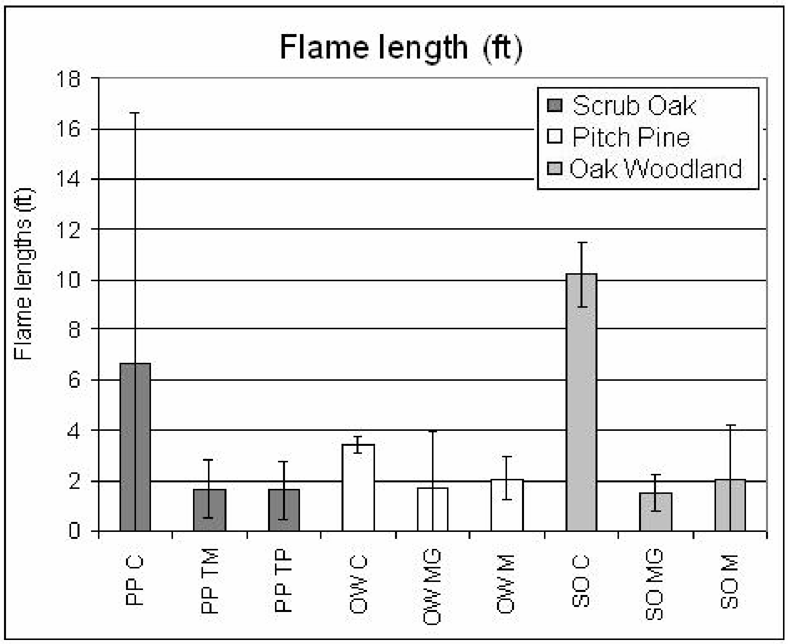

Figure 29. Averaged observed flame length of prescribed fires in research plots. Error bars indicate confidence intervals (p=0.1). Average windspeed in control plots was 3.4 mph and in treated plots was 3.7 mph.

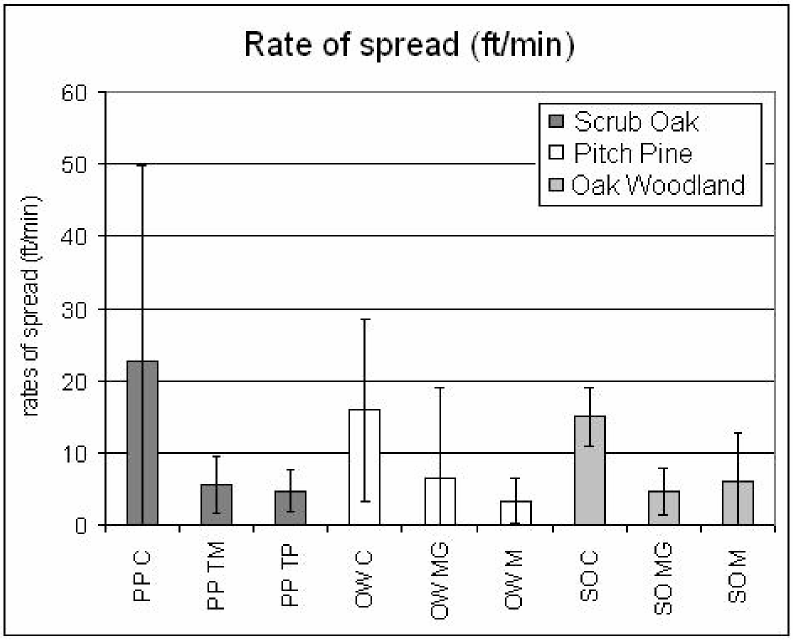

Figure 30. Averaged observed rates of spread for prescribed fires in research plots. Error bars indicate confidence intervals (p=0.1). Average windspeed in control plots was 3.4 mph and in treated plots 3.7 mph.

Table 17. Confidence intervals (p=0.1) for observed average flame lengths and rates of spread of prescribed fires (A = Pitch Pine, B = Oak Woodland, C = Scrub Oak).

A Pitch Pine	control	TM (thin,mow)	TP (thin,pile burn)
rate of spread (ft/min)	0 - 50	1.6 - 9.6	1.9 - 7.7
flame length (ft)	0 - 16.6	0.5 - 2.8	0.4 - 2.8
wind (mph)	0 - 9.4	2.2 - 3.2	2.1 - 4.5

B Oak Woodland	control	MG (mow,graze)	M (mow)
rate of spread (ft/min)	3.4 - 28.6	0 - 18.9	0.1 - 6.7
flame length (ft)	3.1 - 3.8	0 - 4.0	1.2 - 3.0
wind (mph)	0.5 - 5.0	3.7 - 4.9	1.5 - 4.4

C Scrub Oak	control	MG (mow,graze)	M (mow)
rate of spread (ft/min)	11.0 - 19.2	1.4 - 8.0	0 - 12.9
flame length (ft)	8.9 - 11.5	0.8 - 2.3	0 - 4.3
wind (mph)	3.4 - 3.4	3.9 - 5.8	1.6 - 6.8

Table 18. Average fuel loads and depths in the EFB. Data are based on spring 2004 (pre-burn) sampling of control and treatment plots (each averaged over three plots). These data were used to create CFMs for control and treatment plots.

	PP-C	PP-TM	PP-TP	OW-C	OW-MG	OW-M	SO-C	SO-MG	SO-M
fine litter load (tons/acre)	7.8	8.0	6.8	5.24	5.2	5.4	5.68	6.7	8.6
slash load (tons/acre)	0.0	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0
live shrub load (tons/acre)	0.9	0.2	0.6	1.54	0.9	0.9	0.64	0.3	1.1
dead shrub load (tons/acre)	0.2	0.1	0.2	0.26	0.3	0.1	0.21	0.1	0.4
litter depth (ft)	0.3	0.2	0.2	0.36	0.2	0.2	0.21	0.1	0.2
slash depth (ft)	1.0	0.0	0.8	0.85	0.5	0.6	1.82	0.3	1.1
shrub depth (ft)	3.0	2.9	1.6	2.92	3.0	2.2	4.27	2.0	1.4

Treatments did not influence overall fuel loading but did alter the vertical arrangement of fuels with slash and shrubs being redistributed to the litter layer. In all plots following treatments, there was no measurable slash, and shrub loads generally dropped to well under half of their pretreatment levels (Table 18). Scrub Oak plots showed the most change from pretreatment condition (shrub depths were less than a quarter, and shrub loads were well under a half their pretreatment values). Scrub Oak plots that were both mowed and grazed over two years had shrub loads that were, by the third growing season, less than a tenth their pretreatment values. Oak Woodland plots were more heterogeneous, because mowing was intentionally done in patches. This can be seen in the variability in fuel loading especially compared to the low variability seen in these plots prior to treatments (Figure 26). In these plots, by the third growing season, shrub loads and depths were closer to half their pretreatment values. As in SO-M plots, shrub loads were dramatically reduced in PP-M stands and were less than a quarter their pretreatment values following treatments.

The shift of fuels from the shrub to the litter layer not only reduced fuel bed depths but also increased packing ratios substantially. This is evidenced by consistent (or decreased) litter depths despite increasing litter loads (Figure 26) following treatments. This was most evident in Pitch Pine and Scrub Oak plots where there were generally significant decreases in litter depths despite significantly increased litter loads. The high pretreatment shrub biomass in Scrub Oak stands caused average litter loads to increase 50 to 100% following mowing. Oak Woodland litter loads increased less due to patchy application of mowing. Litter loads doubled following treatments in thinned Pitch Pine plots where slash was mowed, although litter depths were comparable to other treated plots. Prior to treatments, PP litter loads were generally lower and litter depths significantly higher than in SO or OW (packing ratios were lower in PP prior to treatments). Grazing may have increased compaction of fuel beds further. Litter depths were lower, although not significantly, in grazed plots compared to mowed ones.

Observed fire behavior (for headfires) was lower, usually significantly so, in treated vs. untreated plots (Table 17, Figures 29 and 30). Following treatments flame lengths averaged less than 2 ft. (0.6 m) and rates of spread less than 7 ft/min (2.1 m/min) in all three cover types. Treatments reduced fire behavior so much in all plots that differences between cover types and treatments were small. Flame lengths were reduced on average more than 8 feet (2.4 m) in Scrub Oak stands, 5 feet (1.5 m) in Pitch Pine stands and 4.5 feet (1.4 m) in Oak Woodlands. Rates of spread were reduced on average to under 6.5 ft/min (2 m/min) in Scrub Oak, under 6 ft/min (1.8 m/min) in Pitch Pine, and to under 4 ft/min (1.2 m/min) in Oak Woodlands. That many treated plots did not burn completely, occasionally 75% or less of plots burned (Table 19), suggests that treatments substantially altered fuel continuity. Grazing in addition to mowing resulted in lower average flame lengths and rates of spread in SO plots, but this was less evident in OW plots where treatments were more heterogeneous. Grazing is more expensive, however, than either mowing or pile-burning (Table 20).

Table 19. Percent of each plot that was burned.

Plot	Treatment	% Burned
PP1	C	100
PP5	C	100
PP9	C	100
PP2	T/M	95
PP3	T/M	90
PP7	T/M	75
PP8	T/G/P	80
PP4	T/P	85
PP6	T/P	75
OW2	C	--
OW7	C	100
OW8	C	100
OW1	M/G	88
OW5	M/G	70
OW9	M/G	95
OW3	M	--
OW4	M	97
OW6	M	100
SO4	C	99
SO5	C	99
SO8	C	97
SO1	M/G	80
SO2	M/G	95
SO9	M/G	70
SO3	M	98
SO6	M	99
SO7	M	98

Creating a firelane using harrowing costs about $200-500/acre. However, this does not include the necessary cost of thinning overstory trees (whereas Oak trees were not thinned in the EFB). Fire behavior in harrowed firelanes was modeled using Standard Fuel Model 1 and flame lengths of 2.9 ft (0.9 m) and rates of spread of 59.4 feet/min (18.1 m/min) were predicted for the driest windiest day of prescribed burning.

Table 20. Approximate costs of treatments. Pitch Pine was thinned to a basal area of 30 ft^2/acre, removing approximately 90 trees or 70 ft^2/acre. The cost of harrowing takes into account the costs of repeated harrowing required to create a firebreak level enough to be managed in the future by a standard mower. Cost of mowing with a standard mower accounts for cost of labor but not of equipment.

Treatment	Cost/acre
Mowing with brushhog	$200
Grazing	$900
pile burning	$200
thinning Pitch Pine	$1,500
Harrowing	$200-500
Mowing with standard mower	$8
Prescribed burning	$200-300

Custom fuel models run in NEXUS with weather data collected at the time of prescribed burns predicted observed fire behavior well with nearly one-to-one correlations between observed and predicted values (flame lengths: $r = 0.9$; rates of spread: $r = 0.95$; Figures 31 and 32). Observed flame lengths were generally slightly lower than predicted by CFMs except in Scrub Oak (all treatments) and Pitch Pine-TM, where they were slightly higher (Table 21). Rates of spread were generally slightly underpredicted, except in treated Oak Woodland plots.

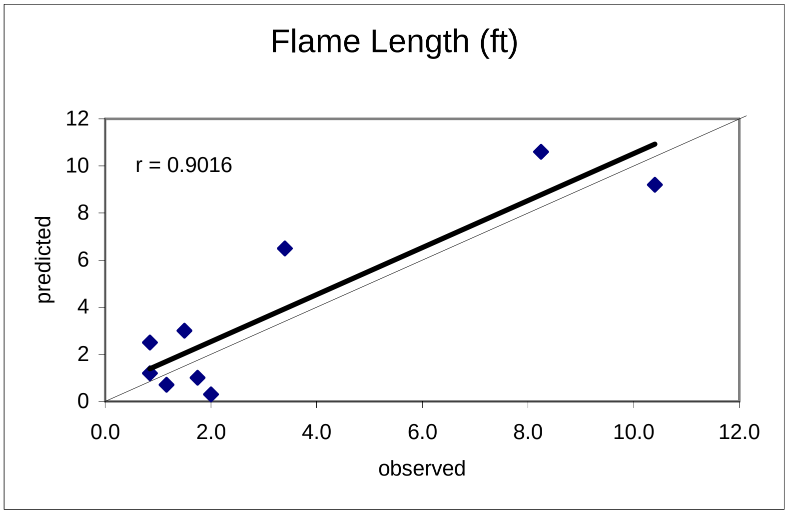

Figure 31. Predicted flame lengths vs. observed for prescribed burns in control and treatment plots. The 1:1 diagonal line represents a perfect fit.

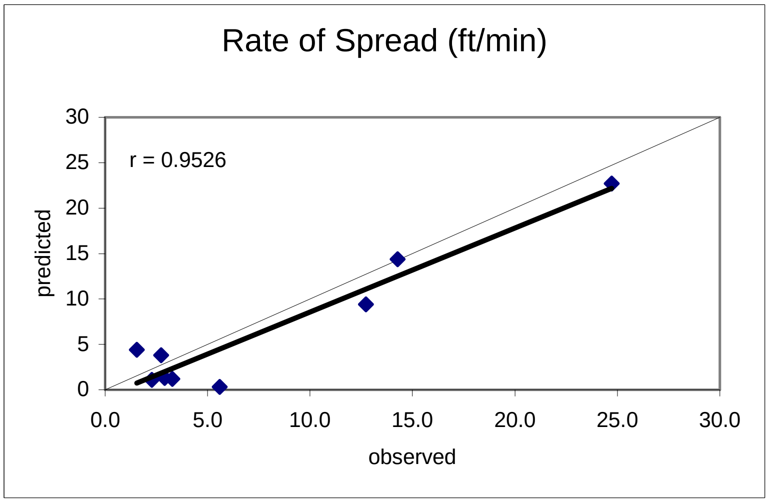

Figure 32. Predicted rates of spread vs. those observed for prescribed burns in control and treatment plots. The 1:1 diagonal line represents a perfect fit. See Appendix J for input data.

Table 21. Observed fire behavior compared to that predicted by our CFM for three vegetation types (two treated plots, one control plot).

Plot number	Treatment	Rate of Spread (ft/min) Observed	Rate of Spread (ft/min) predicted	Flame Length (ft) observed	Flame Length (ft) Predicted
PP1	PP-C	27.2	25.0	9.1	11.7
PP2	PP-T/M	6.1	0.3	2.2	0.3
PP8	PP-T/G	3.6	1.3	0.9	1.3
SO5	SO-C	15.7	15.8	11.4	10.1
SO9	SO-M/G	3.2	1.4	1.3	0.8
SO6	SO-M	2.5	1.2	1.9	1.1
OW8	OW-C	14.0	10.3	3.7	7.2
OW9	OW-M/G	3.0	4.2	0.9	2.8
OW4	OW-M	1.7	4.8	1.7	3.3

Soil Compaction

Mowing does not affect soil compaction, which was no higher in mowed Scrub Oak or Pitch Pine plots than in their respective controls (Figure 11). The fellerbuncher did, however, increase soil compaction. Pitch Pine plots where the fellerbuncher was used for thinning had significantly higher average soil compaction (104 PSI, or 717 KPa) than both the plot where only the grinder was used (99 psi, or 683 KPa) and the control plot (97 psi, or 669 KPa). No significant difference was found in soil compaction between Scrub Oak plots that were grazed for several weeks over the course of two summers and control plots. Both had a mean compaction of 86 PSI or 593 KPa.

DISCUSSION

Landscape Scale

Plants

Harrowed Firelanes as Rare Plant Habitat. Repeated mowing in old firelanes (created in the early-to-mid 20th century) has created high diversity grasslands with few non-native species as well as frequent or large populations of five rare plant species. Several species, which may be better classified as old field rather than early successional species, have developed large and relatively isolated populations within these firelanes and may have particularly benefited from management, which maintains open conditions at the same location over time (e.g., Sandplain Blue-eyed Grass, Purple Needle-grass, and Lion’s Foot). Others have suggested that these species thrive in old fields and may be less able to rapidly colonize newly disturbed areas (Blue-eyed Grass: Greller 1989 and Purple Needle-grass: Evans and Dahl 1955, Smith 1940). Raleigh (unpublished) found that Blue-eyed grass occurred in areas where duff depth and cover of bare soil was similar to that found in randomly placed plots in his study at Wasque on Chapaquidick Island east of Martha’s Vineyard. Other rare species he investigated, including Sandplain

Flax, occurred in areas with significantly lower duff depths and greater bare soil cover than was found generally. We found that Lion's Foot occurs in shrubbier areas with more litter and less lichen cover than in firelanes. Lion's Foot occurs in shrubby habitats elsewhere in New England and the southeastern U.S. (Appendix E). Given that the species is heavily browsed (Everett and Lepley 2002, G. Clarke pers.obs.), fecundity could be greater in shrubbier habitats where plants are less accessible to deer.

MFCSF firelanes appear to support some of the largest populations in the state for the above species. Old firelanes also support frequent occurrences of Sandplain Flax and Papillose Nut-sedge, and the largest reported Papillose Nut-sedge populations in Massachusetts are similar in size to the largest occurrences at MFCSF. Species which were not included in this analysis because only individual occurrences were found at MFCSF (Barren's Adder's Mouth, and Spring Ladies' Tresses) require additional research. However the status of these species, both members of the Orchidaceae family, may be difficult to determine. Orchid population sizes are reported to fluctuate greatly (Richburg 2003, Mattrick 2004), and this appears to be so for MFCSF populations which were first reported at MFCSF in the early 1990s for the Barrens Adder's Mouth and in the early 1980s for Spring Ladies' Tresses.

Each of the rare species colonized new lanes suggesting that harrowing can provide immediate rare plant habitat. Colonization in newly harrowed areas has been more frequent (in the ten years or less since harrowing) for two species, Sandplain Flax and Papillose Nut-sedge, but it is not clear that this should be interpreted as indicating that these species are more disturbance adapted than other rare species, as they were also more frequent in old firelanes and may have had a greater opportunity to colonize newly harrowed areas. It was evident for other rare species that colonization was limited to areas that were near existing populations. Sandplain Flax and Papillose Nut-sedge, as well as a number of other native grassland species, occurred within lanes C and D before they were widened. This facilitated their establishment in newly harrowed areas causing these new lanes to be floristically similar to old lanes. Managers realized that old sections of lanes C and D would be a seed source for establishing vegetation in adjacent newly harrowed areas, so they left the old lanes unharrowed during widening operations (John Varkonda, pers. com.).

Rare Plant Species Outside of Firelanes. Despite intensive searches throughout the Forest, rare plants were found outside of firelanes only along well-used paths (nb, see results for EFB below). Grassland associated species occur in shrubland and forested habitats with thinner organic layers (possibly where bare soil is exposed), but they are mostly associated with Scrub Oak plots where canopy cover is also low. Several Scrub Oak plots supporting grassland associated species were in frost bottoms suggesting that bottoms may not be as floristically depauperate as others have suggested (e.g. Barbour et al. 1998). Rare species may be able to persist in frost bottoms; each of the rare species other than Purple Needle-grass was found in a firelane running through a frost bottom however more research is needed to investigate this further. Frost bottoms have a greater potential for wildfire (Mouw 2002) and stress from temperature extremes (Motzkin et al. 2002a). This could lead to increased loss of soil organic mater, on the one hand, or reduced litter deposition on the other, both leading to greater availability of bare soil for plant establishment. We lack data that would support a hypothesis that similar stands occurred at MFCSF prior to the arrival of Europeans. Open Scrub Oak stands do not have a unique pollen assemblage that would be detected in the sedimentary record, and there are no early accounts of the existence of such stands on MV. Our data do suggest that in the future grassland associates (and possibly rare species) could occur more widely throughout the Forest if management practices which promoted thinner duff, and possibly also open canopies, (e.g. prescribed burning) were adopted.

Invasive Plants The occurrence of invasive plant species at MFCSF seems to be strongly related to firelane management practices and proximity to the exterior of the Forest acting in concert. In some cases, management seems to have facilitated the establishment of invasive species. They have colonized readily within newly harrowed areas, but with only one exception these invaded lanes were on the Forest boundary. Given that invasive species are spreading into firelanes as well as undisturbed habitats in several locations at the periphery of MFCSF, established interior firelanes and undisturbed forested areas may yet be invaded, and continued monitoring is recommended.

Insects

The discovery of Barrens Buckmoth larvae in seven of nine broadly classified vegetation types, but all in locations with similar characteristics at the plot level, suggests that scale is an important factor for larval habitat delineation. Buckmoth larvae were found most often in plots with scrub oak stem densities and other characteristics similar to those found in the Scrub Oak vegetation type, but they were not found exclusively in that vegetation type. This suggests that they are utilizing small patches of the Scrub Oak vegetation type (defined at the plot level) within a variety of vegetation types as defined at the landscape level. Plot-level characteristics may be important in determining individual oviposition sites for adult females selecting the best areas to provide for the larval cluster upon hatching. However, for long-term survival of entire populations of Barrens Buckmoths, large areas of Pitch Pine-Scrub Oak barrens may be necessary (Tuskes et al. 1996, MNHESP 2004). These areas can be heterogeneous natural barrens communities which include numerous patches of ideal oviposition sites, as adult Buckmoths can travel between habitat patches (NatureServe 2004). The specialization on barrens habitats in the Northeast—which are limited in their extent and proximity to one another—effectively limits the species' distribution in the Northeast.

