THE MODERN AND HISTORIC

FIRE REGIMES OF

CENTRAL MARTHA’S VINEYARD, MASSACHUSETTS

A Thesis Presented

By

ADAM ROBERT MOUW

Submitted to the Graduate School of the
University of Massachusetts Amherst in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE

August, 2002

Graduate Program in Organismic and Evolutionary Biology

THE MODERN AND HISTORIC

FIRE REGIMES OF

CENTRAL MARTHA'S VINEYARD, MASSACHUSETTS

A Thesis Presented

by

ADAM ROBERT MOUW

Approved as to style and content by:

____

William A. Patterson III, Chair

____

David R. Foster, Member

____

Todd K. Fuller, Member

____

Matthew J. Kelty, Member

____

Elizabeth Brainerd, Director,
Organismic and Evolutionary Biology

DEDICATION

To my wife, Alex, whose unwavering patience and encouragement makes all things possible.

ACKNOWLEDGEMENTS

I would like to thank my advisor, Dr. William Patterson for all of his tireless help. The members of my committee, Dr. David Foster, Dr. Todd Fuller, and Dr. Matthew Kelty for all their advice and assistance. Thanks to John Varkonda and the Massachusetts Department of Environmental Management for their hospitality and support.

ABSTRACT

THE MODERN AND HISTORIC FIRE REGIMES OF

CENTRAL MARTHA'S VINEYARD, MASSACHUSETTS

AUGUST, 2002

ADAM ROBERT MOUW, B.A., UNIVERSITY OF VIRGINIA

M.S., UNIVERSITY OF MASSACHUSETTS

Directed by: Professor William A. Patterson III

The goals of this project were to determine how fire and vegetation have interacted in the past 150 years in the central Martha's Vineyard, Massachusetts woodlands, and to use this information to determine what management actions could be taken to reduce both the current and future fire danger while protecting unique plant and animal communities. Data were collected from intensive and extensive vegetation sampling, as well as from the interpretation of aerial photos. Two fire regimes were defined for the area: the late historic (1850-1955) and the modern (1955-present day). Data were collected on Manuel F. Correllus State Forest (MFCSF) which comprises 5,190 acres (2,100ha) of scrub oak (*Quercus ilicifolia*), oak woodland (*Q. alba*, *Q. stellata*, and *Q. velutina*), pitch pine (*Pinus rigida*) forest, and conifer plantation (primarily *Pinus strobus, P. resinosa, and Picea glauca*) vegetation in the center of the Island. The vegetation of the Forest has been subjected to frequent wildfires for as long as records are available and was probably burned before the arrival of Europeans in the early 17th century. Using the data collected, the stands of MFCSF were grouped into six vegetation types, and six fuel types. Six custom fuel models, which are assemblies of vegetation structure data that are used by fire behavior simulations to predict fire behavior, were then created from these six fuel types. Using the fire behavior simulators, BEHAVE and FARSITE, potential fire behavior on the Forest was then evaluated.

The role of fire on central Martha's Vineyard has changed substantially since the mid 19th century, when reasonably consistent fire history data were first recorded. Prior to 1955, large (greater than 1,000 acres), frequent (recurrence intervals less than 20 years) fires controlled the vegetation patterns on the central Martha's Vineyard sand plain, the area that now includes MFCSF. Since 1955, fires on the plain have been reported more frequently, but they have been smaller (average size, less than 10 acres, 4ha) and far fewer acres are burnt each year. Fire no longer impacts vegetation at the landscape-level. This change in the role of fire has led to an increase in the cover of oak woodlands (referred to as "later developmental stages") and a decrease in scrub oak (or "young developmental stages") since 1955.

Modeling potential fire behavior using BEHAVE and FARSITE suggests that the transformation of vegetation to later developmental stages and the establishment of plantations and construction of fire roads might be expected to contribute to decreased fire occurrence on the landscape from 1938 to 1995. These results are consistent with the fire records from MFCSF. Although less fire has led to increased fuel loads, the closed canopy structure of the vegetation reduces the exposure of these fuels to wind and drying and thus the potential for catastrophic fires like those of the early 20th century. The exclusion of fire for the past 50 years has led to the development of later developmental stages and a new fire regime that will likely persist into the future.

Although the size of fires has decreased in the past 50 years, the potential still exists for large (>1,000 acres, 404ha) fires on windy, spring days before leaf-out. The effectiveness of management options, including widening fire breaks and creating modified fuel zones, was evaluated with FARSITE to determine the potential usefulness of fire and fuel breaks in stopping or slowing the spread of fire from the Forest. The simulations showed that no combination of these techniques would stop all fires from crossing onto private property, but that the combination of a 200-ft no fuel zone with a 500-ft modified fuel zone would slow the progress of large fires

and aid suppression crews in stopping fires from spreading beyond the Forest boundary. Limitations of this approach to modeling fire behavior on Martha's Vineyard are discussed.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS ... **IV**
ABSTRACT ... **V**
CHAPTER 1 INTRODUCTION ... 1
Justification ... 1
Study Area ... 2
Geology ... 2
Climate ... 3
Native Vegetation ... 3
Land-Use History ... 6
Plantations ... 9
Landscape/Fire Interactions ... 10
CHAPTER 2 METHODS ... 13
Field Sampling ... 13
Vegetation ... 13
Fuels ... 17
Historical Vegetation ... 18
Analysis ... 19
Modern Fuels ... 19
Historic Fuels ... 19
Land Cover Change ... 20
Fire Behavior Modeling ... 20
Modern BEHAVE Simulations ... 20
FARSITE ... 22
CHAPTER 3 RESULTS ... 31
Vegetation Classification ... 31
Modern Vegetation ... 31
Historical Vegetation ... 35
Fuel Classification ... 35
Modern Vegetation as Fuel ... 35
Custom Fuel Model Development ... 36
Land Cover Change ... 37
1938-1952 ... 37
1952-1995 ... 38
FARSITE Modeling of Fire Behavior ... 39
Weather Inputs to FARSITE ... 39
Modern FARSITE Results ... 40
Historic FARSITE Analysis ... 41
Simulated Fire Behavior in Decadent Pine Plantations ... 43
CHAPTER 4 DISCUSSION ... 62
Natural Vegetation Dynamics ... 62
Plantation Development: 1938-1995 ... 63
Changing Fire Behavior in the Forest ... 63
Fire Regimes ... 64
Late Historic Fire Regime (1850 - ~1955) ... 64
Modern Fire Regime (~1955-present) ... 65
Future Vegetation dynamics ... 66
Native Vegetation ... 66

Mature Plantations *67*
Young Plantations *68*
Implications for Fire Regimes 69
CHAPTER 5 APPLICATIONS FOR MANAGEMENT 74
Prescribed Fire 74
Mechanical Treatment 75
Modeling Management Techniques 76
Present-Day Fire Behavior 76
Methods *76*
Results *78*
Discussion *78*
Management Recommendations *79*
CONCLUSIONS 81
BIBLIOGRAPHY 115

LIST OF FIGURES

Figure 1.1. Geology of Martha's Vineyard 11
Figure 2.1. 1995 color infrared aerial photo of Manuel F. Correllus State Forest 27
Figure 2.2. 1998 sampling coverage for MFCSF 28
Figure 2.3. Area burnt by the 1930 and 1946 fires, MFCSF 29
Figure 3.1. Dendrogram used to classify extensively sampled stands into preliminary vegetation classes 44
Figure 3.2. Distribution of oak stands based on percent canopy cover 45
Figure 3.3. Land cover maps for MFCSF, MV, MA (1938, 1952, 1995) 46
Figure 3.4. Ordination of fuels data by stand for MFCSF 47
Figure 3.5. FARITE ignition sites for simulations 48
Figure 3.6. Sample FARSITE simulations using vegetation distribution derived from 1938 and 1952 aerial photos 49
Figure 4.1. Pitch pine forests on MFCSF 70
Figure 4.2. Highly flammable vegetation 71
Figure 5.1. Ignition sites for exterior buffer simulations 83

LIST OF TABLES

Table 1.1. Major fires of Martha's Vineyard, 1855-1999 ... 12
Table 2.1. Data sets used to calculate inputs to BEHAVE ... 30
Table 3.1. Summary information for preliminary vegetation types ... 50
Table 3.2. Higher plants identified in or near relevés in MFCSF ... 51
Table 3.3. Input parameters to BEHAVE ... 53
Table 3.4. Comparison of custom fuel models generated by NEWMODEL routine of BEHAVE ... 54
Table 3.5. Fire behavior results generated from TESTMODEL routine of BEHAVE compared with standard fuel models ... 55
Table 3.6. Acreage by vegetation type from photo interpretation for MFCSF ... 56
Table 3.7. Annual rates of change (acres/year) between vegetation types, 1938-1995 ... 57
Table 3.8. Days with potential high fire behavior based on fire weather data for April 1994 and March-April, 1995 ... 58
Table 3.9. Results of FARSITE simulations for 1938, 1952, 1995 fuels, showing area burnt, fire perimeter and spotting across MFCSF northern boundary ... 59
Table 3.10. Comparison of input values for custom and standard fuel models and compiled fire data for FARSITE simulations in old plantations ... 60
Table 3.11 Results of FARSITE simulations ... 61
Table 4.1. Comparison of fire regimes for central Martha's Vineyard ... 72
Table 4.2. Species found primarily in plantations and disturbed areas. ... 73
Table 5.1. Exterior fire break simulations, FARSITE ... 84
Table 5.2. Interior fire break simulations, FARSITE ... 85