The two vegetation types in which Buckmoth larvae were not found were Pitch Pine and Mature Plantation. These two categories had the lowest mean scrub oak densities of all the vegetation types (Table 10).

The determination that the Barrens Buckmoth is utilizing Scrub Oak habitat patches within broader vegetation types is consistent with its host-plant preference and mobility. Scrub oak is the primary food of this species in the Northeast, and these fairly mobile insects might take advantage of any available habitat when enough is provided, for a population to persist. The preference for dense scrub oak could be explained in a number of ways. Young or recently disturbed scrub oak plants tend to resprout vigorously forming multi-stemmed, bushy plants, whereas older undisturbed scrub oak stems become less dense as some individual stems assert dominance and others die off. These older undisturbed plants may be in an area that, without disturbance, is succeeding to forest reducing the vigor of the scrub oak food plants.

Structural changes in host plants can impact insect survival. The increased morphological complexity of the host plant provides a number of important elements such as greater number of leaves for feeding, protection from predators and parasitoids that do not forage as well with increased structure, more oviposition and resting sites, and climate mediation (Denno et al. 1990, Heinrich 1993, Montllor and Bernays 1993, Legrand and Barbosa 2003).

For species with leaves rich in tannins, second-flush leaves often contain higher concentrations of these anti-herbivore compounds, but host-specific feeders of such plants may be less affected by the increase than generalists (Faeth 1992). This would create areas of reduced competition in which the specialists could compete effectively. This could explain the apparent preference of some rare moth species for Martha’s Vineyard frost bottoms (Goldstein 1997). The phenological window hypothesis suggests that late-hatching representative species of more southerly climate regions can feed on highly nutritious young leaves developing in the phenologically delayed bottoms when upland plants are past their nutritional prime (Feeny 1970, Aizen and Patterson 1995, Goldstein 1997, Wagner et al. 2003). Scrub oak specialists could feed on second and even third-flush leaves after late-spring or early-summer frosts with less competition from tannin-intolerant generalists.

Barrens Buckmoth larvae may also be found in areas of higher scrub oak stem densities (e.g. disturbed sites) due to factors involving temperature, metabolism, and development. Larval Lepidoptera are widely known to be sensitive to changes in temperature and to have optimal species-specific thermal regimes (Casey 1993). Because insects do not metabolically thermoregulate to a significant degree, they depend on the environment to provide the heat needed to increase their metabolic rate (Casey 1993, Kingsolver and Woods 1997, Levesque et al. 2002). Growth rates increase when larvae are exposed to higher temperatures (to a point), partly through increased consumption and utilization efficiency. Barrens Buckmoth larvae hatch early in the summer before the highest air temperatures are reached for the year. To reach and maintain their ideal metabolic temperatures, the larvae are black, setae-covered, cluster-feeding caterpillars that “bask” in the sun to increase temperatures and subsequent developmental rates. They are known to utilize frost bottoms where the highest daily temperatures can be found during the summer. Canopy-free, open Scrub Oak patches would provide ideal basking conditions for such creatures. Low, dense shrubs such as those found in disturbed areas would also provide easier access to the ground where radiant heat can be utilized. Other studies have shown that some larval Lepidoptera have higher growth rates, survivorship, and productivity when reared on sun-exposed vs. shade-grown leaves of the same species (Fortin and Mauffette 2001, Levesque et al. 2002).

The small sample size of Spiny Oakworm Moth larval locations may explain the lack of significant correlations with any habitat variables. In fortuitous (non-random) findings, only nine additional Spiny Oakworm larval clusters were located, compared to 63 additional Barrens Buckmoth larval clusters found outside of organized transect searches. Even given the broad habitat requirements of the Spiny Oakworm, i.e. that it feeds on a variety of oaks including both tree and scrub oak species, identifying individual habitat characteristics is challenging. The Spiny Oakworm can be found high in the closed canopies of oak woodlands as well as on scrub oak bushes mowed on a semi-annual basis. These represent different ends of the spectrum of the vegetation parameters we examined (i.e. canopy cover, and scrub oak cover and density).

Soil Compaction

Despite the fact that sandy outwash plain soils are generally more resistant to compaction than finer textured soils, soils in firelanes are still significantly more compacted than in nearby unharrowed areas (Figure 11). It is unclear what the ecological impact of this compaction might be, however. Soil compaction can affect soil structure, which in turn can affect infiltration and retention rates, aeration, and penetrability by roots (Small and McCarthy 2002). However, the highest soil compaction reading in firelanes was only 160 PSI (1103 KPa), well below 300 PSI (2068 KPa) - the level beyond which most plant roots can not penetrate (Duiker 2002). In an experimental study, Small and McCarthy (2002) found significant growth reductions in only two of six herbaceous species at compaction levels substantially exceeding those we found in harrowed lanes (300 PSI and 500 PSI or 3447 KPa). Furthermore, Gomez et al. (2002) found that compaction of sandy soils to more than 360 PSI (2480 KPa) resulted in an increase (rather than a decrease) in both water holding capacity and plant growth.

Southwest Experimental Fuels Break

Plants

Rare Plants. The colonization of grassland associates (and in a few cases rare species) in experimental plots following treatments suggests that at least some treatments improve rare plant habitat. Establishment of some species, including Nut-sedge, was apparently dependant on the exposure of mineral soil. Deep organic layers may prevent germination of graminoid and herbaceous seed, and may make grassland associates good indicators for basic habitat requirements for rare plants. The organic layer may inhibit germination by its influence on light, temperature and moisture, or in presenting a physical barrier to seeds reaching the soil surface (Baskin and Baskin 1998). Humus is very hard to rewet once dry, so in a dry barrens environment duff may negatively influence water availability for germinating seeds. Deep organic layers prior to treatments may have been the product of decades of fire suppression at MFCSF, although nearly half of the study area burned in the 1946 wildfire, Foster and Motzkin (1999). A number of the species that most frequently colonized within small areas of exposed bare soil in this study, also germinated in areas where litter was consumed by prescribed fires conducted in grasslands on Nantucket (Dunwiddie, 1998).

Habitat may have also been improved by canopy thinning or even by prescribed burning itself. It is not clear whether Lion's Foot occurred in the EFB prior to treatments, but it is likely that plants did occur there and treatments stimulated them to flower (especially if the species is monocarpic- not flowering in the first year- as suggested by limited field observations; see Everett and Lepley 2002). We can not determine from our observations the extent to which reduction in canopy cover due to thinning improved habitat conditions for rare species, as it was within the thinned plots that bare soil was exposed and subsequently colonized. However, occasionally Oak Woodland plots that were not thinned were colonized by grassland associates following treatments (Table 13). Several studies suggest that increasing shrub cover in sandplain grassland and heathlands results in a loss of grass herb and grass richness (e.g. Dunwiddie and Caljouw 1990, Harper 1995), although no studies have isolated the influence of shading alone.

Scrub Oak plots had thinner organic layers than other vegetation types prior to treatments, and both mowing and grazing increased establishment by grassland associates in SO plots despite the high input of litter loads as a result of mowing. This was especially true of plots in the WTB which has evidence of past human disturbance (i.e. an old road grade bisects the bottom). Grazing, unlike mowing, limits contributions to the litter layer, as leaves are browsed from sprouts. A reduction in litter production may facilitate establishment of both grassland associates and non-native species. Currently, grazing does not appear to be a cost-effective means of treating shrub fuels however (Table 20).

Oak woodlands had moderate organic layers prior to treatments and litter layers were not substantially altered due to the heterogeneous treatments and lack of scarification by the fellerbuncher. Canopy cover was intentionally preserved during the application of treatments in Oak Woodland plots. It may be for these reasons that colonization rates were low in treated OW plots.

Although organic layers were relatively deep in Pitch Pine plots prior to treatments and mowing increased litter loads, thinning created patches of bare soil. Slash pile burning, which is comparable in cost to mowing, creates additional areas of exposed soil and precludes the need to mow to reduce slash depths.

More research is needed to determine the range of variability in suitable germination substrates for species of interest, and to determine the impact of mowing on the ability of these species to germinate. It is also not clear what types and frequencies of disturbance will be sufficient to support viable populations of rare plants.

It is unlikely that grassland associated species, and Nut-sedge plants which established in areas exposed by machinery, occurred in experimental plots prior to treatments. However, we do not know if establishment was from the seed bank or from propagules dispersed from outside the break. Increased colonization in Pitch Pine stands where additional management was carried out may suggest that seed was brought in by equipment. Papillose Nut-sedge colonized in exposed areas in the EFB, and similar establishment has been reported in other studies leading to speculation that the species may bank seeds (Oosting and Humphreys 1940, Clinton and Vose 2000, Zaremba 2003). If seed banks do exist, slash pile burning can either stimulate or destroy banked seeds (Clark and Wilson 1994) and can alter a number of soil physical and biological properties which influence plant establishment (see the FEIS for detailed information of fire effects on flora). Slash pile burning may facilitate the establishment of exotic plant species (Haskins and Gehring 2004), and Korb et al. (2004) investigated techniques to minimize establishment at the site of burned slash piles. We saw no non-native species establishing in ash, however. Native grass and herb colonization found in this study was not found following clearcutting and mowing oak woodlands a few miles from the Forest (Lezberg et al., in press) suggesting that seed banks for rare plants may not exist, at least not in Oak Woodlands. Work by Matlack and Good (1990) in a New Jersey coastal plain forest also supports this idea. Grass and herb colonization in the EFB may have been facilitated by its proximity to a seed source (firelanes).

Becauase treatments create palatable new shoots they may also promote deer grazing. Additional research could investigate whether treatments result in increased browse on species of conservation interest. Lion's Foot was heavily browsed within firelanes (pers obs) and one of three stems found in the EFB was browsed when sampled in late September 2005.

Invasive Plants. Only one invasive species occurrence was found in the EFB prior to treatment implementation, and no additional species were found following treatments. Several nonnative but non-invasive species were introduced by sheep into grazed plots, but most did not persist into the second field season.

Insects

To provide habitat for the larval stage of the Barrens Buckmoth, areas of moderately high scrub oak stem densities should be maintained at least in patches across an extensive barrens landscape. The existing Scrub Oak vegetation type and the Grassland vegetation type on MFCSF appear to provide the needed habitat characteristics for this species, but Oak Woodlands and Pitch Pine stands can also be manipulated with the appropriate fuel-reduction techniques to provide similar scrub oak stem densities. Oak Woodland areas can be burned, or mowed and burned to provide habitat, whereas Pitch Pine stands should be thinned, mowed (to reduce slash depths), and burned to create habitat. Canopy closure in these stands is still much higher than found at Buckmoth sites which could make basking more difficult for larvae. Maintaining persistent high density scrub oak might also be difficult in these areas without additional treatment of the canopy. Treatments in these forested communities create scrub oak stem densities that are statistically similar but lower than those found at Buckmoth sites. Over time these will self-thin to lower levels without additional disturbance.

With time, regular repeated management using these fuel reduction techniques could create very different habitat features than we observed during this two-year study. For example, repeated mowing or grazing over a number of years can reduce shrub cover and favor more herbaceous plants. Growing season burns may have different effects than dormant season burns. Studies of longer duration or continued monitoring in these treatment areas over time will add to our understanding of the long-term changes to potential Buckmoth habitat.

Because Spiny Oakworm habitat could not be defined due to the small sample size, no definite conclusions can be drawn of the effects of the treatments on Spiny Oakworm habitat. However, given what we know about the species (Appendix I) and the characteristics of the habitats where they were found (Table 8), we can hypothesize that Spiny Oakworm caterpillars would do best in habitats with high canopy closure of tree oaks, and with some areas of scrub oaks. Thus, Oak Woodland areas probably provide the best habitat for this species, although Scrub Oak and Grasslands also supported it. Further studies with larger samples or examining different variables could define Spiny Oakworm habitat more specifically.

These results show that fuels management on MFCSF can provide habitat for one of the rare species found there. The results of the analysis of Barrens Buckmoth habitat characteristics can guide managers in their attempts to provide habitat for this species while reducing fire danger. However, we cannot assume that the habitat needs of one sandplain insect species are representative of the needs of other rare insect species. Even species which feed on the same host plant as the Buckmoth may have very different habitat needs. For example, the Barrens Dagger Moth (*Acronicta albarufa)* also feeds on scrub oaks and other oak species, but its habitat needs are not clearly understood, and it has been undergoing an inexplicable decline with large areas of apparently suitable habitat devoid of the species (Appendix I).

To assess the impacts of management on the habitats of the other 20 rare insect species of MFCSF, their habitat needs would have to be analyzed more thoroughly. However, a cautious attempt to estimate impacts can be made with our current knowledge. Appendices F and I outline much of the information we currently have on these species, and Appendices G and H contain estimates of management impacts. Numerous studies on a wide variety of insect species show that the response of insect populations to disturbance varies over time, space, and by species (Swengel 1996, Swengel 1998, Panzer and Schwartz 2000, Swengel 2001, Swengel and Swengel 2001, Panzer 2002). Generalists seem to respond most favorably and most quickly to disturbance, taking advantage of abundant new vegetation in a less competitive environment (Swengel and Swengel 2001). Host-specific species may require more time to recover, especially if refugia are not available from which a treated area can be recolonized (Swengel 2001, Wagner et al. 2003). Eighteen of the 22 rare insect species of MFCSF are thought to be at least somewhat specialized in the Northeast, three—the Chain-dotted Geometer (*Cingilia catenaria), Euchlaena madusaria*, and the Woolly Gray (*Lycia ypsilon*)—are polyphagous, and the habits of one—the Barrens Metarranthis Moth (*Metarranthis apiciaria*)—are too poorly known to make an assessment. The location and life stage of the Lepidoptera at the time of management also influences survival. Larvae are susceptible to direct mortality from most management activities, as they are relatively sessile and vulnerable to mechanical treatments and/or fire. Pupae and eggs are not vulnerable if they are spatially protected from management, for example eggs laid in a tree would be safe from either mowing or understory burning, and species that pupate deep underground may also be safe from most fires and mechanical treatments. However, eggs laid directly on low vegetation or pupae located in the leaf litter or otherwise unprotected from management would be susceptible to loss. The vagility of species can also play an important role in survival and recolonization. Species with greater tendencies to disperse can reoccupy managed sites more quickly, whereas poor fliers (for example, Woolly Gray females are wingless and flightless) would have difficulty both escaping the management and moving into a newly managed area. Swengel (1996) suggests that the number of broods a species produces per year has a direct impact on the ability of a species to recolonize an area after disturbance. Bivoltine (producing two broods per year) species such as the Unexpected Cycnia (*Cycnia inopinatus)*, the Three-Lined Angle Moth (*Digrammia eremiata)*, and *E. madusaria* would have more opportunity to recolonize an area than species with only one brood per year. The response of host plants to the treatment also plays a role in herbivorous insect survival. Some species resprout readily after disturbance, whereas others can be eliminated by certain management techniques. Repeated mowing, year after year, in late spring and early summer can deplete a plant of its root reserves increasing the likelihood that the plant will be lost from the site over time. Burning later in the growing season vs. the dormant season can spur certain plant species to resprout with increased vigor or to set more seeds than they would otherwise.

Overall, the fuels reduction techniques examined in this study would probably benefit nearly all of the species in question (Appendix G), as long as they were implemented on a small scale (the entire EFB, for example, is approximately 70 acres, or about 1% of MFCSF) and not repeated in the same area with great frequency. For example, NatureServe (2004) suggests that populations of the Frosted Elfin (*Callophrys irus*) may be fire-aversive and can be lost if unburned refugia and several years between fires for all patches are not maintained. Thinning Pitch Pine would benefit most of these species by creating more of the open habitats and habitat patches nearly all of these species require. Mowing, grazing, and burning would all maintain these open habitats, keeping overstory trees out of frost bottoms so their unique thermal regimes are maintained, and slowing succession to a more forested landscape. However, the immediate impacts are probably negative for many species (Appendix H), as mowing and grazing in the summer can harm vulnerable eggs, larvae, and unprotected pupae. Thinning Pitch Pine in the summer when Imperial Moth (*Eacles imperialis*) eggs or larvae are present could lead to the loss of individuals. Burning in the spring can also be detrimental to unprotected eggs, larvae and pupae of numerous species. The solution to this conundrum – the fact that disturbance is required for the survival of populations but is damaging to individuals – is to vary the spatial and temporal extent of treatments to create a mosaic of different patch sizes with different times since disturbance. The size of individual treatments depends on the availability of habitat across the entire landscape, so that there is, indeed, a link between the intensive management of relatively small areas as fuel breaks and the management of the larger system.

Type, timing, intensity, frequency, and extent of management can all play a role in determining if management will affect these species in a positive or negative way. Swengel and Swengel (2001) suggest that no single management type is most appropriate for any habitat type in any study. Management specific to individual species' needs is often warranted, rather than management aimed at maintaining the overall general habitat type. Given that species have different needs dictates that diversity can only be maintained by encouraging a mosaic of sandplain communities across the landscape.

Fuels and Fire Behavior

Untreated Plots. Fuel loadings and depths in untreated stands in the EFB were similar to stands sampled by Mouw (2002) throughout MFCSF. This is an important finding as it suggests that custom fuel models developed for these plots should be widely applicable across MFCSF. High fine fuel loads characterize barrens vegetation (especially Pitch Pine and Scrub Oak stands) and contribute to both ease of ignition and increased fire behavior. In agreement with our findings, Scrub Oak and Pitch Pine stands sampled by Mouw had higher 1-hr fuel loads than Oak Woodland stands. However, Mouw found that Scrub Oak stands had even higher loadings (9.0 tons/acre; 20 metric tons/ha) than Pitch Pine stands (7.4 tons/acre or 17 tons/ha), while our Scrub Oak and Pitch Pine stands had similar loadings (7.6 tons/acre; 17 tons/ha). Data here and those of Mouw suggest that Scrub Oak stands have the highest fuel bed depths on the Forest. In agreement with our data, Mouw found higher 1-hr fuel loads yet lower live fuel loads in Pitch Pine than in Oak Woodland stands. In both cases this was largely the result of higher litter loads in Pitch Pine stands (Mouw, 2002).

In all three vegetation types, average headfires burning through untreated fuels with moderate weather conditions can not be attacked directly (flame lengths >4 ft; 1.2 m). In Scrub Oak, high flame lengths (averaging 7 ft; 2.1 m) are encouraged by high fuel depths, and high rates of spread (averaging 23 ft/min; 7 m/min) are encouraged by high fine fuel loads. Mouw's data, and observations of a 1996 prescribed burn near the Forest headquarters suggest that higher fine fuel loadings in other Scrub Oak stands of MFCSF can support even greater rates of spread. Woodall (1998) documents rates of spread of 60 ft/minute (18.2 m/min.) and flame lengths of 40 ft (12.2 m) for the 1996 early growing-season burn under conditions of high humidity (75 %) and low midflame wind speeds (2-4 mph; 3.2-6.4 km/hr). Average flame lengths were similar between Pitch Pine and Oak Woodland plots (average 7 ft; 2.1 m) which had similar fuel bed depths. Yet rates of spread are greater in Pitch Pine stands (averaged 23 ft/min; 7m/min versus 16 ft/min; 4.9 m/min in Oak Woodlands) probably due to higher fine fuel loads and lower live shrub loads in Pitch Pine plots.

It has long been recognized that custom fuel models are needed for northeastern barrens, because FBPS standard fuel models either under or overpredict rates of spread and flame lengths in barrens vegetation. By collecting weather and fire behavior data during each prescribed burn we were able to test our CFMs against actual observed behavior. Differences in observed and expected values can result from fuels conditions at the location of fire behavior measurements departing from average conditions used to create CFMs, however we hope differences will be small which will justify the creation of CFMs which can be widely applicable. Our CFMs predicted actual behavior very well in all three vegetation types. Having established that our CFMs are similar to Mouw's we can also conclude that these CFMs are representative of the major MFCSF vegetation types. It is generally desirable for CFMs to over rather than underpredict behavior and it should be noted that flame lengths in Scrub Oak were slightly greater (1.3 ft) than that predicted by the CFM. Rates of spread were also slightly greater than observed in Pitch Pine (2.2 ft/min) and Oak Woodland (3.7 ft/min) plots.