LIST OF APPENDICES

APPENDIX A. Planting record for MFCSF, 1926-1965 ... 86
APPENDIX B. Fire effects on the common species of MFCSF ... 87
APPENDIX C. Field procedures downed-woody fuels inventory procedures ... 91
APPENDIX D. Data sheets for extensive field surveys. ... 102
APPENDIX E. Aerial photo vegetation classification key ... 103
APPENDIX F. TESTMODEL outputs from BEHAVE ... 104
APPENDIX G. Weather data collected at 1300hrs. at MFCSF headquarters for April 1994 and March-April, 1995. ... 109
APPENDIX H. Transition matrices ... 110
APPENDIX I. Reordered AGGLOM data. ... 113

CHAPTER 1 INTRODUCTION

Justification

The goal of this project is to examine the historic and modern vegetation dynamics and the interaction of vegetation and fire for the central Martha's Vineyard, Massachusetts woodlands. This information will then be used to identify historic and modern fire regimes and to determine what management actions could be taken to reduce both the current and future fire danger. It is necessary to understand both the historic and modern fire regimes to determine what effect historic fires have had on the development of Martha's Vineyard's current vegetation, as well as the effect of fire suppression on endangered species' habitat.

A fire regime is a description of the distribution of fire on a landscape including factors such as ignition source, severity, return interval, intensity, size of the fire, and environmental factors such as climate, vegetation, and topography (National Advanced Resource Technology Center, 1997). A fire regime can be defined from a single fire and there is no minimum time period necessary. Fire regimes can be altered by changes in climate and land-use; and for areas such as Manuel F. Correllus State Forest (MFCSF) on Martha's Vineyard, that have been continually impacted by humans over the course of centuries, several historic fire regimes are possible. It is important to determine historical and prehistoric fire regimes as early Colonialists, and before them Native American Indians, used fire as a tool for clearing land on the Island. Knowledge of the historic role of fire will aid in determining the possible effects of future management (which may mimic historic influences, i.e. the return of large-scale disturbance) prior to implementation (Stevens, 1996). Since the establishment of a large publicly owned preserve – MFCSF - in 1908, fires have been fought vigorously and, since the late 1940s, fire has been removed as a major disturbance process on the landscape. The suppression of fire is thought to have led to increased fuel loading (Rivers, 1997). By identifying the current and past fire regimes, this thesis will determine how vegetation distribution has been affected by changes in the fire regime and how changes in vegetation distribution may have affected predicted fire behavior.

A current concern of the Massachusetts Department of Environmental Management (DEM), which manages the Forest, is to reduce fire danger to adjacent residential property through the creation of buffer zones along the Forest's boundaries. The effectiveness of these buffers in protecting surrounding areas can be evaluated through modeling.

Several endangered species, such as the barren's Metarranthis (*Metarranthis apiciaria*), are unique to sandplain vegetation like that of MFCSF (Goldstein, 1997). Several species, especially of lepidoptera, have been in decline over the past century (Goldstein, 1997). Species/habitat associations may develop over many generations, and to the extent that fire is an enduring component of the environment, historic fire regimes have probably impacted these associations. Comparing historic fire regimes to modern ones will allow conservation biologists to determine how variations in fire frequency, severity, and intensity could result in alterations to endangered species habitat.

Study Area

Geology

Manuel F. Correllus State Forest is located in Duke's County on the 100mi^2 (259km^2) island of Martha's Vineyard, six miles (10km) off the south coast of Cape Cod, Massachusetts (Figure 1.1). The Forest occupies glacial outwash deposits in the center of the Island. Topographic variation is low, with the landscape gradually sloping toward the Island's south shore. The terminal moraine of the Pleistocene glaciation intersects the northeast corner of the Forest and is overlain by outwash deposited as the glacier retreated. The remainder of MFCSF is underlain with pro-glacial outwash composed of interbedded sand and gravel (Oldale and Barlow, 1986). The only areas with slopes greater than five percent outside of the northeastern corner of the Forest are the slopes of a series of north/south trending valleys. It was first believed that these valleys were the result of post-glacial erosion of sand and gravel during the Holocene, but recent work by Uchupi and Oldale (1994) suggests that the gullies are the result of ground water seepage (spring sapping) during deglaciation (Figure 1.1).

There are three substrata underlying MFCSF; moraine outwash, moraine outwash underlain by moraine deposits, and undifferentiated sand and gravel created by ground water seepage (Figure 1.1). Soils in the northeast corner of the Forest are derived from the moraine outwash underlain by moraine deposits. The outwash, which underlies over 90% of the Forest, is differentiated sand and gravel without large cobbles, whereas the moraine deposits are less differentiated and do contain larger cobbles and boulders. The gullies created by ground water seepage are comprised of undifferentiated sand and gravel without large cobbles. All of these substrata have high permeability and low water-holding capacities (SCS, 1986).

Climate

The climate of Cape Cod and the islands (Martha's Vineyard, Nantucket, and the Elizabeth Islands) is humid continental with a moderate-to-large annual range in temperatures. There are well-developed winter and summer seasons, and precipitation is plentiful in most months (Patterson, 1983). Average monthly precipitation ranges from 4.7 inches (12.1cm) in November to 2.9 inches (7.5cm) in July (Stormfax, 1990). Although precipitation is evenly distributed throughout the year, periods of drought, lasting several weeks to a few months, are not uncommon (Stormfax, 1990). Humidity levels are typically high, but in the spring, dry days with low humidity and high winds are not unusual. Snow cover occurs during the winter, but it does not persist for extended periods. Temperatures are moderated somewhat by maritime influences. Winds are most commonly from the southwest in the summer and from the northwest during the winter (SCS, 1986). Thirty-year averaged weather data for Martha's Vineyard indicate that July is the hottest month with an average temperature of 69.8ºF (20.9ºC), and January is the coolest (average temperature of 29.3º F (-1.5ºC) (Stormfax, 1990).

Native Vegetation

MFCSF is comprised of 5,190 acres (2,125ha) of scrub oak (*Quercus ilicifolia* and *Q. prinoides*) thickets, oak woodlands (*Q. alba*, *Q. stellata*, and *Q. velutina*), pitch pine (*Pinus rigida*) forests, and plantations (primarily *Pinus strobus, P. resinosa, and Picea glauca*) representing approximately ten percent of the total area of Martha's Vineyard (Figure 1.1). The area of the Forest north of Edgartown-West Tisbury Road is divided into 31 compartments, each approximately 150 to 200 acres (62.5ha to 83.2ha) in size. Dirt roads delimit the perimeter of each compartment and allow access to the interior of the Forest in the event of a fire. The Pohogonot tract, the area of MFCSF south of Edgartown Road, was purchased in 1995 and has not been divided into compartments (Foster and Motzkin, 1999).

The plant associations of MFCSF are typical of sandplain vegetation communities which are found throughout the Northeast on xeric, nutrient-poor sites (Finton, 1998). Examples are the pine barrens of New Jersey; Long Island and Albany, New York; southern Maine; the Connecticut Valley; and the pitch pine-scrub oak woodlands of Cape Cod (Olsvig, 1980 and Finton, 1998). Common species are pitch pine, huckleberry (*Gaylussica baccata*), scrub oak, sweet fern (*Comptonia peregrina*), wintergreen, (*Gaultheria procumbens*), bracken fern (*Pteridium aquilinum*), and blueberry (*Vaccinium* spp.) (Finton, 1998). Sandplain communities are rapidly being lost to development in the Northeast (Finton, 1998). Cryan (1985) estimated that less than half of the historic acreage of sandplain vegetation remains.