Treated Plots. In Oak Woodland and Scrub Oak stands, mowing and grazing (if first preceded by mowing) are both effective ways to reduce shrub and slash loads. Mowing, unlike grazing (or slash pile burning), does not consume fuels, and actually increases fine litter loads. However, the fine fuels created by mowing are highly compacted and their flammability is very low. Once mowing has been carried out (which is necessary to provide palatable stems –sprouts- for sheep) grazing and mowing can be used to maintain reduced shrub growth and in terms of fuels and fire hazard reduction, mowing and grazing treatments produce very similar results. However grazing is more expensive than mowing even despite the fact that sheep, unlike the mower, did not need to be transported to the island. In the third year following treatments shrub loads were measurably lower in Scrub Oak plots that were treated once (with mowing) versus those that were treated three times (mowing, grazing, grazing). Repeated treatments can reduce shrub root stores by repeatedly forcing sprouting and removing above-ground biomass. Once repeated treatments have reduced root reserves, replenishment may take a long time. Root reserves are unlikely to have been greatly impacted by the few (<3) treatments used in experimental plots, and without additional treatments shrub fuels in all plots may rebound within 5 years (Nelson, 2001). Mowing in Pitch Pine stands treated shrub and slash fuels and like mowing in other plots effectively compacted fine fuel loads. Mowing and pile burning are both effective for reducing the fire hazard associated with downed pine slash, especially if it is allowed to dry. Thinning of Pitch Pine stands is crucial to fire hazard reduction in barrens. Because the lower branches of retained Pine trees were removed it is unlikely that ladder fuels will easily build in these stands. It is likely that most tree recruitment in these thinned stands will be less flammable Oak species and as a result the thinning treatment should have a long-lasting effect.

Creating firebreaks using alternative techniques can be equivalent in cost to the conventional method of harrowing (although grazing is more expensive). Long-term maintenance costs in harrowed firelanes may also be comparable if prescribed burning is used to maintain treated areas in the EFB. Fire behavior in treated areas of the EFB is also comparable to that predicted in harrowed firelanes, at least in the first year following treatments.

Custom fuel models, tested against observed fire behavior, are needed for treated barrens fuels for the prediction of wild- and prescribed fire behavior. Low fire behavior in treated plots resulted in CFMs for these plots performing especially well. Predicted flame lengths were within 2ft. of that observed but underpredictions occurred in Pitch Pine TM plots (2ft). Predicted rates of spread were generally within 3 ft/min but underpredictions of nearly 6 ft/min occurred in Pitch Pine TM plots and 2 ft/min occurred in Pitch Pine TG and Scrub Oak MG plots. Observed and predicted values were very similar in Scrub Oak plots where treatments were very homogenous.

Soil Compaction

Soils were significantly compacted by harrowing and overstory thinning with a fellerbuncher relative to untreated conditions, but the magnitude of change was small. Because maximum compaction values we observed are low relative to those found to be detrimental in other studies, and compaction may be beneficial to water retention in sandy soils, it seems unlikely that the increased compaction we detected is ecologically significant. Soils of MFCSF are not particularly erosive, especially given the lack to topographic variation on the Forest. Areas of steeper topography (e.g. in the northeast portion of the Forest) should be monitored for erosion if harrowing and/or thinning with the fellerbuncher are applied there in the future.

MANAGING FUEL BREAKS

Rare Plants

Harrowed Firelanes as Rare Plant Habitat

Repeated mowing in old firelanes (created in the early-to-mid 20th century) has created highly diverse grasslands. Although sandplain grasslands are not native to the central plain, they do support large or frequent populations of five rare plant species and the communities themselves are of conservation interest. The rare species (with very few exceptions) are not found off firelanes (however, see below). Several appear secure in that they occur frequently in firelanes, namely Sandplain Flax and Papillose Nut-sedge. Others (e.g. Sandplain Blue-eyed Grass, Purple Needle-grass, and Lion’s Foot) occur far less frequently but have developed large occurrences in old firelanes and may have particularly benefited from mowing which maintains open conditions once they are created by harrowing. Mowing before early June or after late September or October is unlikely to interfere with the flowering or fruiting of these species and should maintain or expand existing occurrences. However, periodic growing season treatments may be necessary to reduce the vigor of shrubs that might establish the lanes. Installing exclosures around occurrences of Lion’s Foot may be necessary to protect them from heavy deer browsing. Harrowing clearly provides immediate habitat for these five rare plant species provided their propagules can disperse to the newly exposed mineral soil.

Continued documentation of the colonization of new lanes by rare species (relative to where existing populations occur) will be helpful in understanding the factors that influence colonization. Additional research will be needed for some species (Barren's Adder's Mouth, and Spring Ladies' Tresses) which apparently occur at only one location each in old firelanes of MFCSF.

Alternative Management and its Influence on Rare Plant Habitat

Our results indicate that grassland associates and rare species could occur in woodlands and shrublands on the Forest that are managed as fuel breaks. The presence of grassland associates is a good indicator for the presence of suitable rare plant habitat. Without treatment, scrub Oak stands of MFCSF tend to have thinner organic layers (and low overstory cover) and more frequently support grassland associated species. Following treatments in the SW EFB, Scrub Oak plots also showed a greater increase in the presence of grassland associates than other vegetation types. Lion's Foot was also found following treatments in a Scrub Oak stand; treatments, including burning, may have stimulated existing plants to flower. In Oak Woodland and Pitch Pine plots, where organic layers are deep and overstory cover high prior to treatments, establishment of grassland associates following treatments was largely restricted to areas of bare soil exposed by machinery and the burning of brush piles. Papillose Nut-sedge, which may bank seeds in the soil, emerged in several of these areas. Mowing treatments do not create bare soil, but rather increase litter load and may be detrimental to the creation of appropriate seedbed conditions for these species. Removal of slash following mowing may be necessary if grassland associates are to be encouraged. Prescribed fire effectively does this. Grazing could be an alternative to mowing plus burning but is more expensive.

Invasive Plant Species

It can not be assumed that established firelanes and forested/shrubland areas are immune to invasion. Invasions are occurring on boundary lanes near seed sources off the Forest. The slower colonization of more isolated, newly created exterior lanes by native species is paralleled by increased colonization of these areas by invasive species. However, the isolated nature of these invaded lanes may slow the spread of invasive species into other firelanes. Currently these exterior lanes are not annually mowed, although if that is done (as is planned) it is not likely to eradicate invasive species if mowing is done in the fall, as is the practice. More aggressive management would be needed to specifically target invasive plant occurrences. Top-killing invasive plants during the growing season (from mid-July to mid-August), especially if mowing is timed to occur during periods of low rainfall, can substantially reduce the vigor of invasive woody species (Richburg, 2005 expected).

Insects

The finding that Barrens Buckmoth larvae utilize Scrub Oak patches within larger stands of other cover types suggests that scale should be considered when making management decisions. What appears as an unbroken forest of oak trees in an aerial photograph may in reality contain a multitude of small patches of grassland, heathland, or shrubland suitable for "open habitat" insect species' survival. Many of the 22 rare insect species of MFCSF are known to utilize small openings within forested habitats making landscape level management decisions more difficult. At the same time, without connectivity between patches or enough total area of suitable habitat at that landscape level, populations of a species may disappear.

Managing sandplains to maintain healthy populations of rare insect species is a difficult task, given that the 22 species of MFCSF have different habitat needs and their temporal vulnerability of species varies from one species to the next. Using natural history information for these species (Appendices F and I), we have attempted (in Appendix H) to establish the seasonal impacts of four fuels management techniques—Pitch Pine thinning, mowing, grazing, and burning—on populations of each of the 22 species. Because most require open habitats dominated by scrub oaks, heath, or herbaceous plants, thinning Pitch Pines would probably benefit them, as it would create more open habitat. Thinning Pitch Pine should have little direct impact on most of these species, as few of them inhabit closed conifer forests. It should be noted, however, that some of these species will utilize open patches within forests so some direct mortality may occur. The exception to this is the Imperial Moth, whose larvae feed on Pitch Pine needles on Martha's Vineyard. They may even utilize non-native pines in plantations. Thinning Pitch Pine overstories during the summer when the eggs are on the trees or when larvae are feeding would probably cause direct mortality to Imperial Moths.

Other fuel reduction techniques would negatively impact numerous species in every season, with every treatment/season combination probably negatively impacting at least 10 species. A lack of knowledge about the pupation locations of six of the species [the Three-lined Angle Moth (*E. madusaria*) the Barrens Itame (*Itame* sp.*1)*, the Woolly Gray, the Southern Ptichodis (*Ptichodis bistrigata)*, and the Faded Gray Geometer (*Stenoporpia polygrammaria)*] makes estimating their vulnerability during the pupal stage very difficult. The host plant and habitat needs of the Barrens Metarranthis Moth are so poorly understood that management impacts cannot be addressed. However, even without this information it is clear that, despite possible short-term adverse impacts on individual organisms, the long-term maintenance of populations of all species will only occur through active management of the vegetation. Management will be most effective in restoring and maintaining rare Lepidoptera habitat when it creates spatial and temporal heterogeneity across the landscape. The overall and long-term effect of these treatments is almost always positive if management is conducted to maintain a patchwork of habitats (Appendix G). The underlying need is to retain spatio-temporal variation among sites of the same ecosystem type through a variety of management interventions.

Maintenance of host plants for all rare insect species and maintenance of the ecological processes that keep the system functioning properly are first steps. Studies to assess the direct impact of management on particular species, and long-term monitoring of treated areas will advance our ability to manage sandplains appropriately from the perspective of rare insects. Determining if, in fact, Barrens Buckmoths recolonize the EFB in the patterns we predict, and how long full recolonization takes would advance our understanding of the impact of management on a portion of the Buckmoth population on MFCSF. More information is needed on the life histories, vulnerabilities and habitat specifics for many of the species in question before we can manage their habitats and populations with confidence. Combining future experiments with enhanced or even routine fuels management programs would allow us to increase our knowledge, reduce fire danger, and learn how to manage sandplains more effectively in the future. Even the simple act of collecting observational data over time will increase our knowledge of these species and aid us in our attempts to balance the threat of wildfire with the needs of a healthy sandplain ecosystem. What is learned in the EFB area will advance our ability to manage the broader sandplain ecosystem. For, although caution is advised before extensive management is applied, the cost of no active management, allowing succession to forested landscapes, would have a severe, negative effect on rare insect species.

Fuels and Fire Behavior

The combined effect of flammability and fine fuel loading creates the possibility for intense surface fires in barrens vegetation (especially in Scrub Oak stands) and crown fires in Pitch Pine. Most woody sandplain species resprout vigorously following cutting or topkilling and can fairly rapidly replenish above-ground biomass. Growing season treatments have an advantage over dormant season treatments in that they result in depletion of root reserves and reduced vigor of resprouting woody stems. Reduced sprout vigor slows the reaccummulation of fine fuels in the form of litter. Prescribed burning is difficult to apply during the growing season because summer droughts can cause smoldering, which can make mop up difficult and can lead to smoke management problems. Smoke production from prolonged burning is a particular problem during the summer tourist season. However as fire intensity, spotting and crowning potential can be high in the dormant season, there are constraints to prescribed burning in the spring. Mechanical treatments offer the advantage that they can be easily applied in the growing season and are not weather dependant. Prescribed burning in untreated stands can create dead woody fuels when live fuels are killed but not consumed. Thus, reducing fuels through repeated burning is not only potentially hazardous in the first few years of its application, but could take several years to reduce fuels to the levels found in plots treated over one or two years with mechanical plus prescribed fire treatments (Patterson and Crary 2004). This study focused especially on the effectiveness of mechanical treatments for fuels reduction.

This research investigated a number of techniques for the reduction of surface fuels. Mowing alters fuel arrangement by incorporating fine slash and shrub fuels into a compacted litter layer with reduced flammability due to increased packing ratios. Sheep graze new sprouts which emerge after mowing, and thus retard new litter production, but grazing is more than four times as expensive as mowing. Because oak trees are not flammable and tend to reduce surface wind speeds (Mouw 2002), they should be retained when possible in Scrub Oak and Oak Woodlands. Oak Woodland understories can be treated with prescribed fire to reduce litter and shrub fuels, but burning will top-kill most stems less than 1-2” (2.5-5 cm) dbh. Burning in Oak Woodlands does not appear to benefit rare plants (by facilitating their invasion), but gaps in canopies created by stem mortality and resprouting oak stems will provide habitat for rare insects. Coppicing oaks with prescribed fire will promote the long-term maintenance of ancient oak stools.

Thinning Pitch Pine stands reduces the potential for crown fires (Duveneck 2005). Based on field data collected in Montague, MA, an active crown fire in a Pitch Pine stand thinned to 20-30 ft^2/acre (4.5 – 7 m^2/h) (comparable to thinned pitch pine stands in this study) required greater 20-ft (6-m) windspeeds (61 mi/hr, or 98 km/hr) than untreated stands (21 mi/hr, or 34 km/hr) for crown fire evolution (Duveneck 2005). Slash from thinning contributes to surface fire intensity (but without the threat of evolution to crown fires), so treatment of slash is necessary. Sheep did not graze freshly cut Pitch Pine slash despite the fact that they grazed lower branches of Pitch Pine trees and saplings in this and past management projects at MFCSF (Varkonda, pers. com). Mowing following thinning treats slash and shrub fuels simultaneously. Slash fuels can also be treated by pile burning in the winter. Piles should be covered for two-three months before burning to prevent snow and ice embedding in piles. The costs of mowing vs. pile burning treatments are comparable.

Creating firebreaks using alternative techniques can be comparable to using harrowing, because oak dominated stands did not have to be thinned in the experimental break. In the long term, maintenance costs are likely to be lower in firelanes that in the EFB, even if prescribed burning is used to maintain the EFB. Fire behavior in the Experimental Fuel Break in the year following treatments was comparable to that predicted for harrowed firelanes (using the driest, windiest day-of-burn windspeeds and humidities).

Alternative fuels manipulation strategies successfully reduce fire behavior and can be used to widen existing firelanes in order to increase the opportunity for firefighters to suppress advancing fires. A wildfire which crosses into an area with fuels managed in one of the above ways will exhibit substantially reduced rates of spread and flame lengths, although ongoing treatments are required. Shrub biomass and, in turn, fire behavior will recover if no additional treatments are applied - usually within five years (Nelson 2002). It is not yet known how long or to what extent compacted litter layers will reduce fire behavior, although lack of fuel continuity and low rates of spread limit the usefulness of prescribed fire when reapplied at one-to-two-year intervals in Oak/Pine Forests at Cape Cod National Seashore (Patterson and Crary 2004). The reduction in crown fire potential in thinned Pitch Pine stands will be long-lasting, especially if recruitment in these stands is dominated by oaks, which is likely without substantial soil disturbance to expose mineral soil.

Ancient Oak Woodlands

Coppice oaks are a common feature of New England forests. They are generally produced by harvesting, which often leaves stumps 15-30 cm (6-12 inches) in height. Most of these stems are the product of only 2 or 3 generations of vegetative sprouting from the original stem of seedling origin. The stems of a sprout clump often grow into one another and grow over the decaying stump.

Coppice oaks found at MFCSF differ in structure. Sprout-origin stems emerge from the ground individually, with the largest clumps having coppice stool diameters greater than 1 m (3.3 ft), but with little of the stool visible above ground. It may be possible for this structure to develop from the cutting of a large oak stem and subsequent burning of the stump. However, because of the frequency of fires before 1955 and the slow growth rates of oaks on these sandy sites, it is unlikely that many oaks reached a size that would produce a 1 m (3.3 ft) diameter stump. The more probable origin of these large sprout clumps is from repeated killing of small stems from fire or from cutting followed by fire, with each new set of stump sprouts developing from buds at the root collars of the previous generation of sprouts. This process is similar to the repeated cutting of small diameter stems in traditional coppice management.

Centuries of experience with oak coppice management and data from more recent research show that sprouts originating from belowground buds near the root collar have a lower probability of early stem decay, compared to sprouts arising from aboveground buds. The traditional method for producing stumps of low origin was to cut the stems as close to the ground as possible (Peterken 1993). Burning the stump is more effective because it kills all aboveground buds (Roth and Hepting 1943). Based on this evidence, there are two ways (described below) to maintain the coppice stand structure of the stands on MFCSF that closely follow the process by which the current stands have likely developed. A third method is described, which can be used to approximate the structure if prescribed fire is not used:

1. Use prescribed fire if the current oak sprout stems are small enough (< about 2.5 inches or 6cm dbh) to be killed by the fire.

2. Cut the oak sprout stems, followed by prescribed fire to burn the stumps. This can be used for stems of any diameter. The height of the stumps is not a critical factor in this method.

3. Cut the oak sprouts, keeping the stumps as low as possible. With stumps close to ground level this may be sufficient. If stumps are taller than about 5 cm (2 inches), then 2 to 5 years later, cut the young sprouts that have originated from high on the stump.

The coppice oak structural feature appears to be fairly common at MFCSF. In stands sampled by Mouw (unpublished) with >20 ft^2/acre of Oak, an average of 73% of the basal area is composed of coppice stems of White, Black, Scarlet or Post Oak. Stands that burned in the 1930s and 40s had significantly higher proportion of total oak basal area (85%) in coppice stems compared to stands not burned at that time (Hawthorne, unpublished data).

Photo by D. Brennan.

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Zaremba, R.E. 2004. *Scleria pauciflora Muhlenberg ex Willdenow var. caroliniana and Scleria pauciflora Muhlenberg ex Willdenow var. pauciflora* (Few-flowered nut-rush) conservation and research plan for New England. New England Wild Flower Society. Framingham, MA. 45 pp.

APPENDIX A. List of plant species appearing in text and appendices. Listed below are common and scientific names

common name	scientific name
Bentgrass	*Agrostis* sp.
Nantucket Shadbush	*Amelanchier nantucketensis*
Pearly Everlasting	*Anaphalis margaritacea*
Sweet Vernalgrass	*Anthoxanthum odoratum*
Bearberry	*Arctostaphylos uva-ursi*
Purple Needle-grass	*Aristida purpurascens*
Clasping Aster	*Aster patens*
Showy Aster	*Aster spectabilis*
Wavy-leaved Aster	*Aster undulatus*
Pennsylvania Sedge	*Carex pensylvanica*
Oriental Bittersweet	*Celastrus orbiculata*
Spotted Wintergreen	*Chimaphila maculata*
Bastard Toad-flax	*Comandra umbellata*
Horseweed	*Conyza canadensis*
Orchard-grass	*Dactylis glomerata*
Poverty-grass	*Danthonia spicata*
Common Hairgrass	*Deschampsia flexuosa*
Depauperate Panic-grass	*Dichanthelium depauperatum*
Forked Panic-grass	*Dichanthelium dichotomum*
Autumn-olive	*Elaeagnus umbellata*
Pilewort	*Erechtites hieraciifolia*
Flat-topped Goldenrod	*Euthamia* sp.
Fescue	*Festuca filiformis*
Wild Strawberry	*Fragaria virginiana*
Black Huckleberry	*Gaylussacia baccata*
Bushy Rockrose	*Helianthemum dumosum*
Velvet-grass	*Holcus lanatus*
Golden Heather	*Hudsonia ericoides*
Orange Grass	*Hypericum gentianoides*
Rush sp.	*Juncus* sp.
Beach-pinweed	*Lechea maritima*
Thyme-leaf Pinweed	*Lechea minor*

APPENDIX A (cont.). List of plant species appearing in text and appendices. Listed below are common and scientific names

common name	scientific name
Round-headed Bush-clover	*Lespedeza capitata*
Blue Toadflax	*Linaria canadensis*
Sandplain Flax	*Linum intercursum*
Honeysuckle	*Lonicera* sp.
Whorled Loosestrife	*Lysimachia quadrifolia*
Barren’s Adder’s Mouth	*Malaxis bayardii*
Timothy	*Phleum pratense*
Pokeweed	*Phytolacca americana*
Nuttall's Milkwort	*Polygala nuttallii*
Racemed Milkwort	*Polygala polygama*
Cinquefoil	*Potentilla* sp.
Fall Rattlesnake-root	*Prenanthes trifoliolata*
Lion's Foot	*Prenanthes serpentaria*
Scrub Oak	*Quercus* sp.
Bear-oak	*Quercus ilicifolia*
Dwarf Chinquapin-oak	*Quercus prinoides*
Black Locust	*Robinia pseudoacacia*
Multiflora Rose	*Rosa multiflora*
Sheep-Sorrel	*Rumex acetosella*
Little Bluestem	*Schizachyrium scoparium*
Papillose Nut-sedge	*Scleria pauciflora var. caroliniana*
Sandplain Blue-eyed Grass	*Sisyrinchium fuscatum*
Elliot's Goldenrod	*Solidago elliottii*
Sweet Goldenrod	*Solidago odora*
Downy Goldenrod	*Solidago puberula*
Rough Goldenrod	*Solidago rugosa*
Spring Ladies’ Tresses	*Spiranthes vernalis*
White Clover	*Triodanis perfoliata*
Blueberry	*Trifolium repens*
Violet sp.	*Viola* sp.
Bird's Foot Violet	*Viola pedata*

APPENDIX B. List of insect species appearing in text and appendices. Listed below are common and scientific names

Common Name	Scientific name
Coastal Heathland Cutworm	*Abagrotis nefascia benjamini*
Barrens Dagger Moth	*Acronicta albarufa*
Spiny Oakworm Moth	*Anisota stigma*
Frosted Elfin	*Callophrys irus*
Gerhard's Underwing	*Catocala herodias*
Purple Tiger Beetle	*Cicindela purpurea*
Melsheimer's Sack-bearer	*Cicinnus melsheimeri*
Chain-dotted Geometer	*Cingilia catenaria*
Unexpected Cycnia	*Cycnia inopinatus*
Three-lined Angle Moth	*Digrammia eremiata*
Imperial Moth	*Eacles imperialis*
(no common name)	*Euchlaena madusaria*
Slender Clear-wing	*Hemaris gracilis*
Barrens Buckmoth	*Hemileuca maia*
Barrens Itame	*Itame sp. 1 (*near *inextricata)*
Woolly Gray	*Lycia ypsilon*
Barrens Metarranthis Moth	*Metarranthis apiciaria*
Coastal Swamp Metarranthis	*Metarranthis pilosaria*
Pink Sallow Moth	*Psectraglaea carnosa*
Southern Ptichodis	*Ptichodis bistrigata*
Faded Gray Geometer	*Stenoporpia polygrammaria*
Pine Barrens Zale	*Zale sp. 1 (*near *lunifera)*

APPENDIX C. Conservation Status Definitions (from www.natureserve.org)

The conservation status of a species is designated by a number from 1 to 5, preceded by a letter reflecting the appropriate geographic scale of the assessment (G = Global, N = National, and S = Subnational). The numbers have the following meaning:

1 = critically imperiled
2 = imperiled
3 = vulnerable to extirpation or extinction
4 = apparently secure
5 = demonstrably widespread, abundant, and secure.

For example, G1 would indicate that a species is critically imperiled across its entire range (i.e. globally). In this sense the species as a whole is regarded as being at very high risk of extinction. A rank of S3 would indicate the species is vulnerable and at moderate risk within a particular state or province, even though it may be more secure elsewhere.

Extinct or missing species and ecological communities are designated with either an "X" (presumed extinct or extirpated) if there is no expectation that they still survive, or an "H" (possibly extinct or extirpated) if they are known only from historical records but there is a chance they may still exist. Other variants and qualifiers are used to add information or indicate any range of uncertainty.

NatureServe Global Conservation Status Ranks

GX = **Presumed Extinct** (species) – Not located despite intensive searches and virtually no likelihood of rediscovery.

Eliminated (ecological communities) – Eliminated throughout its range, with no restoration potential due to extinction of dominant characteristic species.

GH = **Possibly Extinct** (species) – Missing; known from only historical occurrences but still some hope of rediscovery.

Presumed Eliminated (historic, ecological communities) – Presumed eliminated throughout its range, with no or virtually no likelihood that it will be rediscovered, but with the potential for restoration, for example, American Chestnut Forest.

G1 = **Critically Imperiled** – At very high risk of extinction due to extreme rarity (often 5 or fewer populations), very steep declines, or other factors.

G2 = **Imperiled** – At high risk of extinction due to very restricted range, very few populations (often 20 or fewer), steep declines, or other factors.

APPENDIX C (continued).

G3 = **Vulnerable –** At moderate risk of extinction due to a restricted range, relatively few populations (often 80 or fewer), recent and widespread declines, or other factors.

G4 = **Apparently Secure –** Uncommon but not rare; some cause for long-term concern due to declines or other factors.

G5 = **Secure –** Common; widespread and abundant.

G#G# = Range Rank – A numeric range rank (e.g., G2G3) is used to indicate the range of uncertainty in the status of a species or community. Ranges cannot skip more than one rank (e.g., GU should be used rather than G1G4).

GU = **Unrankable –** Currently unrankable due to lack of information or due to substantially conflicting information about status or trends. Whenever possible, the most likely rank is assigned and the question mark qualifier is added (e.g. G2?) to express uncertainty, or a range rank (e.g. G2G3) is used to delineate the limits (range) of uncertainty.

GNR =Unranked – Global rank not yet assessed.

GNA =Not Applicable – A conservation status rank is not applicable because the species is not a suitable target for conservation activities.

Subnational (i.e. State) Conservation Status Definitions

SX = **Presumed Extirpated –** Species or community is believed to be extirpated from the state. Not located despite intensive searches of historical sites and other appropriate habitat, and virtually no likelihood that it will be rediscovered.

SH = **Possibly Extirpated** (Historical) – Species or community occurred historically in the state, and there is some possibility that it may be rediscovered. Its presence may not have been verified in the past 20-40 years. A species or community could become SH without such a 20-40 year delay if the only known occurrences in a state were destroyed or if it had been extensively and unsuccessfully looked for. The SH rank is reserved for species or communities for which some effort has been made to relocate occurrences, rather than simply using this status for all elements not known from verified extant occurrences.

S1 = **Critically Imperiled –** Critically imperiled in the state because of extreme rarity (often 5 or fewer occurrences) or because of some factor(s) such as very steep declines making it especially vulnerable to extirpation from the state.

APPENDIX C (continued).

S2 = **Imperiled –** Imperiled in the state because of rarity due to very restricted range, very few populations (often 20 or fewer), steep declines, or other factors making it very vulnerable to extirpation from the state.

S3 = **Vulnerable –** Vulnerable in the state due to a restricted range, relatively few populations (often 80 or fewer), recent and widespread declines, or other factors making it vulnerable to extirpation.

S4 = **Apparently Secure –** Uncommon but not rare; some cause for long-term concern due to declines or other factors.

S5 = **Secure –** Common, widespread, and abundant in the state.

SNR =Unranked – State conservation status not yet assessed.

SU = **Unrankable –** Currently unrankable due to lack of information or due to substantially conflicting information about status or trends.

SNA =Not Applicable – A conservation status rank is not applicable because the species is not a suitable target for conservation activities.

S#S# = Range Rank – A numeric range rank (e.g., S2S3) is used to indicate any range of uncertainty about the status of the species or community. Ranges cannot skip more than one rank (e.g., SU should be used rather than S1S4).

NEPCoP Regional Divisions

1 = **Globally rare**

2 = **Regionally rare**, and either rare throughout New England or reach the edge of their range in New England and have either fewer than 20 populations in New England or if there are more than 20 populations, populations are small and more vulnerable to extinction

3 = **Locally rare**

4 = **Historic**

APPENDIX D. Grass and herb species occurring in research plots (several commonly occurring species removed) and the number of plots (by habitat type) where each species occurred prior to (2002 sampling) and following (2004 sampling) treatments. Also shown is the number of burn piles colonized (of 24 surveyed throughout Pitch Pine stand in the EFB in 2004) and the number of plots where establishment had occurred in areas of bare soil exposed by machienery. Also identified are those species not found in forested/shrubland plots (outside of firelanes) at the landscape scale.

Number of burnpiles established (of 24 surveyed)	Number of plots where establishment occurred in exposed bare soil	not in forested/ shrubland plots sampled at landscape scale	species	Number of plots species occurred in					
				OW pre	PP pre	SO pre	OW post	PP post	SO post
	1	X	*Agrostis sp.*					1	5
	1	X	*Anaphalis margaritacea*				1		1
	1	X	*Anthoxanthum odoratum*					1	
			Arctostaphylos uva-ursi		1	7			6
		X	*Aster patens*						1
		X	*Aster spectabilis*				1		1
		X	*Aster undulatus*						1
		X	*Carex pensylvanica*					1	1
			Chimaphila maculata	3	3		2	1	
			Comandra umbellata			3			2
	1	X	*Conyza canadensis*					1	2
		X	*Dactylis glomerata*					1	
1		X	*Danthonia spicata*			1			3
			Deschampsia flexuosa	1		1	1		6
1		X	*Dichanthelium depauperatum*						4
4	6		*Dichanthelium dichotomum*			1	4	6	8
	1	X	*Erechtites hieraciifolia*					3	8
		X	*Euthamia sp.*			1		1	3
	1	X	*Festuca filiformis*			1		1	
		X	*Fragaria virginiana*		1				
4	5		*Helianthemum sp.*			7	1	4	7
	1	X	*Holcus lanatus*				1	1	

APPENDIX D (continued).

Number of burnpiles established (of 24 surveyed)	Number of plots where establishment occurred in exposed bare soil	not in forested/ shrubland plots sampled at landscape scale	species	Number of plots species occurred in					
				OW pre	PP pre	SO pre	OW post	PP post	SO post
	2	X	*Hudsonia ericoides*			1		2	1
		X	*Hypericum gentianoides*					1	2
	1	X	*Juncus sp*					1	2
	1	X	*Lechea maritima*					1	4
2	4	X	*Lechea minor*					5	3
	1	X	*Lespedeza capitata*				1		1
		X	*Linaria canadensis*						3
	6		*Lysimachia quadrifolia*	1		5	3	4	8
		X	*Phleum pratense*						1
		X	*Phytolacca americana*					1	1
		X	*Polygala nuttallii*						1
			Polygala polygama			1			
			Potentilla sp.			1			3
			Prenanthes trifoliolata	1			1	1	
	1	X	*Rumex acetosella*					1	
			Schizachyrium scoparium			1			6
		X	*Sisyrinchium fuscatum*			1			
		X	*Solidago elliottii*						1
			Solidago odora	2		2	3	1	4
		X	*Solidago puberula*						2
		X	*Solidago rugosa*					1	3
		X	*Trifolium sp.*						1
		X	*Trifolium repens*					1	
		X	*Viola spp.*						2
		X	*Viola pedata*						1

APPENDIX E. Rare Plant Literature Review

Overview

Rare plant species of coastal New England are, for the most part, similar in that they are generally at the northern edge of their ranges and they are disturbance-dependant. Within New England, many of these species are almost entirely restricted to the southeastern coastal plain. They may be rare simply because they are at the edge of their range and are restricted to coastal areas with more moderate climates. But disturbance may also be an important factor limiting the distribution of these species. Near coastlines, open conditions are promoted by salt spray, and in pre-colonial times large Native American populations and the greater importance of fire along the coast may also have contributed to the availability of suitable habitat.

Many species that are rare today are documented as having occurred in early colonial New England by herbarium specimens checked for consistency of identification (e.g. Everett and Lepley, 2002). The existence of several species endemic to New England provides further support to the idea that certain rare species have been isolated in coastal areas for many centuries or longer. Historical records also suggest that some coastal rare species, such as Lion's Foot (*Nabalas serpentaria*) and Purple Needle-grass (*Aristida purpurascens*), may have been more common and widespread during the Colonial period than today. It is not clear, however, whether this is a result of an earlier range expansion in response to widespread land clearing or if it represents a range contraction from the prehistoric period.

Rare coastal plant species are disturbance-adapted and most are now restricted to areas which have been heavily disturbed by humans. We do not know what comparable habitats were available to them in pre-colonial times. Nor do we do know which general habitats currently support these species, because searches have generally been restricted to areas that have a history of human disturbance. Dunwiddie et al. (1996) sampled a number of grassland and heathland sites in New England and found that many but not all rare plants occurred predominantly in grasslands. There is a need for searches within areas perceived to be unsuitable habitat for these species. However habitats and their environmental characteristics have likely changed since pre-colonial times as a result of altered fire regimes (in coastal areas fire was reduced in importance following colonization) and by more than four decades of fire suppression. Given this, intensive searches may be necessary and unsuccessful searches may not indicate that particular habitats could not or did not support these species.

Cape Cod and the islands support one of the main centers of biodiversity in the state of Massachusetts (NHESP, 2001) and yet this region is one that is most threatened by human development. Several rare species which occur in this region are endemic and globally rare (e.g. Sandplain Gerardia, *Agalinis acuta;* once reported at MFCSF). Many other species at the edge of their range are locally rare in Massachusetts. At MFCSF these include three species that are endangered (Barren's Adder's Mouth, *Malaxis bayardii*; Lion's Foot; and Papillose Nut-sedge, *Scleria pauciflora var. serpentaria*), one that is Threatened (Purple Needle-grass) and six that are Special Concern (e.g. Sandplain Flax, *Linum intercusum*; Table 1) in Massachusetts. It is important to conserve species at the edge of their range, because it can prevent range contraction and is likely to be important in terms of preserving genetic diversity at the species level especially when populations have been isolated for lengthy periods of time.

Species Biology

Many coastal rare plant species appear to be disturbance adapted, but there is little known of their biology. A number of grassland species including some rare species such as Purple Needle-grass and Lion's Foot, are capable of long distance dispersal by animal vectors or wind. Some may have long seed longevity, perhaps up to many decades (e.g. Papillose Nut-sedge, see appendix) but there has been little research to substantiate this for other rare species in New England coastal grasslands. In many cases basic reproductive ecology is not known, although self-compatibility is often suspected (e.g. Sandplain Flax and Papillose Nut-sedge). Rare species may possess adaptations which would allow them to persist in small populations, self-compatibility being one such example. Of the five rare plant species at MFCSF all occur in non-grassland habitats in the more central portions of their range south of Massachusetts. Papillose Nut-sedge, Purple Needle-grass, Sandplain Flax, and Blue-eyed Grass all occur in long-leaf pine savannahs in the southeast which undergo occasional fire, for example. In New England there are extant occurrences of these five rare plant species in shrubland or woodland habitats and herbarium specimens document their occurrence in such habitats in the historic period (note: Blue-eyed Grass may be one exception). In the late 1800's or early 1900's, Purple Needle-grass, Sandplain Flax, and Lion's Foot were all collected from pine barrens habitat in Massachusetts, with one Sandplain Flax population persisting until the 1970s.

Several additional state listed species which have not been seen in recent years at MFCSF (Sandplain Gerardia, and Eastern Silvery Aster, *Aster concolor*) are known from only single small populations there (Barren's Adder's Mouth, and Spring Ladies' Tresses), or whose identification proved to be problematic (Nantucket Shadbush, *Amelanchier nantucketensis*; Bushy Rockrose, *Helianthemum dumosum*) have not been included in the following summaries.

<u>Purple Needle-grass.</u> Purple Needle-grass is a densely tufted perennial, non-rhizomatous bunchgrass of the Poaceae family. 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 has northern disjunct occurrences in Michigan and Wisconsin. The species has a global and national rank of G5 and N5 meaning "secure". Aside from an individual population in southern Ontario, Massachusetts is at the northern edge of the species range. There are 18 extant populations in the state where it is listed as Threatened. Extant occurrences are generally found in sandplain grasslands, although several are within heathlands, and one is from a railroad bed. What appears to be one of the largest populations in the state occurs in a pasture that has been continuously grazed since the time of colonization. In the southern

part of its' range, Purple Needle-grass occurs in pine and oak savannahs, unplowed prairies including the tall-grass and mixed-grass prairies of Kansas and Oklahoma, abandoned fields, glades, rock outcrop communities, and powerlines and roadsides.

Sandplain Flax. Sandplain Flax is a perennial herb of the Linaceae family. Plants flower in July and August, although individual flowers may persist only one day. Seed production occurs in August and September. Germination tests suggest that the species may be a short lived perennial. The species may be self compatible as is the case for other members of the genus and is supported by flower longevity and anatomy. The species ranges from Massachusetts along the coastal plain to North Carolina and extends inland to northwestern Georgia, northern Alabama, and eastern Tennessee with disjunct occurrences in Indiana. A number of states track the species, suggesting that it may be rare throughout it's range (Snyder, 1994). The species global and national ranks are G4 and N4 meaning "apparently secure". In Massachusetts there are 41 occurrences, which are restricted to Cape Cod and the islands, and the species is ranked as Special Concern. Extant populations generally occur in sandplain grasslands but other habitats include cemeteries, a powerline and sandpit, heathlands and pine/oak barrens, in addition to several occurrences on coastal plain pond shores. In the southern part of its range the species occurs not only in grasslands but also in pitch and long-leaf pine stands that have undergone prescribed fire or wildfire.

Lion's Foot. Lion's Foot is an herbaceous, taprooted plant of the Aster family. The plant is considered to be perennial but field observations suggest that plants may flower only once in a lifetime. Flowers are produced in August and September and are thought to be insect-pollinated. Seeds are produced in September and October and are wind-dispersed. Several observations suggest that plants may flower only when in open sunny conditions. Lion's Foot is found in the Eastern US, and its range extends south to Florida, west to Tennessee and North to Massachusetts. The species is considered secure in the mid-Atlantic and southeast and as a result is ranked G5 and N5. In Massachusetts there are seven extant populations in the state nearly half of them contain fewer than 6 plants. The species may be adapted to persisting in small populations and also appears to do so in the southern part of its range. Extant occurrences are from grasslands and heathlands but also are found in powerlines, in open woods, and on an eroding coastal cliff. The species may be self-compatible as are some other Asters which occur in small populations but this has not yet been investigated for Lion's Foot. Deer appear to selectively browse this species (G. Clarke, pers. obs.).

Papillose Nut-sedge. Papillose Nut-sedge is a monoecious and perennial member of the sedge family. Nut-sedge pollen is wind dispersed and despite adaptations which probably promote outcrossing, the species is probably self-compatible. Seeds are produced between July and September. Seeds seem to require a cold treatment in order to germinate and may be viable in the soil for long periods, the best evidence for this coming from Oosting and Humphreys (1940). The plant has thick rhizomes and following management, plants have been found to successfully establish from root fragments. The range for Papillose Nut-sedge extends from southern coastal New England south to Florida and Texas and west to Kansas and Michigan. Most populations for the species in Massachusetts have been reported in 1980 or later and it has been suggested that the species may have more recently migrated to the northeast. There are eleven extant occurrences in the state and the species is listed as “Endangered”. Extant occurrences occur in grasslands and heathlands and in a sandpit. Fire has apparently created appropriate habitat for Nut-sedge in both the southern part of the range (e.g. Clinton and Vose, 2000) as well as in New England where there are three known examples of populations establishing or re-establishing following fire. One of these New England populations re-established after having been last reported nearly a century and a half earlier suggesting that the seed may be viable for long periods. Nut-sedge also germinated from a soil seed bank sample collected from a stand that had been forested for over a century in North Carolina (Oosting and Humphreys, 1940).

Sandplain Blue-eyed Grass. This perennial herb of the Iridaceae family flowers from June to July and occasionally into August and disperses fruit from July to as late as October. Other members of the genus have been found to be toxic to herbivores (Mendez et al., 1993), self-compatible (Cholewa and Henderson, 1984), heavily infested with VAM fungi (Trufem et al., 1990) and to contain allelopathic chemicals which suppressed growth of neighboring plants (Takahashi et al., 1995) but it is not known whether Blue-eyed Grass may share any of these features. Aside from disjunct occurrences in Nova Scotia, the species extends from Massachusetts south along the coastal plain to Florida and Louisiana. 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, cemeteries, roadsides. There are also individual records from a cemetery, woodland, shrubland, and coastal rocky bluffs (NHESP). In the South, the taxonomy of the genus *Sisyrinchium* is in question making assessments of the habitat of Sandplain Blue-eyed Grass in the south difficult.

Management Effects on Plants

Overview. Of the fifteen rare plant species that occur at MFCSF, all but one (Nantucket Shadbush) are found largely, if not exclusively, within the firebreaks (Massachusetts Natural Heritage Program, 2001), suggesting that firebreak construction and maintenance favors the establishment and survival of these species. This is consistent with some research that has found that cutting and burning treatments (burning has been conducted in MFCSF firebreaks) in sandplain grasslands can reduce shrub cover and increase species diversity depending on the type and timing of the treatment. When these treatments were performed in areas where rare species occur, they frequently maintain or increase the size of rare plant populations.

Coastal rare plant species are presently almost exclusively associated with grasslands and heathlands with a history of human disturbance. Many appear to colonize following disturbances such as plowing and can be found in powerline right-of-ways, sandpits, and cemeteries, as well. Fire has apparently created or recreated appropriate habitat for the Papillose Nut-sedge on three occasions in Massachusetts. The Nut-sedge also established following burning treatments in a xeric oak pine forest in the southern Appalachians (Clinton and Vose, 2000).

That rare plant species are adapted to disturbances can be seen from the habitats they occur in within New England. In Massachusetts many rare plants occur in habitats described as sandplain grasslands and heathlands and these generally have a history of plowing and are frequently managed with occasional to regular mowing. New England habitats also include railroad beds (Purple Needle-grass), sandpits (Sandplain Flax, Nut-sedge), powerline right of ways (Sandplain Flax, Lion's Foot), cemeteries (Sandplain Flax, Blue-eyed Grass), along trails (Lion's Foot) and roadsides (Blue-eyed Grass). Field observations also suggest that some species may flower more prolifically when canopy cover is reduced (e.g. Lion's Foot: Everett and Lepley, 2002; Purple Needle-grass: Pessin, 1933) or following establishment in recently disturbed areas (Nut-sedge: Zaremba, 2003).

Environmental Controls on Species Distributions. Dunwiddie et al. (1996) assessed whether a number of environmental variables were predictive of the grassland or heathland types they identified. They found significant differences in soil texture and nutrient availability only between heathy grasslands (which are scarce on Martha's Vineyard) and the other grassland types. Substrate, soil texture, and available cations did not differ significantly among the grassland types that occur on Martha's Vineyard. From these results, Dunwiddie et. al. (1996) concluded that much of the variation they found in grasslands probably reflects differences in disturbance and successional histories. In a study at Wasque and Long Point on Martha's Vineyard, Raleigh et al. (1998) compared the abiotic conditions at occupied versus randomly selected, unoccupied sites for five rare species that occur at MFCSF: Nuttall's Milkwort (*Polygala nuttallii*), Sandplain Flax, Bushy Rockrose, Blue-eyed Grass, and Nantucket Shadbush. Neither available soil nutrients (P, NH_4, Al, Ca, Mg, and K) nor pH were significantly different between occupied and unoccupied sites. However, for all species, the cover of bare ground was significantly higher, and shrub cover and duff depth were significantly lower at most rare plant locations than at randomly chosen unoccupied sites. One exception was that Blue-eyed Grass populations were not associated with significantly lower duff depths (Raleigh, 1998). Raleigh (1998) did find that the cover of bare mineral soil, bare ground, duff, and shrubs were significantly different between rare plant locations and randomly chosen sites for most of the species he studied (with the conspicuous exception of Nantucket Shadbush).