Sandplain communities, and those of MFCSF in particular, provide habitat for many endangered species. Recent efforts have catalogued over 25 species of rare and endangered lepidoptera inhabiting the sandplains of Martha's Vineyard. Many of these are obligate sandplain inhabitants. Five species of fritillary butterflies have been extirpated from the Vineyard in the past 40 years (Goldstein, 1997). The barren's Metarranthis (*Metarranthis apiciaria*) is currently found only on the sandplains of Martha's Vineyard. Goldstein (1997) suggests that the presence of frost bottoms - areas of extreme temperature fluctuation due to rapid elevation changes - plays a major role in sustaining these endangered populations which are increasingly at risk due to habitat loss. Frost occurs later in the spring in these bottoms than elsewhere on the Forest thereby providing immature leaves that supply a nitrogen-rich food source after the upland foliage has matured (Goldstein, 1997). Using data collected on Martha's Vineyard, Goldstein (1997) concludes that during the past 100 years, sandplain and grassland obligate species have declined at a greater rate than generalists. This corresponds with the decline in grasslands and sandplains vegetation. Lepidoptera are not the only endangered or threatened species found on MFCSF. More than ten plant species on the Massachusetts Natural Heritage Endangered Species Program Watch List can be found in the upland portions of the Forest (Goldstein, 1997). Threatened avian species, such as the short-eared owl (*Asio flammeus*) and the northern harrier (*Circus cyaneus*), also occur in the Forest (Rivers, 1997).

Many sandplain communities are disturbance dependant (Patterson, 1999; Little, 1979). Historic fire return intervals in pitch pine/scrub oak vegetation are less than 50 years (Oliver and Larson, 1996). Longer return intervals result in increased dominance by more mesic hardwood forests. Short return intervals are atypical of New England forests and make sandplain communities unique among northeastern vegetation types (Patterson et al. 1983; Chokkalingam 1995, Foster and Motzkin, 1999). The historic return interval for fire in New England ranges from 150 to 800 years, much longer than for most western and southeastern United States (Oliver and Larson, 1996).

Wind, in the form of hurricanes and severe thunderstorms, is an important factor influencing the disturbance regime of New England forests (Boose et al., 1994). Although some damage can occur, the native vegetation of MFCSF is not affected by wind to the same degree as are plantations. Analysis of wind damage from Hurricane Bob in 1991 showed no damage to scrub oak stands and little damage to hardwood and pitch pine forests on MFCSF (Foster and Motzkin, 1999). Broken crowns and uprooted trees were common in old plantations of all species with plantations of white and red pine especially heavily damaged. The estimated return interval for storms capable of causing this level of damage is 30 to 40 years, well within the life span of these pines (Boose et al., 1994; Foster and Motzkin, 1999). These storms are the most common stand-replacing events in the Northeast.

Most fires on the New England landscape, both current and historical, are anthroprogenic in origin (Patterson and Sassman, 1988). Although lightning fires are common in other parts of the country, thunderstorms in New England are typically accompanied by rain, which limits the spread of fires that do occur. At Cape Cod National Seashore (CCNS), for example, there have been no lighting originated fires since its establishment in 1960, while there have been over 400 human-caused fires (Patterson et al., 1983; and data on file at CCNS).

Anthroprogenic fire has shaped the landscape of New England since before European settlement (Bromley, 1935; Day, 1953; Patterson and Sassman, 1988). Native Americans used fire as a tool for clearing understory vegetation and providing new vegetation to support game species such as white-tailed deer (*Odocoileus virginianus*) (Bromley, 1935 and Day 1953) although it is not known if this occurred on the central sandplain of Martha's Vineyard (Stevens, 1996; Ruffner and Patterson, 1999). Fire was also employed to clear areas for agriculture and to protect Native American settlements from wildfires (Pyne et al., 1996). Evidence from hearths shows that Native Americans in New England were utilizing fire as early as 12,000 years BP, although it is unclear when the practice of setting fires for hunting and agriculture purposes began (Patterson and Sassman, 1988).

Land-Use History

M. F. Correllus State Forest was established in 1908 as a reservation for the last remaining population of the heath hen (*Tympanuchus cupido*), a race of the prairie chicken. The Forest was managed as habitat for heath hen until its extinction in 1932 (DEM, 1994). Through the course of the next 70 years, additional lands were purchased to bring the total acreage to 5,190 acres (2,100ha). Beginning in the 1920s and continuing through the early 1990s, approximately 1,700 acres (688ha) were planted with conifer species in an effort to provide timber for island industry. Due to the droughty soils, periodic fires, and insect and disease infestations, many of these plantations failed. The plantations are no longer expected to generate income for the Commonwealth of Massachusetts and are recognized as economic failures (Rivers, 1997).

Historical documentation suggests that by the early 17th century there were between 3,000 and 3,500 Native American inhabitants on Martha's Vineyard (Richardson, 1985). Historical and archeological evidence for areas of mainland New England suggests that Martha's Vineyard supported a greater Native American population density than typically occurred on the mainland (Stevens, 1996). Owing in part to this high density of Native Americans, fire has been an important environmental variable on Martha's Vineyard since before the time of European settlement. Evidence for this comes from Stevens's (1996) fire history studies, which show a decrease in charcoal content of sediments for parts of the Island after European settlement. This implies a decrease in fire occurrence with the arrival of Europeans. Sedimentary analyses were not possible on MFCSF, because it lacks permanent water bodies.

European settlers reached the Island in the early 17th-century, and by 1670 there were 180 Europeans living on Martha's Vineyard. At this time, the Native American population was in decline due to disease (Foster and Motzkin, 1999). Through the colonial period, agriculture and grazing resulted in the clearing of much of the woodlands on Martha's Vineyard. Although agriculture was extensive, there was little cultivation on the glacial outwash in the center of the Island (Foster and Motzkin, 1999). The area that now comprises MFCSF was, however, probably cut repeatedly for fuelwood during the colonial period (Foster and Motzkin, 1999).

Although it is clear that sandplains were used extensively for grazing, timber, and industry (primarily pine tar) once settlement began, there is some disagreement as to the vegetation of Northeastern sand plains during the early colonial period. Some evidence suggests that oak savannas - tree oaks with a primarily grass understory - were present on the Island (Stevens, 1996). The modern barrens vegetation is believed to be the product of historical disturbances, especially fire (Whitaker, 1979; Milne, 1985). Extensive oak savannas occurred in the Midwest, but it has never been shown that they existed in the Northeast (Carey, 1994). Although pollen studies of lagoon sediments suggest that grass was important in the near coastal environment, (Stevens, 1996), forest history studiessuggest that pitch pine and scrub oak were dominant on the central plains (Foster and Motzkin, 1999). The presence of highly specialized, scrub-dependant, lepodoptera such as the buck moth (*Hemileaca maia*) suggest that the barrens may have existed for millennia in much the same composition as the modern vegetation (Schweitzer and Rawinski, 1988), although there is little historical data to corroborate this theory. Stevens (1996) concludes that, based on pollen evidence, the "historic landscape of Martha's Vineyard was characteristically forests and woodlands dominated by oak or mixed oak-pine, and occasional pine-dominated stands, interrupted by localized grassy clearings associated with Indian land uses along the shorelines of coastal ponds."

Colonial era landuse opened much of the landscape to agricultural fields and pasture. Agriculture abandonment and a shift to coal rather than wood as the primary fuel source in the middle of the 19th century allowed much of Martha's Vineyard to revert to woodland in the early and middle 20th century (Dunwiddie, 1994; Foster and Motzkin, 1992). Although MFCSF was still used as a source of firewood, the effects of logging on the Forest were reduced by the early 20th century (Foster and Motzkin, 1999). The establishment of the Forest in 1908 prevented fragmentation of the central sandplain, but the development boom of the past 40 years has created a fragmented landscape as well as an overall loss of forested acres elsewhere on the Island (Foster and Motzkin, 1999).

Following establishment of MFCSF, fire was fought vigorously with limited initial success. Fires greater than 1,000 acres (417ha) in size are recorded as having occurred 16 times from 1867 to 1929 on the Island as a whole (Table 1.1, derived from Foster and Motzkin, 1999). Many of these originated in or burned through the droughty central regions of the Island. Large fires in the 1920s are thought to have been a contributing factor in the extinction of the heath hen (Adams, 1992). Since the last large fire in 1954, improved fire fighting equipment and techniques have limited fire occurrence on MFCSF. The paucity of fire on the Forest in the past 50 years is believed to have allowed standing and downed fuels to build up to levels that would make fighting a fire in the Forest difficult (DEM, 1994).

Plantations

Plantations comprise one-third of the total acreage of MFCSF. White, red, and Scots pine and white spruce were the principal species planted. Planting began in 1925 when a seedling nursery was developed (Appendix A). By 1941, 600 acres (243ha) of plantations had been established, primarily by hand, in native scrub oak vegetation. No new plantations were established from 1942 to 1963, but between 1963 and 1967, 627 (254ha) additional acres of conifers were planted, primarily by machine (Foster and Motzkin, 1999). A "Lother" planting machine was pulled through native vegetation and created a furrow in which the seedlings were planted. Although the machine knocked down the standing stems of native species, there was little mortality and the native vegetation was left largely intact (Foster and Motzkin, 1999). Planting activity on the Forest waned in the 1970s, with only a few research plots established. Limited planting continued through the early 1990s, but has now ceased. There are no current plans to plant non-native conifer species on the Forest (DEM, 1994).