Grazing. Although a number of rare plant species occur in former pastures, few have been documented to persist where active grazing is occurring. One notable exception is in the case of Purple Needle-grass. One of the largest populations for this species in the state, containing many hundreds of individuals, occurs in a pasture which has been actively grazed by sheep since colonization (NHESP). Purple Needle-grass has apparently benefited from the grazing and is apparently not palatable to sheep. One study found that Bushy Rockrose was more frequent in an area that was abandoned from grazing about 4 decades before and an adjacent area which had not been grazed more recently than a century before which may indicate that this species was favored by the grazing (Dunwiddie, 1997). Sandplain Flax may be unpalatable to grazing animals as all members of the genus have been found to produce compounds which may be toxic or acidic (Zaremba, 2003). Lion's Foot is one of the few species occurring at MFCSF which is obviously selectively grazed by deer (Clarke, pers. obs.) but it is not clear whether domesticated grazers would also find them palatable.

Mowing. Many rare plant occurrences are presently supported in habitat defined as sandplain grassland and it is likely that many of these areas are managed with mowing. The occurrence of rare plants in the firelanes of MFCSF, for example, also suggests that mowing has benefited those species found frequently there. Mowing at MFCSF was conducted in the summer for many decades up until the past two decades when fall mowing was instituted. The largest known population of Lion's Foot in Massachusetts, containing approximately 50 stems, has been maintained with periodic mowing (Everett, 2002). Mowing has also reportedly created suitable habitat for Purple Needle-grass in the Southeast (Diamond et al., 2002; Ray, 1959). Mowing also apparently created appropriate habitat for Blue-eyed Grass 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).

Burning. Several rare species, including Sandplain Flax, Papillose Nut-sedge, and Blue-eyed Grass are associated with fire maintained communities in the southeast, such as longleaf pine barrens. Several authors have also suggested that wildfire or prescribed burning has favored certain species of conservation interest in New England based on observations made in the southeast (Purple Needle-grass: Pessin, 1933; Sandplain Flax: Snyder, 1994; Papillose Nut-sedge, Clinton and Vose, 2000). There has been less opportunity to assess the impact of fire on these species in New England. 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 Blue-eyed Grass. Between the early 1980's and the mid 1990's, three sets of treatments at Ram Pasture seven biennial summer burns, five spring burns, and three late summer/fall mowings resulted in the increase in Blue-eyed Grass populations. However over the same period biennial spring burning resulted in the loss of one preexisting Blue-eyed Grass population (Dunwiddie, 1998).

One species that does seem to have repeatedly benefited from prescribed burning is *Scleria pauciflora*. There are two documented instances when Papillose Nut-sedge established or reestablished following fire. In Ram Pasture on Nantucket, Papillose Nut-sedge plants became established following several summer burns where they were not known to occur previously (Dunwiddie, 1998). Another Massachusetts Nut-sedge population re-appeared in 1989 about five years following prescribed burn, the last sighting having been in 1846. Following the application of summer thinning and fall burning treatments in a oak-pine stand in the southern Appalachians, Papillose Nut-sedge established within research plots where it did not occur previously in the third growing season following treatments (Clinton and Vose, 2000).

APPENDIX F. Natural history features of rare insect species of MFCSF. These features play a role in determining the effects of management techniques on populations. * denotes life stage at which species overwinters.

Name *(Scientific name,* common name)	# broods per year	Egg stage	Larval stage	Pupal stage	Pupation location	Adult stage	Larval host plant(s)	Habitat/ host plant specificity
Abagrotis nefascia benjamini (Coastal Heathland Cutworm)	one	late summer to fall	fall and winter into summer*	June and July	probably in soil	July-Sept	Possibly grasses	not clear, probably specialized
Acronicta albarufa (Barrens Dagger Moth)	one	July-Aug	July-Sept	late Sept-mid-June*	in soil in flimsy cocoon	mid-June-early Aug	*Quercus ilicifolia*, possibly other *Quercus* spp.	specialist
Anisota stigma (Spiny Oakworm Moth)	one	June-July (2 weeks)	July-Sept	Sept-June*	under-ground	June-early Aug	*Quercus* spp., especially *Q. ilicifolia* and *Q. prinoides*	somewhat specialized
Callophrys irus (Frosted Elfin)	one	mid-May-early June	*late May-early July*	late July-April*	*in surface litter*	*May-mid-June (diurnal)*	*Baptisia tinctoria*	specialist
Catocala herodias gerhardi (Gerhard's Underwing)	one	Aug-April*	Apr-June	*June-July*	*in surface litter*	July-Aug	*Quercus ilicifolia*	specialist
Cicindela purpurea (Purple Tiger Beetle)	½ (2-year life cycle)	May (2 weeks)	June-June (1 year)*†	July (2-4 weeks)	below ground	Aug-May (10 months)*† (diurnal)	Predatory	predator in specific habitat
Cicinnus melsheimeri (Melsheimer's Sack-bearer)	one	July	Aug-April*	May-early June	*in leaf shelter, either in litter or on low stems*	June-early July	*Quercus ilicifolia*	specialist
Cingilia catenaria (Chain-dotted Geometer)	one	Sept-May*	June-Aug	Aug-Sept	on vegetation	Sept-early Oct	Usually *Gaylussacia* spp., *Vaccinium* spp., or *Myrica* spp.	polyphagous

Name *(Scientific name,* common name)	# broods per year	Egg stage	Larval stage	Pupal stage	Pupation location	Adult stage	Larval host plant(s)	Habitat/ host plant specificity
Cycnia inopinatus (Unexpected Cycnia)	two	May & late July-early Aug	June & late Aug-April*	April & July	Surface litter	May & late July-early Aug	*Asclepias spp*., especially *A. tuberose*	specialist
Digrammia eremiata (Three-lined Angle Moth)	two	June & Aug	*July & Sept*	*late July, Oct-May**		June & Aug	*Tephrosia virginiana*	specialist
Eacles imperialis (Imperial Moth)	one	mid-June-mid-Aug (2 weeks)	Aug-Sept	Sept-June*	under-ground	mid-June to mid-Aug	Polyphagous, with a preference for *Pinus rigida* on Martha's Vineyard	specialist on MV
Euchlaena madusaria	two	June & Aug	July & Sept-May*	May & July		June & Aug	*Vaccinium spp*. preferred, also *Prunus spp., Betula spp.*	polyphagous
Hemaris gracilis (Slender Clear-wing)	one	May-June (~1 week)	June-July (~1 month)	Aug-May*	in surface litter	mid-May-mid-June (diurnal)	*Vaccinium angustifolium* and *Vaccinium vacillans*	specialist
Hemileuca maia (Barrens Buckmoth)	one	Oct-May*	May-July	Aug-Sept	just below soil surface	late Sept-Oct (diurnal)	*Quercus ilicifolia* and occasionally *Q. prinoides*; other hosts in late instars	specialist
Itame sp. 1 (near inextricata) (Barrens Itame)	one	July-May*	*May-early June*	June		*late June-July (~2 weeks)*	*Quercus ilicifolia*	specialist
Lycia ypsilon (Woolly Gray)	one	May	late May-early July	July-late April*		late April-early May	Polyphagous	polyphagous

Name *(Scientific name,* common name)	# broods per year	Egg stage	Larval stage	Pupal stage	Pupation location	Adult stage	Larval host plant(s)	Habitat/ host plant specificity
Metarranthis apiciaria (Barrens Metarranthis Moth)	one	June (~10 days)	July-Aug	Aug-late May*	probably in leaf litter	late May-June	Unknown	habitat & host plant poorly understood
Metarranthis pilosaria (Coastal Swamp Metarranthis)	one	late June-July (10-20 days)	July-Aug (6-10 weeks)	Sept-May*	in leaf litter	June-early July	*Vaccinium macrocarpon*, probably also *V. oxycoccos*; possibly other *Ericaceae*	specialist
Psectraglaea carnosa (Pink Sallow Moth)	one	Oct-April*	May-June	July-Sept	under-ground	late Sept-Oct	*Vaccinium spp., Quercus ilicifolia,* possibly others	somewhat specialized
Ptichodis bistrigata (Southern Ptichodis)	one	June	June-July	Aug-May*		late May-early June	Unknown, but probably legumes and/or grasses	specialist
Stenoporpia polygrammaria (Faded Gray Geometer)	one	June	July-Aug	Sept-May*		June	Unknown	probably specialist
Zale sp. 1 (near lunifera) (Pine Barrens Zale)	one	May-June (2 weeks)	June-July	Aug-May*	*in soil*	*May-early June*	*Quercus ilicifolia*	specialist

†The Purple Tiger Beetle is a carnivorous beetle which has a two-year life cycle, and spends the immature portions of its life below ground feeding just at the surface or hibernating in winter. The adult also overwinters below-ground. Since this species is not herbivorous, vegetation management impacts on this species would be very different from impacts on species of Lepidoptera.

APPENDIX G. Possible impacts of fuels management techniques on rare insect species on MFCSF, provided sufficient recolonization time is allowed between treatments. See Appendix H for potential immediate impacts based on season of management, and see Table S1 and Appendix S for more specific life history information.

Species	Thin	Mow	Graze	Burn
Abagrotis nefascia benjamini (Coastal Heathland Cutworm)	Removal of overstory would enhance open grassland/meadow habitat; species has been found in openings within forest and can utilize small habitats	Mowing would probably enhance habitat by keeping it open	Grazing would probably enhance habitat by keeping it open	Burning would probably enhance habitat by keeping it open, although excessively large fires may eliminate from small habitat patches
Acronicta albarufa (Barrens Dagger Moth)	Thinning would benefit this species by increasing scrub oak cover, thinning of oaks to savannah may be beneficial by increasing scrub oak while maintaining overstory oaks	Removal of scrub oaks undesirable such as could occur through heavy, frequent mowing (multiple times/year), but annual mowing may not negatively impact species	Removal of scrub oaks undesirable such as could occur through heavy, frequent grazing (multiple times/year), but infrequent grazing to encourage scrub oak resprouting may be beneficial	All life stages may be susceptible to fire so patchy, infrequent fire best. Fire could be used to maintain scrub oak and young tree oak species, which are capable of resprouting with multiple stems after disturbance
Anisota stigma (Spiny Oakworm Moth)	Thinning would benefit this species by increasing scrub oak cover, thinning of oaks to savannah may be beneficial by increasing scrub oak while maintaining overstory oaks	Removal of scrub oaks undesirable such as could occur through heavy, frequent mowing (multiple times/year), but infrequent mowing to encourage scrub oak resprouting may be beneficial	Removal of scrub oaks undesirable such as could occur through heavy, frequent grazing (multiple times/year), but infrequent grazing to encourage scrub oak resprouting may be beneficial	Patchy, infrequent fire best. Fire could be used to maintain scrub oak and young tree oak species, which are capable of resprouting with multiple stems after disturbance
Callophrys irus (Frosted Elfin)	Removal of overstory would enhance open grassland/meadow habitat and encourage growth of host plant	Mowing would probably enhance habitat by keeping it open; host plant frequently found along regularly mowed firelanes	Grazing would probably enhance habitat by keeping it open; host plant frequently found along firelanes	Patchy, infrequent fire best. Burning would probably enhance habitat by keeping it open; this species may colonize wildfire scars; frequent burns may be detrimental

Species	Thin	Mow	Graze	Burn
Catocala herodias gerhardi (Gerhard's Underwing)	Thinning would benefit this species by increasing scrub oak cover, especially in frost bottoms where overstory should be removed entirely to retain unique temperature features	Regular mowing probably not good for this species; removal of scrub oaks undesirable but infrequent mowing to discourage tree growth and encourage scrub oak resprouting may be beneficial	Removal of scrub oaks undesirable such as could occur through heavy, frequent grazing; infrequent grazing to discourage tree growth and encourage scrub oak resprouting may be beneficial	Patchy, infrequent fire could be used to maintain scrub oak and to discourage trees from encroaching into frost bottoms
Cicindela purpurea (Purple Tiger Beetle)	Opening canopy could enhance habitat, especially with soil scarification; have been found in openings within forests	Mowing would probably enhance habitat by keeping it open, especially with some soil disturbance	Grazing would probably enhance habitat by keeping it open, especially with some soil disturbance such as through creation of livestock trails	Burning would probably enhance habitat by keeping it open; high intensity burns which remove all litter and vegetation probably beneficial; firelines could also create good habitat
Cicinnus melsheimeri (Melsheimer's Sack-bearer)	Thinning would benefit this species by increasing scrub oak cover, especially in frost bottoms where overstory should be removed entirely to retain unique temperature features	Regular mowing probably not good for this species; removal of scrub oaks undesirable but infrequent mowing to discourage tree growth and encourage scrub oak resprouting may be beneficial	Removal of scrub oaks undesirable such as could occur through heavy, frequent grazing; infrequent grazing to discourage tree growth and encourage scrub oak resprouting may be beneficial	Patchy, infrequent (every 50 years) fire could be used to maintain scrub oak and to discourage trees from encroaching into frost bottoms
Cingilia catenaria (Chain-dotted Geometer)	Opening canopy of closed forest could enhance habitat as this species inhabits both woodlands and heathlands where huckleberry and blueberry dominate	Mowing to maintain shrubland/heathland characteristics would be beneficial; a mowing regime (or location) that maintains grasslands at the expense of shrubs and heath would not	Grazing to maintain shrubland/heathland characteristics would be beneficial; a grazing regime (or location) that maintains grasslands at the expense of shrubs and heath would not	Burning would probably enhance habitat by increasing growth of host plants (especially *Vaccinium*); populations seem to increase on MV following burns
Cycnia inopinatus (Unexpected Cycnia)	Removal of overstory would enhance open grassland/meadow habitat where hostplant can exist	Mowing would probably enhance habitat by keeping it open	Grazing would probably enhance habitat by keeping it open	Burning would probably enhance habitat by keeping it open

Species	Thin	Mow	Graze	Burn
Digrammia eremiata (Three-lined Angle Moth)	Removal of overstory would enhance open grassland/meadow habitat and encourage growth of host plant	Mowing would probably enhance habitat by keeping it open; host plant frequently found along regularly mowed firelanes	Grazing would probably enhance habitat by keeping it open; host plant frequently found along firelanes	Patchy, infrequent fire best. Burning would probably enhance habitat by keeping it open
Eacles imperialis (Imperial Moth)	Thinning pitch pine will reduce host plant	Mowing would probably not affect this species if pitch pine forests maintained, but mowing does remove pitch pine seedlings which are also utilized	Grazing would probably not affect this species; heavy grazing may remove some pitch pine seedlings	Burning should not severely affect species as host plant is fire tolerant and resprouts from base and with "water sprouts" along trunk after disturbance
Euchlaena madusaria	Removal of overstory would probably enhance habitat as hostplants often found along forest edges and in openings	Mowing could enhance habitat by keeping it open; host plants (*Betula* and *Prunus* as well as *Vaccinium*) often found along regularly mowed firelanes	Grazing could enhance habitat by keeping it open; host plants (*Betula* and *Prunus* as well as *Vaccinium*) often found along regularly mowed firelanes	Patchy, infrequent fire best. Burning would probably enhance habitat by keeping it open and by encouraging *Vaccinium* growth
Hemaris gracilis (Slender Clear-wing)	Removal of overstory would enhance open grassland/meadow habitat; species has been found in openings within forest and can utilize small habitats	Mowing would probably enhance habitat by keeping it open; annual mowing elsewhere has maintained species	Grazing would probably enhance habitat by keeping it open	Burning would probably enhance habitat by keeping it open and by encouraging *Vaccinium* growth
Hemileuca maia (Barrens Buckmoth)	Thinning would benefit this species by increasing scrub oak cover; scrub oak dominated openings within forest may provide oviposition sites	Removal of scrub oaks undesirable such as could occur through heavy, frequent mowing (multiple times/year); persists in annually mowed firelanes	Removal of scrub oaks undesirable such as could occur through heavy, frequent grazing (multiple times/year), but infrequent grazing to encourage scrub oak resprouting may be beneficial	Patchy, infrequent fire could be used to maintain scrub oak and to discourage trees from encroaching into frost bottoms

Species	Thin	Mow	Graze	Burn
Itame sp. 1 (near inextricata) (Barrens Itame)	Thinning would benefit this species by increasing scrub oak cover	Removal of scrub oaks undesirable such as could occur through heavy, frequent mowing (multiple times/year), but infrequent mowing to encourage scrub oak resprouting may be beneficial	Removal of scrub oaks undesirable such as could occur through heavy, frequent grazing (multiple times/year), but infrequent grazing to encourage scrub oak resprouting may be beneficial	All life stages may be susceptible to fire so patchy, infrequent fire best. Fire could be used to maintain scrub oak and young tree oak species, which are capable of resprouting with multiple stems after disturbance
Lycia ypsilon (Woolly Gray)	Thinning would probably benefit this species as it feeds on numerous low shrubs	Infrequent mowing would probably enhance habitat by maintaining a variety of low shrub species; wingless flightless female cannot avoid machinery and dispersal is low	Infrequent grazing would probably enhance habitat by maintaining a variety of low shrub species	Patchy, infrequent fire would probably enhance habitat by maintaining a variety of low shrub species; poor disperser as female is wingless and flightless
Metarranthis apiciaria (Barrens Metarranthis Moth)	Habitat and host plant unknown so affects of management unkown	Habitat and host plant unknown so affects of management unkown	Habitat and host plant unknown so affects of management unkown	Habitat and host plant unknown so affects of management unkown
Metarranthis pilosaria (Coastal Swamp Metarranthis)	Thinning would probably not affect this species, although creating openings in wet pine forests may be beneficial	Mowing may enhance growth of Ericaceae, but this species appears to prefer bogs and wetlands	Grazing may enhance growth of Ericaceae, but this species appears to prefer bogs and wetlands	Hot fires which encourage the growth of Ericaeae could benefit this species, particularly in or near wetlands
Psectraglaea carnosa (Pink Sallow Moth)	Thinning would benefit this species by increasing scrub oak cover	Removal of scrub oaks undesirable such as could occur through heavy, frequent mowing (multiple times/year), but infrequent mowing to encourage scrub oak and *Vaccinium* resprouting may be beneficial	Removal of scrub oaks undesirable such as could occur through heavy, frequent grazing (multiple times/year), but infrequent grazing to encourage scrub oak and *Vaccinium* resprouting may be beneficial	Patchy, infrequent fire probably needed to maintain shrubby habitat but threat of loss from frequent (>2+/decade) fire; appears to prefer unburned habitat to burned habitat

Species	Thin	Mow	Graze	Burn
Ptichodis bistrigata (Southern Ptichodis)	Removal of overstory would enhance open grassland/meadow, oak savannah habitat	Mowing would probably enhance habitat by keeping it open	Grazing would probably enhance habitat by keeping it open	Patchy, infrequent fire best. Burning would probably enhance habitat by keeping it open
Stenoporpia polygrammaria (Faded Gray Geometer)	Removal of overstory would enhance open grassland/meadow habitat and encourage growth of host plant	Mowing would probably enhance habitat by keeping it open; host plant frequently found along regularly mowed firelanes	Grazing would probably enhance habitat by keeping it open; host plant frequently found along firelanes	Patchy, infrequent fire best. Burning would probably enhance habitat by keeping it open
Zale sp. 1 (near lunifera) (Pine Barrens Zale)	Thinning would benefit this species by increasing scrub oak cover, especially in frost bottoms where overstory should be removed entirely to retain unique temperature features	Regular mowing probably not good for this species; removal of scrub oaks undesirable but infrequent mowing to discourage tree growth and encourage scrub oak resprouting may be beneficial	Removal of scrub oaks undesirable such as could occur through heavy, frequent grazing; infrequent grazing to discourage tree growth and encourage scrub oak resprouting may be beneficial	Patchy, infrequent fire could be used to maintain scrub oak and to discourage trees from encroaching into frost bottoms

APPENDIX H. Possible immediate impacts of seasonal fuels management techniques on rare insect species on MFCSF. Seasons are defined as calendar season (see below). Plus (+) indicates the treatment would likely benefit the species, minus (-) indicates the treatment would likely be detrimental for the species, no symbol indicates there should be no effect to the population, ? suggests there is not enough information to make a determination. See Table S10 for longterm and overall effects of treatments on species.