Species planted were generally ill-suited for sites in the Forest and required a great deal of effort to maintain. Between 1930 and 1960 management focused on eliminating the white pine weevil (*Pissodes strobi*) and pruning young plantations. Beginning in the 1960s, the red pine plantations were infected with *Diplodia pinea*, a fungal pathogen. These areas began to die and salvage operations were begun in the 1970s. Other species have suffered defoliation or stem mortality from a variety of pathogens (Foster and Motzkin, 1999).

The original goal of establishing plantations was to provide timber for local markets and forestry businesses. A local market never developed, however, and without on-Island markets and given the prohibitively high cost of transporting equipment and timber to and from the mainland, the plantations have never been economically successful (DEM, 1994). Programs have been designed to promote private companies' use of the timber (e.g. utilizing pine stems for replacement utility poles), but the amount of timber harvested has always been small (DEM, 1994).

Landscape/Fire Interactions

Topographic variation of the Forest is low, and although topography can have a large influence on fire behavior in the Western United States, steep slopes do not contribute to wind generated (accelerated) fires on the Atlantic coastal plain. The gullies created by spring-sapping do increase the potential for severe fire behavior, but this is primarily due to the mixed scrub oak/grass/forb vegetation they support and not topography. The effect of these gullies on fire behavior is limited by their spatial distribution. Although the gullies can extend for up to one mile (1.6km) in length, their maximum width is considerably less – only a few tens of yards/meters – and they represent less than 1% of the total area of the Forest. However, the lack of topographic variation on the Forest does influence the way fires spread across the landscape. Although areas of extreme slope can promote fire spread, hilly terrain provides barriers to fire expansion. The lack of such barriers on MFCSF has allowed large fires to spread through the broad expanses of scrubby vegetation.

The maritime climate of Martha's Vineyard affects the behavior of fires burning in MFCSF. The two weather factors that have the greatest influence on fire behavior are wind and moisture (in the form of precipitation and humidity). Wind direction varies on a daily basis, but tends to be from the south/southwest during peak fire season. Following precipitation, strong winds can dry fuels quickly and promote rapid fire spread once an ignition occurs.

Soils affect vegetation type and fuel moisture - two important factors influencing fire behavior. The glacial outwash underlying most of the Forest consisted of sand and gravel (Oldale and Barlow, 1986) which favor flammable ericaceous plant species (Appendix B). Coarse soils retain little water and create droughty soil conditions which allow for easier ignition and fire spread. Although precipitation is common in all months, the combination of strong winds and droughty soils can result in rapid drying of fuels. In addition, during dry periods, fuel moisture levels can drop to very low levels. Low relative humidity, especially in the spring, facilitates rapid evaporation and drying of fuels.

Figure 1.1. Geology of Martha’s Vineyard

, modified from Oldale and Barlow (1986)

Table 1.1. Major fires of Martha’s Vineyard, 1855-1999

CHAPTER 2 METHODS

Field Sampling

Vegetation

Data used to define modern fire regimes were collected from a variety of sources. Field sampling during the summers of 1996 through 1998 incorporated both extensive and intensive characterizations of vegetation and fuel bed characteristics. Detailed procedures are outlined in Appendix C. Extensive sampling involved stand surveys (Appendix D). All stand types were initially mapped from aerial photographs (1995/color infra-red/1:12,000) with interpretations by Janice Stone of the University of Massachusetts Resource Mapping Unit of the Department of Forestry and Wildlife Management on the basis of canopy height, canopy cover, and, where possible, dominant canopy species. The Forest's 31 compartments were delineated into 635 stands (Figure 2.1). From these, 110 were selected for sampling, with at least the three largest stands in each compartment sampled (Figure 2.2). In those compartments where greater than 60% of the total compartment acreage is contained within three stands, additional stands were not sampled, and the extra time was used to increase total sampled acreage in compartments where three stands comprise <60% coverage. The 600-acre Pohogonot Tract is not divided into compartments (Figure. 1.1), so eleven additional stands comprising 80% of the tract were sampled. Acreage of individual stands was estimated using a dot grid.

The purpose of the extensive surveys was to collect basic data - species cover and vegetation structure – from as much of the Forest as possible. These data were used to field check the vegetation classification based on the 1995 aerial photo interpretation (Appendix E). Data were also collected so that they could be used in BEHAVE's NEWMODEL to create custom fuel models (Burgan and Rothermal, 1984).

BEHAVE is a program used to estimate wildfire parameters such as rate of spread, flame length, and fireline intensity. The program allows the user to chose from 13 standard fuel models (Anderson, 1981) or to create custom fuel models based on local fuel parameters using the

NEWMODEL section (Burgan and Rothermal 1984; Anderson, 1986; Anderson and Chase, 1989; Del'Orfano, 1996; Patterson, 1999). Custom fuel models combine vegetation data (e.g. shrub height) and fuels data (e.g. fuel loading) which, when run with BEHAVE, yield estimates of fire behavior parameters.

Extensive field sampling proceeded as follows. An initial plot was located near the center of a stand. There a relevé (Mueller-Dombois and Ellenberg, 1974) with a radius of approximately 10m was sampled with species recorded in four strata: grass and forbs, low shrubs, high shrubs, and canopy. Each species in each stratum was assigned to a cover class: 1 (>1%), 2 (1%-5%), 3 (5%-25%), 4 (25%-50%), 5 (50%-75%), or 6 (75%-100%). One of these cover classes was also assigned to the stratum as a whole. From the initial relevé location, nine additional plots were selected for sampling. Each was located approximately 45m from the previous sample point. The azimuth from one point to the next was determined randomly by glancing at the second hand of a watch and multiplying the seconds by six. If the direction was within 60° of the return path to the previous sampling point, a new azimuth was chosen. Repeated use of this process assured random, but reasonably complete, sampling of the stand as a whole.

At each plot, in addition to the relevés, several environmental and vegetation variables were also sampled (Appendix D). The presence of an Ap (plow) horizon was determined using a soil auger. Slope was measured with a clinometer and aspect was recorded as a cardinal direction to the nearest 45º. Slope and aspect affect fire behavior and are inputs to the Fire Area Simulator (FARSITE). FARSITE is a computer program in which fire can be simulated using BEHAVE fuel models and site-specific data. On plots of approximately $1m^2$ centered on each point, the height of each understory vegetation layer was measured with 10cm precision. Understory and litter cover were estimated to +/-10%. Canopy cover was determined using a spherical densiometer by averaging measurements taken at each of the four cardinal directions (N, S, E, and W). Canopy height and height to the base of the live crown, which are inputs to FARSITE and are used to determine crown fire potential, were estimated to the nearest 1.5m. Basal area was determined using a Cruz-all with either a 5 or 10 ft^2/acre ($1.15m^2$/ha or $2.30m^2$/ha) basal area factor so that at least ten stems were recorded at each point. For pines, both dead and live individuals were recorded, and for oaks both total stems and stems that were part of coppice stumps were recorded. The purpose of recording both live and dead pine stems was to determine the health of plantations. The health can be inferred from measures of canopy cover, but variations in canopy cover from stand to stand could also be the result of different planting patterns.

For oaks, Foster and Motzkin (1999) noted that many Martha's Vineyard oak stems are from what appear to be ancient stools and are an unusual feature for a New England forest. They suggest that it would be beneficial to understand more about their distribution. Oaks were considered part of coppice stumps if the stems were in close proximity and appeared to intersect at or below the soil surface. Stems that split into multiple stems above the litter layer were not considered to be of coppice origin. They represent multiple stems from the same sprout, whereas stems that intersect below the litter layer appear to be multiple sprouts from a common root collar. The purpose of recording coppice versus single oak stems was to determine which oak stands had established primarily vegetatively after repeated disturbances, typically harvesting or fire, and which stands might have been established primarily from seed. A high percentage of coppice stems in a stand might suggest a history of disturbances that killed above-ground stems while leaving the root collar intact.

Special attention was paid to finding new species between sampling points, and a list of all species occurring within each stand was compiled. The purpose of recording species not present on individual plots was two-fold. First, by recording less common species, I hoped that both invasive and rare species could be identified. Little is known about the distribution of such species on MFCSF outside of fire lanes (Foster and Motzkin, 1999). This information will be useful in discussions of future management options and in evaluating the effects of past management practices. Second, by observing species distributions throughout the stand, it was possible to determine if the relevé was an accurate representation of the stand as a whole.

The stand surveys were an efficient method of sampling a large percentage of the Forest. With the data, I hoped to merge more than 100 stand classification groups used in the aerial photo interpretation into a more manageable number of vegetation classes (preferably fewer than ten) to produce a landscape-level vegetation map. This was necessary to develop meaningful conclusions about spatial and temporal variations in vegetation. With over 600 stands represented by over 100 classes on a vegetation map, it is difficult to identify broad patterns that might influence fire pattern at a landscape scale.

Vegetation types were defined by classifying stands using species presence and distribution data collected from the 121 relevés. This was done by creating a hierarchical dendrogram with AGGLOM, a FORTRAN program that defines vegetation groups at one level as subclasses of higher levels (Patterson et al., 1983). AGGLOM uses a matrix of importance values to group relevés according to species similarities. Each relevé is positioned in N-dimensional hyperspace, where N equals the number of species for the suite of relevés. The dendrogram is then created by sequentially measuring distances between points and then between the centers of successively larger groups of points. Absolute (Euclidean) distance was used as it emphasizes species abundance for which I had information in the form of Braun-Blanquet cover classes. This method reduces the contribution of species with low importance values (e.g. moss and lichens) when creating the divisions (Patterson et al., 1983). To obtain input values for AGGLOM, I had to reduce the up-to-four values per species per relevé (one for each vegetation strata) to a single value. This was accomplished by the following method. A value of one (1) was given to each species present, then the cover class values (1 through 6) for all vegetation layers was added to one (1) with one (1) subtracted for each layer in which the species occurred. Thus a species with minimal cover (i.e. <1%) in one stratum would have a value of 1 (1+1-1=1). A species with cover of 5%-25% (3) in the forb layer, 1%-5% (2) in the low shrub layer, 25%-50% (4) in the high shrub layer, and 0% (0) in the canopy would have a value of 1+3+2+4+0-3=7 (method modified from Clark and Patterson, 1985; Motzkin et al., 1993; Motzkin et al., 1999). The resulting dendrogram was then used to classify stands into vegetation classes.

Fuels

Determining fuel loads is more time intensive than determining vegetation heights and covers, so ten stands representing the range of fuel conditions in the Forest were selected for intensive sampling. This intensive sampling involved downed woody fuel inventories (modified from Brown, (1974) Appendix C); harvesting 40cm by 40cm plots for mass of litter, herbaceous, and low shrubs; and sampling 1m by 1m scrub oak plots for mass of live and dead scrub oak stems (Patterson, 1999). The stands selected were at least five acres (2ha) in size so that the 20 points of the down-woody fuel inventory did not cross stand boundaries. By selecting stands that had been previously extensively sampled, it was possible to extrapolate results from the 10 intensively sampled stands to stands with similar characteristics sampled as part of the extensive sampling.

Litter, herb, and low shrub loads were determined by removing live and dead plant material from plots delineated by a randomly located square frame of PVC pipe with internal dimensions of 40cm by 40cm. Ten plots were sampled in each of ten stands. Plots were located approximately 30m apart using the random azimuth method described above. Once a point was located, the square was placed flush on the litter surface. Except for scrub oak, which was not sampled at these plots, all stems were cut at the humus surface and placed into one of two bags (for low shrubs or herbs). All litter, including downed wood, was placed in a separate bag. Samples were dried in a convection oven at 70°C for at least 72 hours and, once dried, weighed by category [live wood, live herbs, non-woody dead material (litter), and dead wood by diameter class - 0-0.64cm, 0.64-2.54cm, 2.54-7.6cm, and >7.6cm, corresponding to 1-, 10-, 100-, and 1000-hour time lag classes of fuels]. Weights were recorded to the nearest 0.1gm and converted to tons per acre. English units were used, as these data are inputs to BEHAVE and managers in the United States are unfamiliar with metric outputs as descriptors of fire behavior.

It was necessary to sample scrub oak stems separately because their size and clumped distribution made sampling them on 1600cm^2 plots impractical. Ten plots were randomly located at ten randomly selected points in each of the ten stands. A square PVC pipe frame, 1m by 1m, was placed flush against the litter surface. The basal diameters of scrub oak stems rooted within the frame were measured to the nearest 0.25cm. Using allometeric equations derived from data collected at Waterborro, ME (Patterson, 1999), I estimated the dry weight of scrub oak fuels by time-lag class (1-, 10-, and 100-hr fuels). These data were then combined with those from the 40cm by 40cm plots to determine the total shrub and litter mass by fuel size class.

All data were entered into computer spreadsheets. For downed woody fuels, a template was used to calculate fuel loads and fuel heights following procedures in Brown (1974). Constants were available from Patterson (Patterson, 2000).

Historical Vegetation

The primary sources of data for historical vegetation are aerial photos from 1938 and 1952. These photos were interpreted by Janice Stone using the same mapping criteria as for the 1995 photos. Nineteenth century documents from the area describe the Plain as looking much the same as it did in the early 20th century – a field of dense, scrubby oak (Foster and Motzkin, 1999). Because anthropogenic impacts on the Plain during the late historic period (~1850-1955) were similar in type, primarily logging and wildfire, photos for 1938 are probably representative, in a general way, of vegetation in the area during 1850-1940. There are, however, no species data for the period, so the historical vegetation map was created solely from the aerial photo interpretation.

I collected information about vegetation (cover types and their aerial extent), fuels (to the extent that they can be interpreted from vegetation) and fire occurrence in order to define historic fire regimes for the period 1850-1955 (Table 1.1). GIS ARCVIEW maps are also available from Harvard Forest for the 1930 (5,000 acres, 2,023ha.) and 1946 (300 acres, 121ha.) fires (Figure 2.3).

Analysis

Modern Fuels

In order to classify stands based on fuel characteristics, ordination analysis were performed using PCORD. PCORD creates a visual representation of the relative relationships between data sets, in the case of this study, stands. The power of the program is that these relative relationships are based on multiple variables.

Detrended correspondence analysis (DCA), a type of ordination, was used to compare the ten intensively sampled stands using fuels data collected from the downed woody fuels inventory, the 40cm by 40cm biomass plots, and the 1m by 1m scrub oak biomass plots. This analysis was performed to determine if the stands were unique with respect to fuel characteristics. The stands were initially selected because they appeared to represent the primary vegetation types, but I had to determine if types had different fuel characteristics or if two or more vegetation types shared similar fuel characteristics. This information was needed to convert the vegetation map to a fuels map for use in FARSITE.

A second DCA was performed with data collected from the extensive sampling of stands: percent cover and heights for grasses and forbs, low shrubs, high shrubs, and canopy, as well as percent cover for litter, height to the base of the live crown and total basal area. The purpose of this ordination was to determine how the 121 sample stands vary with respect to fuel characteristics not sampled on the intensively sampled stands. Based on these ordinations, I hoped to identify associations between the extensively sampled and the intensively sampled stands so that I could reclassify the 121 stands into fewer than about 10 fuel categories. Data from the intensively sampled stands were then used to create custom fuel models from the reduced set of fuel categories.

Historic Fuels

Once fuels models were developed based on modern vegetation/fuel associations, stands delineated from historic photos were assigned fuel models. A lack of description of historic fuels based on field sampling required that I assume that stands that looked similar on old air photos had similar fuel characteristics. I assumed, for example, that stands classified as scrub oak in 1938 and in 1952 have fuel loads similar to scrub oak stands sampled in 1996-98, and that fuel bed characteristics did not change, except following fire, throughout the historical period. Differences in fuel bed characteristics between the two periods would most likely be due to differences in how long it had been since stands had burned. Modern stands have generally not burned for several decades, but those from the earlier period burned with shorter return intervals, so if anything, fuel loads of historic stands may have been lower that those I measured. Nelson (2001) has shown that scrub oak fuel beds recover to preburn conditions within about five years, however, it does not appear that most historic stands burnded more frequently than that (Table 1.1).

Land Cover Change

For the 1938m 1952, and 1995 photo interpretation, Janice Stone developed transition matrices that document changes in vegetation for the periods 1938-1952, 1952-1995, and 1938-1995. These transition matrices were used to evaluate how vegetation development and changes in fire regimes are related.

Fire Behavior Modeling

Modern BEHAVE Simulations

After grouping MFCSF stands based vegetation/fuel characteristics, fuel parameters were averaged within categories and custom fuel models were developed. Inputs to NEWMODEL include 1-, 10-, 100-hr litter and shrub loads, liter and shrub cover, litter and shrub depth, live 1-hr fuel loads, surface-area-to-volume ratios for 1-hr litter, 1-hr shrub, and live woody fuels, and heat content for dead fuels and live leaves and twigs.

Data sets used to develop custom fuel models are listed in Table 2.1. I had to calculate a total (the sum of low and high shrubs) shrub height and cover, as BEHAVE does not allow entering parameters for separate shrub strata. For cover, a single value was calculated by taking the average cover for each stratum, plus the covers of both strata and dividing the result by two. For example, if the low and high shrub covers for a stand were 50 and 70 percent respectively, then the total shrub cover would be [50+70+(50+70)/2]/2 or 90% cover. This method assumes that there is some overlap between the two layers so that the calculated value is less than the sum of the individual covers but greater than the average of the two. To more accurately determine overlap, future field observations should include percent cover of the high and low shrub strata both separately and as total shrub cover.