Treatment/Season	sp 1	sp 2	sp 3	sp 4	sp 5	sp 6	sp 7	sp 8	sp 9	sp 10	sp 11	sp 12	sp 13	sp 14	sp 15	sp 16	sp 17	sp 18	sp 19	sp 20	sp 21	sp 22	TOTAL
PP Thin Spring	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	?		+	+	+	+	+ 19 - 0
PP Thin Summer	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+	?		+	+	+	+	+ 19 - 1
PP Thin Fall	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	?		+	+	+	+	+ 19 - 0
PP Thin Winter	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	?		+	+	+	+	+ 19 - 0
Mow Summer		-	-	-	-		-	-	-	-		-	-	-	-	?	?			-	-	-	+ 0 - 15
Mow Fall	-			-	-		-	-	-	?		-	-		-	?	?		-	?	?		+ 0 - 10
Graze Spring	-			-	-		-	-	-	?		-	-	-	-	?	?		-	?	?		+ 0 - 11
Graze Summer			-	-			-	-	-	-		-	-	-	-	?	?			-	-	-	+ 0 - 13
Burn Spring	-	-		-	-		-	-	-	?		-	-	-	-	?	?		-	?	?		+ 0 - 12
Burn Summer		-	-	-	-		-	-	-	-		-	-	-	-	?	?			-	-	-	+ 0 - 15
Burn Fall	-	-		-	-		-	-	-	?		-	-	-	-	?	?		-	?	?		+ 0 - 12
Burn Winter	-	-		-	-		-	-	-	?		-	-		-	?	?		-	?	?		+ 0 - 11

APPENDIX H (continued)
Seasonal dates

Spring – March 21-June 20
Summer – June 21-Sept 20
Fall – Sept 21-December 20
Winter – December 21-March 20

Species List
1. *Abagrotis nefascia benjamini* (Coastal Heathland Cutworm)
2. *Acronicta albarufa* (Barrens Dagger Moth)
3. *Anisota stigma* (Spiny Oakworm Moth)
4. *Callophrys irus* (Frosted Elfin)
5. *Catocala herodias gerhardi* (Gerhard's Underwing)
6. *Cicindela purpurea* (Purple Tiger Beetle)
7. *Cicinnus melsheimeri* (Melsheimer's Sack-bearer)
8. *Cingilia catenaria* (Chain-dotted Geometer)
9. *Cycnia inopinatus* (Unexpected Cycnia)
10. *Digrammia eremiata* (Three-lined Angle Moth)
11. *Eacles imperialis* (Imperial Moth)
12. *Euchlaena madusaria*
13. *Hemaris gracilis* (Slender Clear-wing)
14. *Hemileuca maia* (Barrens Buckmoth)
15. *Itame sp. 1 (near inextricata)* (Barrens Itame)
16. *Lycia ypsilon* (Woolly Gray)
17. *Metarranthis apiciaria* (Barrens Metarranthis Moth)
18. *Metarranthis pilosaria* (Coastal Swamp Metarranthis)
19. *Psectraglaea carnosa* (Pink Sallow Moth)
20. *Ptichodis bistrigata* (Southern Ptichodia)
21. *Stenoporpia polygrammaria* (Faded Gray Geometer)
22. *Zale sp. 1 (near lunifera)* (Pine Barrens Zale)

APPENDIX I. Rare Insect Species Information

The Coastal Heathland Cutworm (*Abagrotis nefascia)*

This is a member of the Family Geometridae, with a global conservation status of G4, a state conservation status of S3, and is ranked by the Commonwealth of Massachusetts as a Species of Special Concern. The range of this species is limited to the Northeastern US; it has been found in MA, CT, NJ, RI, and on Long Island in NY (MNHESP 2004, NatureServe 2004). In MA, it is found in the southeast, primarily on Cape Cod and the offshore islands (Goldstein 1997, MNHESP 2004). The habitat of this species includes coastal dune, grasslands with dry sand, oak and pine forests, and open heathland-grassland sandplain habitats (Goldstein 1997, MNHESP 2004, NatureServe 2004). This species likely feeds on the new growth of various shrubs and herbs, and possibly grasses (MNHESP 2004, Nelson personal communication). The eggs of this species are laid towards the end of summer, and then hatch in the fall. The species overwinters in the larval stage, and the caterpillars emerge in the spring (usually May) and feed on the new growth of shrubs, herbs, and possibly grasses. They pupate in June and the adult moths emerge in July and can still be found through September (MNHESP 2004, NatureServe 2004). It is thought that individuals can move substantial distances, and the populations fluctuate between not rare in good years and very rare in poor years (NatureServe 2004). This species is listed in MA due to its extremely limited and discontinuous range (it is endemic to the Northeastern US) and its somewhat specialized habitat (MNHESP 2004, NatureServe 2004). Threats to the species include development, aerial spraying for insect pests, succession, fire suppression, and excessively large fires on unprotected sites (NatureServe 2004). Recommendations for the maintenance of this species include protecting habitat, maintaining and monitoring known populations, searching for new populations, determining the habitat needs more precisely to better maintain the habitats (MNHESP 2004, NatureServe 2004).

The Barrens Dagger Moth (*Acronicta albarufa)*

This is a member of the Family Noctuidae, with a global conservation rank of G3G4, a state conservation rank of S2S3, and is ranked by the Commonwealth as a Threatened Species. The range of this species was historically from MA to Ontario to NM and NC with some states within that range showing no records of it, but it has since been extirpated in several states (MNHESP 2004, NatureServe 2004). It is currently still extant in Missouri, Ontario, Massachusetts, Virginia, and New Jersey (NatureServe 2004). The habitat of this species is dry, open oak dominated sites including pitch pine-scrub oak barrens, scrub oak thickets, and oak savannahs on sandy soils (Wagner et al. 2003, MNHESP 2004, NatureServe 2004) although exactly what makes for appropriate habitat is still somewhat unclear (NatureServe 2004); may be associated with frost bottoms on MV (Goldstein 1994). The larval foodplant appears to be scrub oak in New England, although it may feed on other *Quercus* spp. as well (Rockburne and Lafontaine 1976, Wagner et al 1997, Wagner et al 2003, MNHESP 2004, NatureServe 2004) and possibly *Prunus* spp (Goldstein 1997). Although the ecology is poorly understood for this species (NatureServe 2004), we do seem to know something of the lifecycle. In the North, the females lay eggs on scrub, or other oak, leaves from July to early August, and the eggs hatch soon thereafter and mature until late September (Jones and Kimball 1943, MNHESP 2004). They pupate in the soil with a flimsy cocoon (MNHESP 2004). In NJ and Missouri, the adults may be active as early as late May and have a protracted emergence. It has also been suggested that in these areas eggs laid by mid June will produce a partial second brood of adults in mid or late August. In this case, larvae would be present almost all summer and into October in New Jersey and Missouri. Pupae do not appear to overwinter more than once (NatureServe 2004). This species is listed in MA due to its limited population in the state, its declining population in other areas (MNHESP 2004), and its extremely fragmented range (NatureServe 2004). The ecology of the species and its exact habitat needs are poorly understood, and the cause of decline and its absence in vast areas within its overall range and habitat are unknown (NatureServe 2004). Threats to the species include habitat fragmentation, development, aerial spraying for insect pests, fire suppression, and deer damage (MNHESP 2004, NatureServe 2004). Recommendations for the maintenance of this species include protecting habitat, maintaining and monitoring known populations, searching for new populations, documenting the habitat needs more precisely to better maintain the habitats (MNHESP 2004, NatureServe 2004). Protection from gypsy moth spraying with Dimilin, as well as from severe gypsy moth defoliation in some situations may be warranted (NatureServe 2004). The conservative use of fire with moderate (five year?) fire intervals combined with a patchy fire distribution such that the entire habitat is never burned within a three year period would probably be prudent as some information suggests that all stages are vulnerable to fire. Monitoring for the responses to fire would help us understand the best management techniques; at present it appears that mortality might be lower in more naturally timed summer fires than in fall or spring prescribed burns (NatureServe 2004).

The Spiny Oakworm Moth (*Anisota stigma)*

This is a member of the Family Saturniidae, with a global conservation status of G5, a state conservation status of S3, and is ranked by the Commonwealth of Massachusetts as a Species of Special Concern. The range of this species is fairly extensive, from Massachusetts and southern Ontario to Florida, west to Minnesota, Kansas and Texas (Holland 1968, Covell 1984, Tuskes et al. 1996). The habitat of this species in New England, where it is near the northern limit of its range (Wagner et al. 2003), appears to be dry sandplain communities such as scrub oak thickets and open pitch pine-scrub oak barrens (Wagner et al 2003, NatureServe 2004) and frost bottoms (Goldstein 1994, Goldstein 1997). Southward, the habitat is more generalized and includes more mixed hardwoods (NatureServe 2004). This species feeds almost exclusively on *Quercus* spp.—especially *Q. ilicifolia* and *Q. prinoides*—although it has also been reported on hazelnut (Jones and Kimball 1943, Holland 1968, Ferguson 1971, Covell 1984, Goldstein 1997, Wagner et al. 1997, Wagner et al. 2003, Nelson personal communication). Adults of this species, like other Saturniids, do not feed, so adult behavior is almost entirely devoted to reproduction (Tuskes et al. 1996, Wagner et al 2003). The eggs (usually between 5 and 20 at a time) of this species are laid soon after mating in June and July (Jones and Kimball 1943, Ferguson 1971, Covell 1984, Tuskes et al. 1996, Nelson personal communication), egg development takes approximately two weeks. There appears to only be one brood, although flight times vary with location (Tuskes et al. 1996, Wagner et al. 1997). Early-instar larvae are gregarious, but the larval clusters are usually small.

Later instars become solitary feeders (Tuskes et al. 1996, Wagner et al. 1997). Caterpillars are usually active between August and September, although they may remain above-ground into November in some areas (Wagner et al. 1997, Nelson personal communication). The pupae overwinter in subterranean chambers rather than cocoons (Holland 1968, Tuskes et al. 1996). The adults of this species are primarily nocturnal, although activity including calling, mating, and oviposition may take place during the day as well (Covell 1984, Tuskes et al. 1996). The wild silk moths have been declining, especially in the northeastern US, since the 1960s (Tuskes et al. 1996). This is probably due to habitat destruction and control measures directed against the gypsy moth, and possibly because of the increased use of mercury vapor lights which may disrupt their mating (Tuskes et al. 1996, Boettner et al. 2000). However, there has been some suggestion that this species can tolerate smaller habitats than most silk moth species (NatureServe 2004), and Tuskes et al. (1996) suggest that the widespread, low-density populations of silk moths may be relatively immune to local or temporary adverse conditions.

The Frosted Elfin (*Callophrys irus*)
This is a member of the Family Lycaenidae, with a global conservation status of G3, a state conservation status of S2S3, and is ranked by the Commonwealth of Massachusetts as a Species of Special Concern. The range of this species is from southern Maine west across New York and west to Wisconson, south along the Atlantic Coast and Appalachians to Florida (Opler and Malikul 1998, Glassberg 1999). It has been found in AL, AR, CT, DC, DE, GA, IL, IN, KS, KY, LA, MA, MD, ME, MI, NC, NH, NJ, NY, OH, OK, PA, RI, SC, TN, TX, VA, WI, WV and Ontario in Canada (NatureServe 2004). The habitat of this species is dry, open, disturbance-dependent habitats on sandy soils, including openings in pitch pine-scrub oak barrens, powerline cuts, airports, gravel pits, edges and fields near woods and scrub (Scott 1986, Opler and Malikul 1998, Glassberg 1999, Wagner et al. 2003). The presence of tree cover for shelter from the wind or for shade seems critical for the *Baptisia* feeder and airport populations of it tend to concentrate near edges or groves of young pines (NatureServe 2004). This species feeds on wild indigo and lupine (*Baptisia tinctoria*, *Lupinus perennis*) (Scott 1986, Opler and Malikul 1998, Glassberg 1999, Wagner et al. 2003, Nelson personal communication). The egg stage runs from mid-May through early June, then larvae hatch and feed, pupate in late July in the surface litter, at which point they overwinter. Adults emerge between May and mid-June and are diurnal (Scott 1986, Opler and Malikul 1998, NatureServe 2004, Nelson personal communication). Threats to this species include habitat fragmentation and loss, development, silviculture, prescribed burning, deer overpopulation, fire suppression (NatureServe 2004). Recommendations for maintenance of this species include inventories and protection of habitat, conservative burning or no fires, and possibly mowing. Regularly cut habitat at the airports supports populations of this species in NJ (Wagner et al. 2003, NatureServe 2004).

Gerhard's Underwing (*Catocala herodias gerhardi*)
This is a member of the Family Noctuidae, with a global conservation status of G3T3, a state conservation status of S3, and is ranked by the Commonwealth of Massachusetts as a Species of Special Concern. The range of this species is from southeastern

Massachusetts, southeastern NY, southern NJ and in the Appalachian through NC (Covell 1984, MNHESP 2004, NatureServe 2004). It has been found in CT, MA, NC, NJ, NY, VA and WV but is mainly found in four areas: Cape Cod and the islands, the Long Island Pine Barrens, the New Jersey Pine Barrens, and in the mountains of WV and NC (NatureServe 2004). The habitat of this species is dry sandplain communities such as scrub oak thickets, open pitch pine-scrub oak barrens, and rocky summits and ridges with scrub oak (Covell 1984, Wagner et al. 2003, MNHESP 2004, NatureServe 2004) and often in frost bottoms on MV (Goldstein 1997). The larvae of this species feed on the young leaves and flowering parts of *Q. ilicifolia* (Covell 1984, Wagner et al. 2003, MNHESP 2004, NatureServe 2004), however adult food sources are unclear and they may not feed (NatureServe 2004). The eggs of this species are laid on scrub oak in July, and the eggs overwinter. The nocturnal larvae emerge in spring (late April or May) and mature in about three weeks. In May or June the larvae pupate in a cocoon among the leaf litter, and the adults emerge about three weeks later, in July and into August (Jones and Kimball 1943, Covell 1984, MNHESP 2004, NatureServe 2004). The nocturnal adults are active mainly after 2 a.m. (MNHESP 2004). This species can be common in most years in MA, NY, and NJ—although it is rare in Appalachia—but it does occasionally have severe population crashes (NatureServe 2004). Adults have been found large distances from known suitable habitat, so this species may be able to disperse well (NatureServe 2004). Wagner et al. (2003) suggest that this species may reach its greatest population densities in the Northeast in frost pockets, and that regularly mowed vegetation does not support this species. This species is considered rare due to its limited range, population, and habitat, and the loss and fragmentation of that habitat (MNHESP 2004, NatureServe 2004). Threats to the species include development and habitat fragmentation, fire suppression which leads to succession to tree species or repeated mowing which would reduce its food plant, gypsy moth spraying (Wagner et al. 2003, MNHESP 2004, NatureServe 2004). Wildfire can remove the species from an area until young resprouting scrub oaks are able to once again produce catkins, which this species may need (Jordan unpublished). Recommendations for the maintenance of this species include protection of current populations and their habitats, staggered burning across the landscape so that burned areas can be recolonized from unburned areas, prohibiting the use of widespread insecticide spraying in spring and summer (MNHESP 2004). “An outstanding indicator species for Northeastern Sandplain Pitch-pine/Scrub Oak Barrens.” NatureServe 2004

The Purple Tiger Beetle (*Cicindela purpurea)*

This is the only beetle (Order Coleoptera) on this list, and it is a member of the Family Carabidae. It has a global conservation status of G5, a state conservation status of S2S3, and is ranked by the Commonwealth of Massachusetts as a Species of Special Concern. The range of this species is from Vancouver to Quebec in Canada, in most of the U.S. except perhaps the southernmost states of LA and FL. It is widely distributed in North America (Leonard and Bell 1999, NatureServe 2004). The habitat of this species is open, flat areas, in openings in woods, along meadow paths, grassy roadsides and grassy areas of sand dunes (Leonard and Bell 1999, NatureServe 2004). Like all tiger beetles of our area, this species predatory and feeds on small arthropods (Leonard and Bell 1999, Nelson personal communication). This species is diurnal and hunts for its food by chasing down prey on warm sunny days on open ground, and capturing victims with their long mandibles (Leonard and Bell 1999, NatureServe 2004). This species is present as an adult in both spring (March-mid June) and in the fall (late August-mid October), and it has at least a two-year life cycle. Adults mate and lay eggs in the spring (about 50 at a time, each in its own hole 5-10mm in the ground) in exposed soil in grassy places (along trails, streambeds, dirt roads). Larvae emerge after about 2 weeks, often after a rain. The larvae excavate a hole or burrow and wait for prey at the top of the burrow. They go into hibernation as third instars in the fall, then re-emerge in the spring to continue feeding. They pupate in late June and July, then emerge as adults in August. After feeding through the fall, the adults hibernate in a sealed underground burrow, from which they emerge to feed again in the spring (Leonard and Bell 1999). Populations of tiger beetles are affected by abundance of food, suitable soil for burrowing, weather, and the presence of natural enemies including predators and parasites (Leonard and Bell 1999). Threats could include loss of habitat, including through ORV use on open sand soils, old dirt roads or trails, etc.

Melsheimer's Sack-bearer (*Cicinnus melsheimeri*)
This is a member of the Family Mimallonidae, with a global conservation status of G4, a state conservation status of S2S3, and is ranked by the Commonwealth of Massachusetts as a Threatened Species. The range of this species is much of the eastern U.S.; from MA and southern Ontario to Florida, west to Wisconsin, Texas, Colorado and Arizona (Holland 1968, Franclemont 1973, Covell 1984, MNHESP 2004). It occurs widely throughout the southern U.S. and northward in sandy oak barrens or other dry habitats (Franclemont 1973, MNHESP 2004). In Massachusetts it appears to be near the northern limit of its range (Wagner et al. 2003) and may be represented in New England only populations on Cape Cod and the offshore islands of Massachusetts (Goldstein 1997). The habitat of this species includes sandplain pitch pine-scrub oak barrens, especially scrub oak thickets (Wagner et al. 2003, MNHESP 2004) and it may be a frost bottom obligate on MV (Goldstein 1997). This species feeds on *Quercus ilicifolia* (Jones and Kimball 1943, Franclemont 1973, Covell 1984, Wagner et al. 2003, Nelson personal communication). In August, when the young larvae of this species hatch, they build a hiding place from two small leaves stitched together with silk, within which they feed. As the caterpillars mature, they build cases from leaves which they carry about with them as they move. The larvae overwinter in these "sacks", on the surface of the ground among the leaf litter, and pupate late in the spring (Holland 1968, Franclemont 1973, MNHESP 2004). The nocturnal adults emerge soon after and are present May-July (Jones and Kimball 1943, Covell 1984, MNHESP 2004, Nelson personal communication). The adults do not feed (Wagner et al. 2003). This species is listed in MA due to its population decline, decrease in distribution, and current rarity in the state. Threats include development, habitat fragmentation, fire suppression leading to succession, widespread spraying with insecticides in spring or summer (MNHESP 2004). Recommendations for the maintenance of this species include protecting and maintaining the habitat using controlled, infrequent (every 50 years), patchy fires such that current populations can recolonize burned areas, maintaining and monitoring known populations, searching for new populations, and prohibiting the use of insecticide during the active stages of its life cycle (between April 15 and September) (MNHESP 2004).

The Chain-dotted Geometer (*Cingilia catenaria)*

This is a member of the Family Geometridae, with a global conservation status of G4, a state conservation status of S2S3, and is ranked by the Commonwealth of Massachusetts as a Species of Special Concern. The range of this species is from southeastern Canada to Maryland, west to Ohio and Kansas. It may be locally abundant to the point of being a pest in some years, especially northward but is becoming increasingly rare over much of its former range in the Northeast, especially in mainland New England (Goldstein 1997, Wagner et al. 2001). The habitat of this species is coastal plain shrubland habitats such as heathlands, bogs, and shrubby dunes or other areas dominated by huckleberry, with populations often reaching high densities following burns (Goldstein 1990, Wagner et al. 2001). This species is polyphagous, but seems to have a preference for *Gaylussacia* spp., *Myrica* spp., *Vaccinium* spp. (Jones and Kimball 1943, Goldstein 1997, Wagner et al. 2001, Wagner et al. 2003, Nelson personal communication). This species overwinters in the egg stage and hatches in the summer (Wagner et al. 2001) when the larvae are sometimes abundant enough to defoliate various host plants (Jones and Kimball 1943, NatureServe 2004). Pupation occurs in August and the adults emerge in September (Jones and Kimball 1943, Covell 1984, Nelson personal communication). Loss of habitat could threaten this species, and fire could be utilized to spur the growth of host plants, as this species can reach high densities following burns (Wagner et al. 2001).

The Unexpected Cycnia (*Cycnia inopinatus*)

This is a member of the Family Arctiidae, with a global conservation status of G4, a state conservation status of S1S2, and is ranked by the Commonwealth of Massachusetts as a Threatened Species. The range of this species is from New Jersey to Florida, west to South Dakota and Texas, and it has been found in AR, IN, MA, MI, NC, OH, and VA (Covell 1984, NatureServe 2004). The only known New England occurrences are thought to be on Martha's Vineyard where this species may reach its northern limit (Goldstein 1997). The habitat of this species is grasslands and it feeds on milkweeds (*Asclepias* spp.), preferring *A. tuberosa* (Covell 1984, Goldstein 1997, Nelson personal communication). This uncommon species has two broods per year, one hatching in June and the other in August, and it overwinters in the larval state. The caterpillars pupate in April and July and fly in May and late July (Covell 1994, Nelson personal communication). Loss of habitat to development and succession threaten this species, and efforts should be made to maintain habitat where the host plant can thrive.