For shrub height, BEHAVE requires average shrub height, a value that is usually calculated as 70% of measured shrub height (Burgan and Rothermal, 1984). To use this conversion factor, high shrub height must have been calculated as the height of the tallest branch within the sample area not the "average height of the high shrubs" (Burgan and Rothermal, 1984). Because shrub heights I collected represent the average height of the high shrubs and not maximum height, this conversion factor was not needed.

BEHAVE calculates a single fuel depth as the average of all litter, grass, and shrub height measurements, corrected for the cover of each. Litter on MFCSF typically comprises 75% of the total fuel weight in a stand and has a cover approaching 100%. Because fuel depth is weighted for cover, errors in measuring litter depth substantially impact the overall fuel depth. Errors in estimating the heights for the shrub layer are often minimized by low cover values, but for litter this is not the case.

Dead, downed material is defined for BEHAVE as either litter (dead, downed non-woody material) or slash (dead, downed woody material above the litter). Two categories are defined, because BEHAVE was designed primarily for use in western United States landscapes where dry conditions allow downed stems to persist and build up on the ground and where much of the downed wood is slash (i.e. "activity fuels"). Downed stems on MFCSF decompose quickly and are rapidly assimilated into the litter (when compared to western United States environments), so all material, both woody and non-woody, was considered to be litter. Calculating litter depth using only those data where a leaf was the highest downed material results in predictions of fire behavior that differ substantially (i.e., 50% or less) from fire behavior observed by Woodall (1998) (Patterson, pers. comm.). Models created using this method typically have moistures of extinction greater than 50%, well over the 25% observed in the field (W. Patterson, unpublished data). For this reason, I calculated average litter depth based on the woody and non-woody material, whichever was greater. At the same time, I did not enter values for the "slash" component into the model.

Once custom fuel models were created, they were compared to outputs of several of the 13 standard fuel models (Andrews, 1986) using the TESTMODEL subsystem which provides estimates for rate of spread and flame length given a standard set of environmental conditions (fuel moistures, slope, and midflame windspeed). This was done to determine if it was necessary to use custom fuel models in sandplain vegetation types, as has been suggested by Woodall (1998), Del'Orfano (1996), and Patterson (1999, 2000, 2001).

Once I identified appropriate fuel models for the Forest, each of the 635 stands on the 1995 map was assigned a fuel model. This produced a "fuels map" which was used in FARSITE simulations of landscape-level fire behavior.

FARSITE

Model Applications

One of the major limitations to using BEHAVE in a landscape-level analysis is its inability to incorporate site-specific variations in topography and time-transgressive variations in weather parameters. The Fire Area Simulator (FARSITE) program takes these variables into account when creating landscape-level simulations of fires. FARSITE was created by Dr. Mark A. Finney of Systems for Environmental Management, Missoula, Montana with funding from the National Interagency Fire Center (NIFC), Boise, Idaho and the US Forest Service's Intermountain Fire Sciences Laboratory, Fire Behavior Research Work Unit, Missoula. FARSITE integrates fuels information with local topography and weather conditions to predict fire behavior. Optional data layers that improve the predictability of the model include crown height and crown bulk density (Intermountain Fire Sciences Laboratory, 1998). FARSITE requires fuels, elevation, aspect, and slope data layers in a GIS, all at the same USGS topographic map scale.

FARSITE was developed with the goal of modeling wildfires in the western United States, so its accuracy in modeling fires on Martha's Vineyard is unknown. In particular, FARSITE requires the user to select a dominant canopy species from a list of species commonly found in the western United States. Parameters that can vary based on the dominant canopy species, such as spotting potential and crown bulk density, must therefore be estimated using tree species that do not occur on MFCSF. For every analysis, I chose the western species Douglas Fir to represent pitch pine, the dominant, flammable conifer on MFCSF. With this in mind, I evaluated FARSITE output for fires on MFCSF in the context of fire behavior observations for historic large fires that are known to have burned in southeastern Massachusetts barrens fuels.

Weather Data

One of the advantages of FARSITE is the program's ability to integrate site-specific fuels data with local environmental conditions, including weather. I collected local weather data including min/max temperatures, min/max relatively humidity, and cloud cover for use in the FARSITE simulations. These data were available from MFCSF headquarters, which had collected fire weather during April 11-30, 1994 and March 1-April 30, 1995 (Appendix G). Many of the largest fires on Martha's Vineyard have occurred in early spring when low humidity, high winds, and periods without precipitation promote extreme potential fire behavior. From the available data set, five March/April days were chosen to represent an "average worst day", a day with weather conditions that would likely result in active fire behavior. The data used in the FARSITE simulations were randomly selected from among these five.

During the day for which fire behavior is predicted, FARSITE automatically adjusts the weather conditions during the simulation based on sinusoid curves (Intermountain Fire Sciences Laboratory, 1998). These curves, which resemble sine waves, are based on minimum and maximum daily values and are used to determine specific values for weather parameters for different times of the day.

Wind speed and direction are also required inputs of FARSITE. Unlike weather data, which are entered as ranges for a day, wind data files allow for changes in windspeed every 15 minutes. FARSITE does not modify these data. Daily windspeed and direction data were also collected at MFCSF headquarters in 1994 and 1995. Wind data for selected days were used in the FARSITE simulations.

FARSITE uses canopy cover, canopy height, and wind speed data to develop wind reduction factors for each vegetation type. The canopy of a stand serves a wind shield, which can reduce the ground-level windspeeds by up to 80%. Lower windspeed can lower rates of spread significantly and the lack of a canopy contributes to the high rates of spread observed in vegetation types such as scrub oak and chaparral.

Weather data required for FARSITE (min/max relative humidities and temperatures, rainfall, windspeed and wind direction) were unavailable for the historic period. Instead, data collected on MFCSF for a two-year period, 1994-1995 were used in FARSITE simulations of fires using both modern and historic fuels maps. Weather conditions used in the simulations were not extreme and such conditions likely occurred during the historic period. Using the same weather conditions in both modern and historic fire simulations facilitates comparisons between the two eras.

Modern FARSITE Simulations

Data layers were first created in ARCVIEW and then transferred to FARSITE. I created an optional canopy cover map data layer, because canopy cover influences fire behavior and varies substantially from stand to stand at MFCSF (e.g., It is zero in scrub oak stands but can exceed 75% in old plantations). High canopy cover reduces 20-ft wind speeds and shades fuels so that they dry out more slowly than exposed fuels. I calculated average cover as measured with the spherical densiometer for major cover types. A canopy cover class (0=0%, 1=1%-20%, 2=21%-

50%, 3=51%-80% or 4=80%-100%) was assigned to each stand, and the fuels map was converted in ARCVIEW to a canopy cover map.

Once a fuel map was created, it was linked to topographic maps downloaded from the USGS (http://mapping.usgs.gov). The topographic map was converted to aspect and slope data layers using ARCVIEW's spatial analyst tool. Slope and aspect can impact fire behavior in many ways, including rate of spread.

Simulations were run for ignitions at a series of sites within the Forest. Sites selected were along roads and fire lanes where the chance of human ignition is high. Several ignitions and their associated fires were generated for each location to evaluate the variability in potential burn area. Area burnt (acres) and perimeter (miles) were recorded for each run. I also noted if the fire crossed the boundary of the Forest and moved off state land. The Forest boundary was delineated as thin (30ft) no fuel buffer that represents the fire roads along the northern and eastern boundaries.

I simulated the effects of buffers and managed fuel zones by modifying sections of the fuels map files. Buffers (areas of no fuel) and managed fuel zones (areas of native vegetation that have undergone fuelbed alterations) are currently being constructed to reduce fire danger. Custom fuel models created using the results of fuel manipulation research at Cape Cod National Seashore (CCNS) (Del'Orfano, 1996; W. Patterson, unpublished data) as well as data from test plots on MFCSF (Woodall, 1998) were used to represent modified fuels. A series of simulated fires were evaluated to test the effectiveness of the buffers and managed fuel zones in decreasing spread beyond the Forest boundary. The effectiveness of combinations of management techniques in altering fire behavior at a series of ignition sites was evaluated by determining the percentage of the simulated ignitions that crossed buffers and the average time it took for the simulated fires to do that. The effectiveness of differing fuel types in preventing or delaying fires from crossing over buffers were then compared.

A concern of Forest managers is the deteriorating condition of old plantations. Because the plantations are not economically viable, stems that die are left on-site to decay. Dead, downed stems increase fuel loads and may alter fire behavior in these stands. Standard fuel models with high slash loads were used in FARSITE simulations to estimate the impacts of increased slash on fire behavior in these stands.

Historic FARSITE modeling

In addition to evaluating modern fire behavior, I sought to understand how potential fire behavior has changed on the Forest since the early 20th century. Although hypotheses on historic fire behavior can be developed by examining vegetation patterns, FARSITE can be used to model landscape-level fires. FARSITE allowed me to understand how the distribution of vegetation on the landscape can impact fire behavior.

FARSITE simulations for the historic period were run using the 1938 and 1952 fuels maps. All other data layers (fuel models, weather, slope, aspect) were based on modern data. The modeling of historic fires was done to find out how predicted fire behavior has changed, at least in a qualitative way, in the past 60 years. I evaluated the usefulness of the technique by overlaying maps of simulated outputs from FARSITE on maps of the 1930 and 1946 fires (see Figure 2.3).

Figure 2.1. 1995 color infrared aerial photo of Manuel F. Correllus State Forest

, MV, MA.

635 stands were delineated based on 124 stand classifications

Figure 2.2. 1998 sampling coverage for MFCSF

Figure 2.3. Area burnt by the 1930 and 1946 fires, MFCSF

(Harvard Forest, 1999)

Table 2.1. Data sets used to calculate inputs to BEHAVE

CHAPTER 3 RESULTS

Vegetation Classification

Modern Vegetation

Cluster analysis (AGGLOM) produced a dendrogram in which 121 relevés were combined in groups such that with-in group variability was minimized (Appendix I). I used the resulting dendrogram to define seven preliminary types; heath, young plantations, scrub oak barrens, oak woodlands, oak woodland/scrub oak, pitch pine and older plantations (Figure 3.1).

The first division in the dendrogram (categories I and II) was based primarily on the abundance of both scrub oak species (Table 3.1). In stands where scrub oaks are abundant, huckleberry is generally shorter in stature than the scrub oaks and the huckleberry is considered part of the low shrub layer. In stands where scrub oaks are not abundant, huckleberry is comprises the high shrub layer, with blueberry dominating the low shrub layer. Category II stands with canopy cover of tree oaks or pines >50% contain less scrub oaks than stands with low canopy cover (Category II). The high shrub layer of the category II stands generally contain substantial cover of huckleberry as well as scrub oaks. Stands in category I have a well-developed high shrub layer composed of bear oak and a low shrub layer of huckleberry, blueberry species, and dwarf chinquapin oak. Dwarf chinquapin oak is rarely found in category II stands.

Category I is divided into subcategories IA and IB based on the abundance of scrub oak, huckleberry and blueberry. The oak woodland/scrub oak stands (IB) contain more huckleberry and blueberry than the IA stands which, conversely, have a higher percent cover of scrub oak (high shrubs) and lower cover values for huckleberry and blueberry (low shrubs).

Exotic plantations and heath stands (IA1) are differentiated from scrub oak barrens (IA2) by the presence, in the former, of species like red pine, heather, and bearberry, which are common in the scrub oak barrens. The scrub oak barrens are dominated by scrub oak, with both bear and dwarf chinquapin oak present. Bear oak dominates the high shrub layer with dwarf chinquapin oak occurring beneath the bear oak and in small clearings where bear oak is not present.

Huckleberry and blueberry are abundant in the low shrub layer. Small openings in these stands are dominated by bearberry and lichens and are similar to heath stands. These barrens (IA2) are found in the north/south trending valleys, but they are also found in upland sites and their distribution is not limited by topography on the Forest.

The division between heath (IA1a) and young plantation stands (IA1b) is based on species presence rather than abundance. The young plantation group includes those plantations where the canopy has not yet closed. Included are red pine and white spruce plantations established in the 1960s. These plantations are closely linked to the heath stands because the two groups have similar importance values for scrub oak. The understory of the young plantations is primarily scrub oak with huckleberry and blueberry as minor components. These plantations are generally healthy, and the lack of a closed canopy is due to large initial planting intervals (ten ft by ten ft).

Heathland areas (IA1a) are dominated by scrub oaks, but it is the presence of unique species such as bearberry, heather and lichens that result in these stands comprising a separate category. Combined, the unique species do not cover more than 5% of any one stand, but they are not found in other stands. Although scrub oak percent cover is high, there are patches dominated by lower shrubs, and there are occasional patches of bare ground.

The heath (IA1a) and scrub oak types (IA2) were merged into a scrub oak type, as both types commonly have inclusions of the other. The heath relevés have high cover values for species like heather and bearberry, but these species are also found in scrub oak stands. The scrub oak stands typically contain pockets (from one to five meters in diameter) of vegetation that is more indicative of heath. Conversely, heath stands often contain scrub oak and blueberry, which dominate scrub oak stands. Neither type has an overstory. Therefore, although there are differences in both species distributions and vegetation structure, the two groups are more closely related to each other than any other vegetation type and I grouped them together.

Category II is comprised of the “forest” stands of MFCSF. The first division, into IIA and IIB, is based on the presence of white pine. The older plantation group, IIB, contains old conifers planted in the 1920s and 1930s. Most of these plantations are healthy, although some are beginning to break up. The understory is sparse, with total cover less than ten percent. Blueberry, mayflower, Pennsylvania sedge, and lady's slipper are the most common species. There is little scrub oak or huckleberry. Advance tree oak regeneration is present in areas of blowdowns which create patches with lower percent canopy cover and allow full sunlight to reach the forest floor. The lack of competition and full sunlight allows many species such as black cherry, poison ivy, blackberries, and shining sumac to become established. These species are uncommon elsewhere on MFCSF.

The non-plantation stands of category II are further subdivided based on the presence of pitch pine. The pitch pine and oak woodland stands both contain well-developed high shrub layers of huckleberry and scrub oak.

The lack of a pine/oak type is somewhat unusual for the region. Forested areas on lower Cape Cod typically contain a mix of pitch pine and oaks (Patterson et al., 1983). The lack of mixed pitch pine/oak stands on the Forest may be associated with its fire and land-use history (see chapter 4).

Pitch pine stands (IIA2), which occupy less than five percent of MFCSF, generally consist of a mature canopy of pitch pine with an understory dominated by huckleberry and small amounts of scrub oak and blueberry. Except on recently disturbed ground, there is little advance regeneration of pine. Pitch pine stands contain two species that are rare in stands outside the group - pitch pine and cat briar. Although pitch pine is native to the Island, it is found only rarely in other stands.

Oak woodlands (category IIA1) are distributed throughout the Forest. They typically have a closed canopy of maturing white, post and/or black oak, with an understory dominated by huckleberry and blueberry. Scrub oaks are present, but individual plants are less vigorous than in scrub oak barrens, and their distribution is sparse.

Although classified into one of three vegetation classes, the oak-dominated stands [oak woodlands (IIA1), oak woodlands/scrub oak (IB), and scrub oak barrens (IA2)] form a continuum from oak woodland with little-to-no scrub oak in the understory, to scrub oak barrens with overstory canopy cover of <5%. On the dendrogram, oak-dominated stands are separated based on the amount and size of scrub oak present (Figure 3.2). Stands with tree oak cover of >40% are classified as oak woodlands (IIA1). These stands have an average canopy cover of 66% with 12.9m^2/ha of basal area. High shrubs (scrub oak) in the understory averaged 1.16m in height. Those stands classified as HW2A/B (tree oak cover of >40%) with a SO1A/B (scrub oak cover >40%) understory are placed in the oak woodland/scrub oak category (IB) which represents the middle of the gradient from high to low canopy cover. This group has an average canopy cover of 44.9%, with 10.1m^2/ha of basal area and high shrubs (scrub oak) that are 1.3m tall. The scrub oak group (IA2) contains all oak-dominated stands with a tree oak cover class of C (<40%).

Although all species found on the Forest were used in this analysis (Table 3.2), the classifications are based primarily on those species with high importance values - those which occur with high percent cover in multiple strata. Two of the seven vegetation types are plantations.

Using the dendrogram analysis and field observations, I defined six vegetation types for MFCSF (Figure 3.3):

– The scrub oak and heath vegetation types were combined because they frequently contained patches of each other. This combined scrub oak type contains the “canopyless” stands (with an average canopy cover of less than nine percent).

– The oak woodlands/scrub oak type is an intermediary and contains those hardwood stands with characteristics of both oak woodlands and scrub oak barrens.

– The oak woodland type is comprised of those hardwood stands which have a relatively closed canopy.

– The pitch pine vegetation type contains all stands where pitch pine is adominant canopy species.

– The young plantation type contains the red pine and white spruce plantations established in the 1960s and 1970s.

– The old plantation type contains all plantations, including scotch pine, white spruce, and red pine planted prior to 1960.

Historical Vegetation

Map standards and stand types applied to modern air photos were used to interpret historic vegetation depicted on 1938 and 1952 air photos. Because the same stand types were used to characterize vegetation on all photo series, it was possible to assign stands shown on the historic photos to the six vegetation types identified through sampling the modern vegetation. The resulting vegetation maps are found in Figure 3.3.