The Three-lined Angle Moth (*Digrammia eremiata*)

This is a member of the Family Geometridae, with a global conservation status of G1, a state conservation status of S1, and is ranked by the Commonwealth of Massachusetts as a Threatened Species. The range of this species is from New Hampshire to Florida, west to Wisconsin down to Mississippi and has been found in IN, MA, NC, NJ (Covell 1984, NatureServe 2004). The habitat of this species is grasslands, frost bottoms, and fire lanes of MFCSF (Goldstein 1992b, Goldstein 1997). This species feeds on *Tephrosia virginiana* (Goat's Rue) (Covell 1984, Goldstein 1997, Nelson personal communication). This uncommon species is present as a caterpillar in July and September, as it has two broods per year (Nelson personal communication). The species overwinters in the pupal stage and the adults emerge in June and August (Jones and Kimball 1943, Covell 1984, Nelson personal communication). Habitat loss threatens this rare species, and it would probably benefit from selective burning to restore the grassland component to the forest (Goldstein 1992b).

The Imperial Moth (*Eacles imperialis*)
This is a member of the Family Saturniidae, with a global conservation status of G5, a state conservation status of S1, and is ranked by the Commonwealth of Massachusetts as a Threatened Species. The range of this species is from New England and Quebec south to Florida, west to Ontario and Texas (Covell 1984, MNHESP 2004) but it has disappeared from much of the Northeast (Tuskes et al. 1996). It has been found in AL, AR, CT, DE, FL, GA, IA, IL, IN, KY, LA, MA, MD, ME, MI, MO, MS, NC, NE, NH, NJ, NY, OH, PA, RI, SC, TN, TX, VA, VT, WI, WV. ON and QC in Canada (NatureServe 2004) and it occupied nearly all of the eastern US including throughout Massachusetts (Ferguson 1971, MNHESP 2004). This species has since been extirpated from mainland New England, but it still occurs regularly throughout MV (Goldstein 1997, MNHESP 2004). The habitat of this species in the Northeast is pitch pine stands although it may be found in a variety of forest types (Goldstein 1997, MNHESP 2004). It feeds on numerous species elsewhere (Holland 1968, Ferguson 1971, Covell 1984, Tuskes et al. 1996, Wagner et al. 1997, MNHESP 2004, Nelson personal communication) but it appears to prefer Pitch Pine (*Pinus rigida*) on MV, although it may also utilize other non-native pine species found there (Goldstein 1992a, Goldstein 1997, Nelson personal communication). This species does not feed in adulthood (Tuskes et al. 1996, Wagner et al. 2003) and has one generation per year (Tuskes et al. 1996, Wagner et al. 1997, Nelson personal communication). In the summer, the females distribute their ova in small clutches over a wide area where they take approximately two weeks to hatch (Tuskes et al. 1996). Larvae hatch in July or August and feed through September when they pupate in subterranean chambers where they overwinter (Tuskes et al. 1996, MNHESP 2004). Adults emerge the following summer with a peak in the flight season in late July (Jones and Kimball 1943, Ferguson 1971, Goldstein 1990, Goldstein 1992a, Tuskes et al. 1996, Nelson personal communication). This species is listed as a Threatened Species in MA due to its declining population and threats to its habitat (MNHESP 2004). Declines in populations and the disappearance from New England other than MV could be linked to habitat destruction and fragmentation, gypsy moth spraying, widespread use of mercury vapor lights which could disrupt mating, past DDT use, and parasitoids such as *Compsilura* (Goldstein 1992a, Tuskes et al. 1996, Boettner et al. 2000, NatureServe 2004). Recommendations for the maintenance of this species include protection and monitoring of known populations and their habitats as well as searching for new ones and avoiding spraying for pest species during vulnerable periods (MNHESP 2004). It is thought that this species may be able to withstand spring and early summer burns when the pupae are deep underground (Goldstein 1992b).

Euchlaena madusaria
This is a member of the Family Geometridae, with a global conservation status of G4, a state conservation status of S2S3, and is ranked by the Commonwealth of Massachusetts as a Species of Special Concern. The range of this species includes a few Atlantic States,

and it has been found in MA, NH, NY, RI, and in Ontario in Canada (Holland 1968, NatureServe 2004). The habitat of this species is probably open areas as it prefers to feed on *Vaccinium* spp., as well as *Prunus* spp. and *Betula* spp. (Nelson personal communication). This species has two broods per year, with larvae hatching in July and September. The larvae overwinter and pupate in May and July, emerging as adults in June and August (Nelson personal communication). Loss of habitat could threaten this species.

The Slender Clearwing (*Hemaris gracilis*)
This is a member of the Family Sphingidae, with a global conservation status of G3G4, a state conservation status of S2S3, and is ranked by the Commonwealth of Massachusetts as a Species of Special Concern. The range of this species is from Nova Scotia to Florida, west to Wisconsin, and it has been found in CT, FL, IN, MA, ME, MI, NH, NJ, NY, OH, PA, SC, as well as ON and QC in Canada (Holland 1968, Hodges 1971, Covell 1984, NatureServe 2004). It is apparently rare on mainland New England (Goldstein 1997). The habitat of this species is Pitch Pine-Scrub Oak barrens, heathlands, airports on sandy soils as well as heathy bogs (Goldstein 1997, Wagner et al. 2003, NatureServe 2004). This species feeds on *Vaccinium* spp. and possible other heaths (Covell 1984, Goldstein 1997, Wagner et al. 2003, NatureServe 2004, Nelson personal communication). In May and June this diurnal species lays its eggs, which develop in a week's time. Larvae feed for approximately one month before pupating in a somewhat dense cocoon on the surface of the ground in the leaf litter (Holland 1968, NatureServe 2004, Nelson personal communication). After overwintering as pupae, adults emerge in late May to mid-June (Hodges 1971, NatureServe 2004, Nelson personal communication). Threats to the species include habitat destruction and fragmentation, fire suppression, and the introduced Tachinid fly *Compsilura concinnata* (Wagner et al. 2003, NatureServe 2004). Recommendations for the maintenance of this species include inventories, protection and enhancement of known occupied and potential habitat, connectivity between habitat patches. Population persists in winter mowed portions of airport in NJ (NatureServe 2004). Large areas of habitat may be required for this species (NatureServe 2004).

The Barrens Buck Moth (*Hemileuca maia*)
This is a member of the Family Saturniidae, with a global conservation status of G5, a state conservation status of S3, and is ranked by the Commonwealth of Massachusetts as a Species of Special Concern. The range of this species is from Maine to Florida, west to the Great Plains, and it has been found in AL, AR, CT, DE, FL, GA, IL, IN, KS, KY, LA, MA, MD, ME, MI, MO, MS, NC, NH, NJ, NY, OH, OK, PA, RI, SC, TX, VA, WV (Holland 1968, Covell 1984, Tuskes et al. 1996, NatureServe 2004). It appears to be restricted to barrens areas in the Northeast (Goldstein 1992b, Wagner et al. 2003). The habitat of this species in the Northeast is dry open barrens habitats such as sandplains (Tuskes et al. 1996, Goldstein 1997, Wagner et al. 2003) that are dominated by scrub oaks, including frost bottoms on MV (Goldstein 1992a, Goldstein 1992b). They may utilized the edges of oak forests, unbroken stretches of Scrub Oak, and may reach their highest regional densities in frost bottoms (Goldstein 1992a and b, Wagner et al. 2003). The host plant of this species in the Northeast is primarily oaks, especially scrub oaks like

Quercus ilicifolia and *Q. prinoides*, although late-instar larvae will occasionally feed on other hosts (Jones and Kimball 1943, Covell 1984, Goldstein 1997, Wagner et al. 1997, Wagner et al. 2003). In the south it inhabits forests and feeds on a variety of oaks (Wagner et al. 2003). Adult females oviposit almost exclusively on scrub oaks in New England, laying dozens to hundreds of eggs in a ring around the plant stem. This species overwinters in the egg stage, and gregarious spiny larvae hatch in May and June and feed on newly emerging scrub oak (or other oak) leaves (Jones and Kimball 1943, Holland 1968, Tuskes et al. 1996, Wagner et al. 1997, Nelson personal communication). These larvae are dark cluster-feeders covered with setae, and exhibit a variety of traits adapted for thermoregulation (Goldstein 1992a). Larvae feed independently in late instars, then pupate just below the surface of the ground in August and September, and emerge as adults in late September into October (Jones and Kimball 1943, Holland 1968, Covell 1984, Tuskes 1996, Nelson personal communication). The adults are also predominantly black, and they are diurnal insects that fly on warm sunny days in the fall but do not feed as adults (Holland 1968, Covell 1996, Wagner et al. 2003). This species has one generation although some individuals overwinter for several years (Holland 1968, Tuskes et al. 1996, Wagner et al. 1997). Threats to this species include habitat destruction, fire suppression, gypsy moth control measures, mating disruption from mercury vapor lights (Tuskes et al. 1996, NatureServe 2004). Recommendations include habitat protection and maintenance, reintroduction of fire into the ecosystem, avoid spraying for gypsy moths when the Buckmoth is present and vulnerable.

The Barrens Itame (*Itame sp. 1*, near *inextricata)*
This is a member of the Family Geometridae, with a global conservation status of G2S3, a state conservation status of S2S3, and is ranked by the Commonwealth of Massachusetts as a Species of Special Concern. The range of this species is the Northeastern part of the US, and it has been found in CT, MA, ME, NH, NJ, NY, PA but is most widespread in the Cape Cod and Islands region of Massachusetts and Long Island, NY (NatureServe 2004). The habitat of this species is sandplain pitch pine-scrub oak barrens (Goldstein 1997, Wagner et al. 2003, NatureServe 2004). This species apparently feeds on *Quercus ilicifolia*, but may utilize *Vaccinium* or other Ericaceae as well (Goldstein 1997, Wagner et al. 2003, NatureServe 2004, Nelson personal communication). This nocturnal species overwinters in the egg stage from July to May, in May the larvae hatch out and feed until June when they pupate briefly, possibly in the soil but it is unclear. In late June or early July the adults emerge for a brief two week flight period. This species is apparently a weak flier with a low ability to disperse far (NatureServe 2004). Threats to this species include the loss and fragmentation of habitat, succession, or loss of small habitat patches to wildfire (NatureServe 2004). Protection of remaining occupied and potential habitats, responsible land management, and more surveys are all recommended for the maintenance of this species (NatureServe 2004).

The Woolly Gray (*Lycia ypsilon*)
This is a member of the Family Geometridae, with a global conservation status of G4, a state conservation status of S1, and is ranked by the Commonwealth of Massachusetts as a Threatened Species. The range of this species is from Minnesota to Martha's Vineyard, MA, south to Florida and Texas (Covell 1984, Wagner et al. 2001, NatureServe 2004).

The population in the frost bottoms of MFCSF on MV appears to be the only population in New England, where the species may reach its northern limits, although it is more common further south (Goldstein 1997). The habitat of this species is pitch pine-scrub oak barrens on MV, possibly only in frost bottoms, but it inhabits other forests and woodlands further south (Goldstein 1997, Wagner et al. 2001, Wagner et al. 2003). The species is polyphagous, feeding on numerous woody plants such as *Clethra, Myrica, Prunus*, and *Quercus* in the south, and possibly utilizing similar low shrub plant species such as *Clethra*, *Prunus*, and *Amelanchier* in the North (Covell 1984, Goldstein 1997, Wagner et al. 2001, Wagner et al. 2003, Nelson personal communication). The Woolly Gray begins as an egg in May, hatching in late May into the larval stage which lasts through July in the Northeast (Wagner et al. 2001, Nelson personal communication). The caterpillars pupate in July and overwinter until late April when the adults emerge from pupation (Covell 1984, Nelson personal communication). This species has one generation per year and can be locally common, but the female is wingless and flightless, limiting dispersal (Covell 1984, Wagner et al. 2003). Threats to this species are primarily the loss of the very rare frost bottom barrens habitats in New England to development or succession (Wagner et al. 2003). Because the female of this species is flightless, escape from management and dispersal into new habitats would be slow to impossible, so care must be taken to avoid loss of this species to well-intentioned land management. This species may be vulnerable at all times of the year (pupal location is unknown) so it is recommended that management be undertaken in a patchwork fashion spatially and temporally across the landscape.

The Barrens Metarranthis Moth (*Metarranthis apiciaria)*

This is a member of the Family Geometridae, with a global conservation status of GU, a state conservation status of S1, and is ranked by the Commonwealth of Massachusetts as an Endangered Species. The range of this species was once scattered from the Maine coast to Indiana, south to West Virginia and Pennsylvania, and it has been found in CT, IN, MA, ME, NH, NY, PA, and ON in Canada (NatureServe 2004). This species is currently considered to be absent from mainland New England with a single individual captured in MFCSF on MV in 1994 as the only modern record. The population on MV is thought to be the world's only extant population of this species (Goldstein 1994, Goldstein 1997). The habitat of this species is not at all understood, but on MV it occurs only in frost bottoms in the pitch pine-scrub oak barrens (Goldstein 1997, Wagner et al. 2003, NatureServe 2004). The foodplant of this species is also undocumented (Goldstein 1997, Wagner et al. 2003, NatureServe 2004, Nelson personal communication). The adult of this species occurs in June when it lays eggs. The egg stage probably lasts for about 10 days after which the larvae hatch and persist from July into August. In August the insect pupates and overwinters in this state (probably in the leaf litter), to emerge as an adult for a short flight season in late May to June (NatureServe 2004, Nelson personal communication). The lack of knowledge about this species makes determining and mitigating threats extremely difficult. There is evidence of decline with few survivors, but the source of the decline is undocumented, although it has been suggested to be anything from gypsy moth spraying, prescribed burning, to out of control deer (NatureServe 2004). Recommendations must begin with basic survey work to document the extent of the species, its habitat and host plant requirements, and possible threats.

Existing populations should be protected but without more information the needs of this species may remain unmet (NatureServe 2004).

The Coastal Swamp Metarranthis (*Metarranthis pilosaria)*
This is a member of the Family Geometridae, with a global conservation status of G3G4, a state conservation status of S2S3, and is ranked by the Commonwealth of Massachusetts as a Species of Special Concern. The range of this species appears to be limited to New England and Long Island, NY, and has been found in MA, MJ, RI (NatureServe 2004). In Massachusetts this species is found mostly in the Cape Cod region but turns up occasionally in Boston suburbs (NatureServe 2004). The habitat of this species is wetlands and boggy areas including boggy pine barrens (Goldstein 1997, Wagner et al. 2003, NatureServe 2004), often areas created by hot wildfires, human activity (damming, cutting, clearing) and beaver activity, and can be characterized as acid, unforested to lightly wooded wetlands (NatureServe 2004). This species apparently feeds on Ericaceae such as *Vaccinium* spp. like *V. macrocarpon, V. oxycoccos*, and possibly others (Goldstein 1997, NatureServe 2004, Nelson personal communication). In MA, adults occur in May or June through early July when they lay eggs. The eggs take about 10-20 days to hatch with larvae emerging in July (NatureServe 2004, Nelson personal communication). Larvae feed until August or September (about 6-10 weeks) when they hibernate as pupae in the leaf litter (NatureServe 2004, Nelson personal communication). Adults emerge the next June and are thought to be good dispersers (NatureServe 2004). Threats to this species include habitat loss, mosquito spraying, and succession (NatureServe 2004). Recommendations include protection of habitat, research into specific foodplant and habitat requirements, and continued restrictions on wetlands development (NatureServe 2004).

The Pink Sallow Moth (*Psectraglaea carnosa*)
This is a member of the Family Noctuidae, with a global conservation status of G3, a state conservation status of S2S3, and is ranked by the Commonwealth of Massachusetts as a Species of Special Concern. The range of this species is across New England and into Canada, and it has been found in CT, MA, ME, MI, NH, NJ, NY, PA, and ON and QC in Canada (NatureServe 2004). It occurs predictably at a site in MFCSF in MV (Goldstein 1994) and appears to be not rare in parts of southern NJ, the Cape Cod and Islands area, the Long Island Pine Barrens, and sandy parts of Wisconsin and northern Michigan (NatureServe 2004). It may have been extirpated from CT and RI (NatureServe 2004). The habitat of this species is sandplain pitch pine-scrub oak barrens and heathlands, sandy areas dominated by Ericaceae, unburned or infrequently burned barrens, coastal heath-scrub, frost bottoms (Rockburne and Lafontaine 1976, Goldstein 1997, Wagner et al. 2003, NatureServe 2004). They may require large well managed infrequently burned barrens areas (NatureServe 2004). The host plants for this species appear to be *Vaccinium* spp. and *Quercus ilicifolia* but it has not been documented in the wild (Rockburne and Lafontaine 1976, Goldstein 1997, Wagner et al. 2003, NatureServe 2004, Nelson personal communication). This species overwinters in the egg stage (eggs are laid loose in the sand or litter) from October to April. Larvae hatch to feed on young leaves, maturing to about June when they aestivate underground as prepupae, to pupate in the fall. Adults emerge in late September and fly briefly in early October (Jones and

Kimball 1943, NatureServe 2004, Nelson personal communication). Threats to this species include habitat destruction and fragmentation followed by fire suppression, excessive (>2+/decade) prescribed burns in the fall, winter or spring, gypsy moth spraying, and long-term forest succession (Wagner et al. 2003, NatureServe 2004). This species can apparently survive for decades without fire and they appear to be vulnerable to frequent fire (NatureServe 2004). Surveys for this species should be conducted, protection of large areas of habitat and infrequent patchy burns needed to maintain habitat, although fire should be avoided in areas with no fire history as this species appears to display an aversion to burned areas (NatureServe 2004, Jordan unpublished report). Removal of encroaching overstory trees may be warranted as well (NatureServe 2004).

The Southern Ptichodis (*Ptichodis bistrigata*)
This is a member of the Family Noctuidae, with a global conservation rank of G3, a state conservation rank of S1S2, and is ranked in the Commonwealth of Massachusetts as a Threatened Species. The range of this species is from eastern NJ to Florida, west to Missouri and Texas (Covell 1984), and it has been found in AR, MA, MD, NC, NJ, VA, WI (NatureServe 2004). It appears to be most common on the outer coastal plain and eastern Great Plains (NatureServe 2004). The habitat of this species is not well understood, but it appears to prefer xeric pine/oak scrub, savanna and prairie, sandplain grasslands, scrub oak-grass mix (NatureServe 2004). The host plant is unknown but suspected to be grasses and/or legumes (NatureServe 2004, Nelson personal communication). This nocturnal species lays a single brood of eggs in June, from which the larvae hatch and develop through July and August, pupating in September and spending much of the year (September through May/June) as pupae (NatureServe 2004, Nelson personal communication). Adults emerge in late spring (late May-June) and apparently occasionally disperse and colonize over short distances (NatureServe 2004). Threats to this species include rarity and loss of habitat and excessive prescribed burning (NatureServe 2004). Further surveys for this species to identify habitat and host plant needs would increase our ability to manage for it. Protection of known habitat and reduced prescribed fire frequency using light fires where they are found is also warranted (NatureServe 2004).

The Faded Gray Geometer (*Stenoporpia polygrammaria*)
This is a member of the Family Geometridae, with a global conservation status of GU, a state conservation status of S1, and is ranked in the Commonwealth of Massachusetts as a Threatened Species. The range of this species is from southern Canada to Georgia and Arkansas but it currently only exists on Martha's Vineyard in MA, in Ontario in Canada and possibly in NC (Wagner et al. 2001, NatureServe 2004). The habitat of this species is barrens and woodlands (Wagner et al. 2001), and its host plant is unknown, although suspected to be red and white oaks (Wagner et al. 2001, Nelson personal communication). There is one generation on MV, the larvae feed on leaf tissue in July and August, maturing in September to pupate (Wagner et al. 2001, Nelson personal communication), overwintering at this stage and emerging as adults to lay eggs in June (Wagner et al. 2001, Nelson personal communication). Threats to this species are unknown, but it has declined drastically in the eastern US over the last 50 years

(NatureServe 2004). Recommendations include further research into food plant and habitat needs, protection of known occupied areas, and searches for additional populations (NatureServe 2004). Without more information on the extent, status, and needs of this species, management recommendations are impossible.

The Pine Barrens Zale (*Zale sp. 1, near lunifera)*

This is a member of the Family Noctuidae, with a global conservation status of G3G4, a state conservation status of S2S3, and is ranked in the Commonwealth of Massachusetts as a Species of Special Concern. The range of this species, endemic to the US, is throughout New England, south to Virginia and possibly Florida. It has been found in CT, MA, ME, NH, NJ, NY, PA, RI, VA (NatureServe 2004). The habitat is sandplain pitch pine-scrub oak barrens, especially scrub oak thickets such as found in frost bottoms and may require delayed leaf-out of frost bottoms (Goldstein 1997, Wagner et al. 2003, NatureServe 2004). The host plant for this species is young scrub oak (*Quercus ilicifolia*) foliage (Goldstein 1994, Goldstein 1997, Wagner et al. 2003, NatureServe 2004, Nelson personal communication). Eggs laid in May develop for about two weeks. Nocturnal larvae hatch in the spring (June), feed on scrub oak until pupation in August at which point they overwinter. Adults emerge in May through early June when they lay eggs and begin again (NatureServe 2004, Nelson personal communication). This species is endangered because of its limited range, low numbers, and specialized habitats (NatureServe 2004). Protection and responsible management of habitat can maintain this species.

APPENDIX J. Average fuel loads (tons/acre) and depths (ft) in research plots in the EFB. Data is based on spring 2004 (pre-burn) sampling of control and treatment plots (each is an average of three plots). These data were used to create CFMs for control and treatment plots.

		PP-C	PP-TM	PP-TP	OW-C	OW-MG	OW-M	SO-C	SO-MG	SO-M
LITTER	leaf wt	5.8	4.0	3.9	3.5	2.9	3.2	3.8	3.0	3.0
	1hr	1.0	2.0	1.1	1.0	1.4	1.3	1.2	2.1	2.6
	10hr	1.0	1.9	1.8	0.7	0.8	0.9	0.7	1.6	3.1
	100hr	0.6	1.6	2.2	0.0	0.3	0.0	0.9	0.1	0.2
SLASH	1hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	10hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	100hr	0.6	0.9	1.5	0.5	0.7	0.2	1.2	1.0	1.1
SHRUB	1hr	0.2	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
(dead)	10hr	0.0	0.0	0.1	0.1	0.2	0.0	0.1	0.0	0.3
	100hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SHRUB	leaf wt	0.1	0.0	0.0	0.1	0.2	0.0	0.0	0.0	0.1
(live)	1hr	0.6	0.2	0.4	0.8	0.4	0.5	0.6	0.2	0.7
	10hr	0.1	0.0	0.1	0.7	0.3	0.4	0.1	0.0	0.4
Depths	Litter	0.3	0.2	0.2	0.4	0.2	0.2	0.2	0.1	0.2
	Slash	1.0	0.0	0.8	0.8	0.5	0.6	1.8	0.3	1.1
	Shrub	3.0	2.9	1.6	2.9	3.0	2.2	4.3	2.0	1.4

APPENDIX K: Literature Review: Fuels and Fire Behavior

Overview

Unlike much of New England's vegetation, barrens fuels are highly flammable (Mouw, 2002), and under dry, windy conditions can support extreme fire behavior. Many species occurring in barrens produce volatile hydrocarbons, making live foliage flammable (Crary, 1986). Species such as Scrub Oak (*Quercus illicifolia*) retain dead stems in their canopies and provide well aerated low-moisture fuels in both the growing and dormant seasons. The well drained soils of sandplain barrens create chronically dry conditions which results not only in low fuel moistures, but also in high fuel loadings due to lowered rates of decomposition. Furthermore there are many days in the spring and summer following periods of draught, when humidities are low and wind speeds high. In the spring favorable weather conditions are combined with low live fuel moistures characteristic of the dormant season, resulting in more frequent fire and more intense fire behavior in that season. Pitch Pine (*Pinus rigida*), despite being evergreen, is also more flammable in the spring as a result of low moisture content of one- and two-year-old needles (Patterson, pers. obs.). Fires that are typical of these systems are low severity surface fires (having low residence times as a result of abundant fine flashy fuels) which can have the potential for high rate of spread but crown fires are also possible in pitch pine forests.

Vegetation types which support extreme fire behavior are scrub oak shrublands and pitch pine stands. The lack of a canopy in scrub oak results in higher levels of solar radiation and surface wind speeds, which is conducive to the rapid drying of fuels and greater fire activity. Furthermore the well developed shrub layer supports high fuel loads and depths (Mouw, 2002). Flame lengths of 40-60 feet and rates of spread of 60 feet/minute have been recorded from prescribed fires in scrub oak under conditions of light wind (4-5 mph) and high humidities (75-80%). A wildfire burning through scrub oak vegetation under many conditions would be too intense to attack directly. Furthermore fires burning in scrub oak can not only support high rates of spread but under the right weather conditions can have a high potential for downwind spotting. Furthermore Scrub Oak stands are often very dense and difficult for firefighters to gain access to. Pitch pine stands can support crown fires which are very difficult to control, and can support high rates of spread and frequent spotting. Crown fires have occurred in pitch pine stands in historic times. The 1957 Plymouth fire, for example, supported flame lengths of 100-150 feet and rates of consumption of 18 acres/minute. Unlike barrens on Cape Cod and other parts of New England, there are relatively few pitch pine stands at MFCSF. Tree oak species are less flammable than either Pitch Pine or shrub oak species. High canopy cover in oak woodlands reduces understory growth and this vegetation type has low 1 and 10 hour fuel loads and low fuel depths (Mouw, 2002).

The fairly level topography of the outwash sandplain has also encouraged large scale fires as is documented from early historic period (Mouw, 2002). Frost bottoms, North-south trending valleys, represent little change in elevation from the surrounding sandplain but do influence fire due to their influence on vegetation. These valleys experience a harsher growing environment with higher daytime high and lower nighttime low temperatures. As a result contiguous scrub oak stands with few trees are supported within them, succession seemingly occurring more slowly there (Mouw, 2002).

Mouw (2002) used modern aerial photos and fuels sampling to create modern vegetation and fuels maps. Using these maps and custom fuels models he developed for each fuels type (based on intensive fuels sampling), he modeled expected modern fire behavior at MFCSF using Farsite. In addition, by assuming that vegetation types characterized on historic photos (1938 and 1952) were similar to the same vegetation types in modern times, he also created historic vegetation and fuels maps and modeled fire behavior from those periods. Although historic fuels resulted in larger burn areas, as a result of the more contiguous shrub oak vegetation in historic times, catastrophic fires can occur in modern fuels. In modern fuels, four of five simulated fires (with different ignition locations) crossed the MFCSF boundary within three hours. Although fire threat has been reduced in modern times as a result of altered fuels and vegetation, threat has increased as a result of increased human development outside MFCSF.

Firebreaks will never prevent a fire burning in the fuels of MFCSF from spotting outside the forest boundary nor would they be able to stop the worst fires that could burn at MFCSF. Large fires which burned in the 1950s and 1960s are documented to have moved across four lane highways, and the Plymouth fire of 1957 stopped only upon reaching Cape Cod Bay. Mouw (2002) showed that interior breaks, even if widened to 400 feet, do little to slow the spread of a wildfire into adjacent compartments under average worst case weather conditions. However, exterior breaks did lengthen the amount of time taken for fires to cross outside MFCSF and this effect was more pronounced for breaks that were wider and had more substantial fuel reduction treatments. Increasing the time for a fire to spread outside of MFCSF can provide valuable time for firefighters in suppressing a fire. Firebreaks also provide access (and safe escape routes) for firefighters and can allow them to attack fires before they reach conflagration size. Furthermore, firebreaks may enable the use of prescribed fire to reduce fuel loads in the future. The effectiveness of firebreaks at slowing wildfire spread is dependant on the intensity of the fire upon reaching the breaks, and because this is influenced by the size of the fire and the fuels that are upwind of the firebreak, is greatly influenced by the ignition point. As a result, firebreak creation (location, width and fuel reduction technique) should take into consideration likely ignition sources and the fuels the fire will encounter before hitting the break. As a result of this research, it has been recommended that external firebreaks be widened to 500 feet and interior breaks be widened to 100-200 feet.

APPENDIX L. Conservation of ancient coppice oaks

A conservation issue at MCCSF involves the presence of apparently ancient coppice oaks in stands that are dominated by tree oak species (mainly black oak, white oak, and post oak). These coppice oaks are of interest because the sprouts occur in clumps that form circles with diameters ranging from 20 cm to over 100 cm. These sprout clumps, described briefly by Foster and Motzkin (1999), have no visible stump (coppice stool) above ground. The current live stems are less than 100 years old, but the size of the largest belowground coppice stools suggests that they may be hundreds of years old (no age data are available, however). Thus, these trees may be a legacy of forests that grew on the island prior to European settlement.

Biology of coppice growth

Most hardwood (angiosperm) tree species have the ability to produce vegetative sprouts after the aboveground portion of a tree has been damaged. Sprouts arise from buds either on the stem (stump sprouts or epicormic sprouts) or on the roots (root sprouts), depending on the species. The number and growth rate of sprouts depend on the size and age of the parent stem, and these relationships vary greatly among species. Oak species generally exhibit vigorous production of stump and epicormic sprouts after cutting or damage. The main species of the Northeast central hardwoods and transition hardwoods include red, black, white, and scarlet oak, all of which produce these sprouts.

In normal development, each oak shoot produces a cluster of large buds at the shoot tip, and large intercluster buds distributed individually along the shoot; these buds form in leaf axils. Near the base of the shoot are much smaller buds (most are not visible without magnification) that are not associated with leaf axils (some occur in the axils of bud scales). The large cluster and intercluster buds either produce a shoot the year after they were formed, or die soon after; survivorship of dormant buds is 10% at the end of that year (Wilson and Kelty 1993). The smaller buds generally do not produce shoots in normal (undamaged) growth in the year after they were formed, and these buds have higher survivorship (50% survive through that year). These dormants buds form a "bud bank" on each shoot of the tree. The same process occurs on the first seedling shoot that develops from the germination of an acorn--large cluster and intercluster buds form in the leaf axils, and small buds are produced on the lower stem of the seedling, at and just above the root collar.

Some of the buds in the bud bank survive for many years by producing a bud trace that allows the dormant buds to grow radially at a rate that matches the stem diameter growth, and thus remain just below the bark (Wilson, 1984). If a substantial part of an oak crown is cut or damaged, the hormone-mediated inhibition of the small buds in the bud bank will be released, and epicormic sprouts develop on twigs and branches below the damage (Wilson and Kelty 1993). The buds at the base of the main stem do not form shoots (stump sprouts) unless the entire tree stem is cut or killed. The terms "stump sprout" and "epicormic sprout" differentiate shoots simply based on their location (developing from buds near the base of the tree or higher on the stem or branches), but have similar origin and development.

The probability of an oak producing stump sprouts after being cut or burned varies with age, stump diameter, and site quality. Studies in Virginia and Missouri provide details of these relationships for white and black oak (Roth and Hepting 1943, Johnson 1975). Both species at age 40 with a 10-cm stump diameter have a 75%-90% probability of producing sprouts on moist sites (site index 21 m) but this reduces to 50-65% on dry sites with site index of 15 m. There is a sharper decrease in probability of sprouting with age and size for white oak, approaching zero for trees of age 100 with 50-cm stump diameter; for black oak, sprouting probability is still 40-50% for that age and size. Both species average 6-9 sprouts/stump, but with some stumps having 20 or more sprouts. Reduction in sprout numbers occurs gradually in subsequent years through competition among the shoots growing on an individual stump and with other vegetation as well.

Stump height has an important effect on sprout development. Stumps that are 30 cm high tall have sprouts developing from belowground buds near the root collar as well as from higher on the stump (Roth and Hepting 1943). Sprouts that originate high on the stump have a greater probability of becoming the tallest among the sprouts in a clump, and also a greater probability of developing stem decay through the connection to the decayed heartwood of the stump. Stumps cut at ground level have shoots originating at ground level or below, and burned stumps have only belowground shoots.

Management of coppice oak stands

Coppice management is the oldest silvicultural system, having been well established more than 1000 years ago (Peterken 1993). The objective was to produce large quantities of small diameter stems for fuelwood and other wood products. Many species were used, with oak being common. These stands were harvested on rotations of 5 to 25 years, depending on species growth rates and desired products. Trees were cut close to the ground to produce sprouts that developed from buds at or below ground level, mainly to reduce problems with decay developing in the new sprouts. The concern with stem decay was largely related to the value of the stem for wood products, but also simply for maintaining vigorous stems to serve as the source of buds for the next generation of sprouts.

Coppice management was the most widespread system in Europe until fuelwood and small dimension wood dropped in commercial importance in the early twentieth century. Abandoned coppice stands still persist there, and some stools in these stands are thought to be 500 years old or older, having been cut dozens of times. In old coppice stools, the original circular pattern of stems breaks up and develops into a ring of separate stools with the central core decaying.

The coppice system was initiated in the Northeastern U.S. in the nineteenth century using oak and chestnut for supplying charcoal for metal and brick industries. However, the managed coppice forests were abandoned as fossil fuels became readily available, so there were no forests where repeated coppice harvests were conducted for long periods, as in Europe. However, coppice stands develop whenever hardwood stands are cut, and a rough form of coppice cutting likely developed in many parts of the Northeastern U.S. before the scientific practice of silviculture began in the nineteenth century.

APPENDIX M. FIELD PROCEDURES

DOWNED WOODY FUELS INVENTORY
Manuel F. Correllus State Forest
2002-2004

I. Equipment

A. Measuring devices

1. DBH tapes (2)
2. 100' tapes, marked in feet and tenths on one side, meters of the other (2)
3. yard stick, marked in feet and inches
4. go-no-go gauges (2)
5. spherical densiometer
6. clinometer
7. Cruise-all

B. Other

1. compass
2. map of forest with plots and vegetation types labeled
3. clipboard, pencils, calculator
4. pruning shears
5. 1m x 1m frame made from 1.2" PVC pipes
6. 40cm X 40 cm (1600cm^2) frame made from PVC pipe
7. data sheets
8. paper bags for vegetation samples

II. DOWNED WOODY FUELS INVENTORY

1. Randomly select one of four plot sides and along that side pull out a measuring tape and hang flagging every 25 ft (at 25, 50, 75, 100, and 125). Sampling points are 50 ft. into the plot (heading perpendicular to the plot side) from the 25, 75 and 125 ft distances along the plot side and are 100 ft into the plot (perpendicular to the plot side) from the 50 and 100 ft locations along the plot side. If the southern side of the plot was selected the coordinates of the five sampling points would be 25E,50N; 50 E,100N; 75E,50N; 100E,100N; and 125E,50N.

2. At each point:

a. CANOPY COVER- use the densiometer to measure percent cover of vegetation at breast height in each of the cardinal directions, record as % cover (not % open).

b. VARIABLE RADIUS PLOT- use the cruz-all to count how many trees are "in" a variable radius plot with a basal area factor of 10. List each species, whether live or dead, and its' diameter if in the VRP.

c. look at the second hand on a watch. Sampling plane will extend 50 feet in a direction of the number of seconds shown on your watch (between 0 and 59) times six.

d. attach a measuring tape to a pin at the point

e. extend the measuring tape for 50 feet in a straight line following the above calculated bearing. The tape should lie as close to the ground as possible and vegetation surrounding the plane should be disturbed as little as possible.

f. with one person standing at the end of the sampling plane and another at the point, the clinometer should be used to measure the slope along the line.

g. along the sampling plane:

(1) in the first six feet:

(a) count all intersections between the sampling plane and any dead, unrooted woody material below nine feet. Inter sections should be divided into size classes:

i) 0-1/4 inch diameter
ii) 1/4 to 1 inch diameter
iii) 1-3 inch diameter
iv) 3+ inch diameter

a) for all intersections with pieces larger than 3 inches, measure actual diameter where intersected, perpendicular to the center axis of the piece and record as either sound or rotten.

(b) dig into litter along the ground and record intersections of wood within the litter as well as those above it

(2) between six feet and twelve feet:

(a) count all intersections between the sampling plane and any dead, unrooted woody material larger than 1/4 inch in diameter and below nine feet. Inter sections should be divided into size classes.

i) 1/4 to 1 inch diameter
ii) 1-3 inch diameter
iii) 3+ diameter

a) for all intersections with pieces larger than 3 inches, measure actual diameter where intersected, perpendicular to the center axis of the piece and record as either sound or rotten

(3) between twelve feet and twenty feet:

(a) count all intersections between the sampling plane and any dead, unrooted woody material larger than 1 inch in diameter and below nine feet. Inter sections should be divided into size classes:

i) 1-3 inch diameter

ii) 3+ inch diameter

a) for all intersections with pieces larger than 3 inches, measure actual diameter where intersected, perpendicular to the center axis of the piece and record as either sound or rotten

(4) at 15 feet:

(a) measure the height of the tallest scrub oak or tree shorter than nine feet that intersects the sampling plane between 15 and 16 feet.

(b) measure the height of the tallest other shrub that intersects the sampling plane between 15 and 16 feet.

(c) measure the depth of the litter layer or the highest dead woody fuel (whichever is greater) that intersects the sampling plane between 15 and 16 feet. Write "L" if the measurement was a litter depth and "W" if it was a woody fuel depth.

(5) at 20 feet, measure the depth of the duff layer (base of litter down to top of mineral soil)

(6) between 20 and 50 feet:

(a) count all intersections between the sampling plane and any dead, unrooted woody material larger than 1 inch in diameter and below nine feet. Inter sections should be divided into size classes:

i) 1-3 inch diameter

ii) 3+ inch diameter

a) for all intersections with pieces larger than 3 inches, measure actual diameter where intersected, perpendicular to the center axis of the piece and record as either sound or rotten

(7) at 30 feet:

(a) measure the height of the tallest scrub oak or tree shorter than nine feet that intersects the sampling plane between 30 and 31 feet.

(b) measure the height of the tallest other shrub that intersects the sampling plane between 30 and 31 feet.
(c) measure the depth of the litter layer or the highest dead woody fuel (whichever is greater) that intersects the sampling plane between 30 and 31 feet. Write “L” if the measurement was a litter depth and “W” if it was a woody fuel depth.

(8) at 40 feet, measure the depth of the duff layer as at 20 feet

(9) at 45 feet::

(a) measure the height of the tallest scrub oak or tree shorter than nine feet that intersects the sampling plane between 45 and 46 feet.
(b) measure the height of the tallest other shrub that intersects the sampling plane between 45 and 46 feet.
(c) measure the depth of the litter layer or the highest dead woody fuel (whichever is greater) that intersects the sampling plane between 45 and 46 feet

III. POINT INTERCEPT SAMPLING

1. At every 1.5 ft along the 50 ft transect (used for downed woody fuel inventory sampling)

A. note the presence of any species which would “hit” a vertical line projected from that point in the following height classes:

1. < 0.5 m
2. 0.5 - 2.0 m
3. > 2.0 m

B. Note the ground cover at that point (litter, coarse woody, bare soil)

Note: Abbreviated Brown’s lines were sampled in the spring of 2002 did not include any tallies of 1 hour or 10 hour fuels, did not include measures of duff depth, and did not include point intercept sampling

FIELD PROCEDURES- 40 X 40 cm BIOMASS PLOTS
Manuel F. Correllus State Forest
2002-2004

1. At ten randomly placed plots in each stand, harvest all fuel

    a. from 40 X 40 cm square subplots
    b. standing fuels

        (1) clip stems < 1” at base and separate into live and dead and bag separately
        (2) dry bags and contents at 70° for 4-7 days, separate leaves from woody material, weigh and record weight of contents
        (3) record weight of woody components separately:

            (a) 0-1/4” diameter
            (b) 1/4-1” diameter

    c. dead, downed fuel

        (1) collect as with standing material; after drying, separate into:

            (a) nonwoody (litter)
            (b) woody

                i) 0-1/4”
                ii) 1/4-1”
                iii) 1-3”
                iv) >3”

FIELD PROCEDURES – 1 x 1 m BIOMASS PLOTS
Manuel F. Correllus State Forest
2002-2004

I. At ten randomly placed plots in each stand, tally oak stems by species and live or dead category within diameter classes of 1/4 cm.

A. Measure basal diameters for all scrub oak stems rooted within the plot

1. Measure basal diameters

B. Measure scrub oak stems that overhang the plot but are not rooted within it

1. Determine where the stems cross a vertical projection of the plot boundary and measure diameter at this point, not the basal diameters

II. Laboratory procedures

A. Enter all data into spreadsheet

B. Using allometric equations created from data collected at Waterboro, ME determine the total weight of scrub oak in each time lag class (1, 10, 100, and 1000 hr fuels)

FIELD PROCEDURES- RELEVE
Manuel F. Correllus State Forest
2002-2004

I. RELEVE PLOT

A. Walk around entire plot (0.5 acre or 10 x 10 m) and record all species present and the strata in which they appear (herb, low shrub, high shrub and canopy)

B. For each species within each stratum assign one of the following cover classes

1. 1 (<1%, or trace)
2. 2 (1-5%)
3. 3 (5-25%)
4. 4 (25-50%)
5. 5 (50-75%)
6. 6 (75-100%)

C. Record the range in heights of each stratum

D. Record the cover of each stratum as a whole using the above cover classes

FIELD PROCEDURES- COMPLETE TREE SURVEY
Manuel F. Correllus State Forest
2004

I. For all stems > 1 in. in diameter: record the following:

A. Species
B. Diameter (in cm)
C. Live or dead
D. Vigor: (1 for good. 2 for poor) and note reason for low vigor if possible (including notes about whether vigor was low prior to fire or if likely caused by fire)
E. Crown position (D= dominant, C= co-dominant, I= intermediate, S= suppressed)
F. Number of sprouts
G. Height of tallest sprout
H. Note which stems belong to the same coppice clump