Fuel Classification

Modern Vegetation as Fuel

Six fuel types were developed to model fire behavior on MFCSF. The fuel types were created using the vegetation types identified by the cluster analysis and data collected during fuels sampling. A seventh fuel type, standard fuel model (FM1 - short grass), represents those areas of MFCSF with mowed grass (i.e., around headquarters and in firebreaks).

The fuel types had characteristics derived from intensively and extensively sampled stands. The ordination of stands using fuels data in PCORD yielded the same grouping as the vegetation data, from AGGLOM (Figure 3.4). This is not unusual because stands that share similar vegetation structure (canopy and shrub heights and covers) often have similar fuel characteristics. Fuel depth, cover, and loading, in particular, are heavily influenced by the vegetation type.

Using the NEWMODEL routine of BEHAVE, custom fuel models were created. Inputs for BEHAVE were tabulated by averaging the structure and fuel loading characteristics for all the stands in each fuel type (Table 3.3). A summary of the custom fuel model characteristics is found below and in Table 3.4.

– **Fuel model 30** (oak woodland) has the lowest 1- and 10-hr (4.78t/ac. and 1.25t/ac.) fuel loading of any of the six models. The fuel depth, 0.56ft, is also low when compared to other fuel models. The shrub layer is not well developed, especially compared to fuel model 32 (scrub oak).

– **Fuel model 31** (oak woodland/scrub oak) has fuel loading and depth values that are between fuel models 30 and 32. Fuel model 31 includes those stands that have characteristics of both the oak woodlands and the scrub oak barrens.

– The 1- and 10-hr fuel loads of **fuel model 32** are 7.03t/ac and 2.37t/ac – nearly twice comparable levels for fuel model 30. The increase in fuel loading is due to the presence of a well-developed shrub layer, which also increases the fuel depth to 0.92ft.

– The conifer fuel models have high 1- and 10-hr fuel loads. **Model 33** (young plantations) has fuel loads similar to model 31. The understories of both the young plantations and the oak woodland/scrub oak are primarily scrub oak. Fuel depth is 50% greater for Fuel Model 33 compared to Fuel Model 31, however.

– **Fuel model 34** (old plantations) contains the most 1-hr fuels, but live woody fuel load is <5% that of other models. Understory vegetation is sparse in these old plantations.

– **Fuel model 35** (pitch pine) has 1- and 10-hr fuel loads similar to other models but 100-hr fuel loads of 3.31t/ac, which is more than three times that of any other model. There are dead, downed mature pitch pines scattered throughout these stands.

– Fuel model 1 (grassland) is a standard fuel model. This model represents short grass areas and has no 10- or 100-hr fuels.

Custom Fuel Model Development

Once the fuel models were created they were compared with standard fuel models using the TESTMODEL feature of BEHAVE. The outputs of TESTMODEL are predictions of fire behavior variables such as rate of spread and fireline intensity. A comparison of each custom fuel model and the standard fuel model that yields the most similar predictions of fire behavior can be found in Table 3.5. The models were each run with the same environmental variables (fuel moistures for 1-, 10-, and 100-hr fuels of 6, 7, and 8, respectively; live herb and live woody fuel moistures of 120%, and a 4 mph midflame windspeed, and 0% slope) (Appendix F). These conditions are defined as "medium" environmental conditions by the TESTMODEL feature of BEHAVE.

Land Cover Change

The distribution of land cover by types for 1938, 1952, and 1995 is found in Table 3.6. Once photos were classified, transition matrices were developed for each of three periods - 1938-1952; 1952-1995; and 1938-1995 (Appendix H) – and annualized rates of change were calculated (Table 3.7).

The transition matrices were used to identify broad trends in land cover change. Unlike some other barrens in the Northeast [e.g. Concord, NH; Albany and Long Island, NY (Finton, 1998)] loss of land to development has been low at MFCSF. Thus the most interesting changes involve vegetation stand development and succession. Because plantations are a direct result of human action, changes associated with plantations are discussed separately from changes in native vegetation (defined as all non-planted vegetation). The 1938-1995 period can be best described as the sum of two separate periods and will not be discussed separately.

1938-1952

Native Vegetation

The principal vegetation change during this period was the reduction in the acreage of immature hardwoods from 1,605 to 291 (Table 3.6). Thus 20% of MFCSF was converted from immature hardwoods to other vegetation types in 14 years. The 1930 and 1946 fires burned 5,300 acres (2,145ha) and 1,219 acres (493ha), respectively, within the Forest. Many areas burnt by these fires regenerated vegetatively and would have been typed on the 1938 aerial photo as immature hardwoods. By 1952, oaks had reached pole size and would have been typed as hardwood forest. Hardwood forest and hardwood/scrub oak forest increased from 90 acres (36ha) to 1,283 acres (519ha).

During this period 378 acres (153ha) were converted to softwood plantations (Appendix H). Immature hardwood stands were likely selected for conversion to plantations, because they lack a well-developed understory (i.e., a lower cover of scrub oak). Planting seedlings in these areas would have been less difficult than planting in scrub oak barrens. The majority of the Forest (54%) remained as scrub oak.

Plantations

The acreage of plantations typed as SW1 or MW1 – softwoods or mixed woods with canopies less than 20ft (6m) high, increased more than 550% during 1938-1952 (Appendix A). There were 83 acres (34ha) of plantations less than 40ft (12m) tall in 1938. By 1952 there were 302 acres (122ha) of plantations with canopy heights greater than 20ft (6m). By 1952, plantations present in 1938 would have developed canopy heights greater than 20ft (6m) but this does not account for all of the plantation acreage with canopy heights greater than 20ft (6m). Areas planted after 1938 must have grown to a height greater than 20ft (6m) in less than 14 years. This rate of growth is not uncommon in healthy plantations and suggests that these plantations had successfully established by 1952. During the years leading up to 1952, the growth rates of plantations would not have caused concerns among foresters over the long-term viability of the plantations, and although these plantations are no longer of economic value, this was less clear in the middle of the 20th century.

1952-1995

Native Vegetation

The major vegetation changes between 1952 and 1995 were a decrease in scrub oak acreage from 2,815 acres in 1952 to 1,484 acres in 1995, with a resulting increase in hardwood forest (750 acres to 1,368 acres), and an increase in the acreage of pitch pine (106 acres to 231 acres) (Table 3.6). The shift of "scrub oak" to hardwood forest appears to represent more of a shift from an early developmental stage to a later one rather than a replacement of shrub oak by tree oak species. Although aerial photo interpretation can delineate between vegetation with different structure, it is difficult to differentiate between scrub oak and its structural equivalent - immature hardwoods. These two types are best considered one type - early developmental oak. Thus transformation of large acreages of scrub oak to hardwood forest should not necessarily be seen as a change in dominant species but rather a change in stand structure with little change in species composition. This change is more evident in the 1952-1995 period, because the period had relatively few landscape-level disturbances. For immature hardwood stands to develop into hardwood forest a period free of large-scale disturbance must occur. There were no fires larger than 1,000 acres (405ha) after 1955 (Table 1.1), logging was limited, and only mature pine plantations were affected by windstorms (chiefly Hurricane Bob in 1991).

Since 1952, there has also been an increase in total pitch pine acreage, much of it in the form of mature pitch pine and pitch pine/hardwood forest. The maturing of these forests, as with the oak types, requires a period free of stand-replacing disturbances.

Plantations

There was an overall increase in plantation acreage from 461 (187ha) to 1,186 acres (480ha) during 1952-1995. Canopy heights for plantations established prior to 1952 also increased [from 20-40ft (6-12m) (class 2) to 40ft and above (class 3)]. The increase in acreage is due entirely to plantings; none of the plantation species (red pine, white pine, white spruce or scotch pine) have invaded areas of natural vegetation. Although many plantations are now breaking up, stems of planted species remain in the canopy, and these stands are not yet classified as native vegetation.

FARSITE Modeling of Fire Behavior

Weather Inputs to FARSITE

Analysis of these data shows that during March and April, when fire danger has historically been highest, winds average 12.7mph (5.7m/s) and are most commonly from the south and southwest. Of the 12, 1-week periods I examined, four had precipitation totals of less than 0.1”

(0.25 cm). During these weeks, the average maximum and minimum humidities were 81.3% and 54.2%. Of the 81 days sampled over this two-year period, minimum humidity levels were below 40% for 12% of the days and below 25% for seven percent of the days. This combination of weather conditions does not occur often, but it does occur occasionally on Martha's Vineyard. Of the 81 days sampled, 10 had windspeeds >10 mph, a minimum relative humidity of <40% and no precipitation for at least two days.

From the available data, five days were randomly chosen from among those 81 days which had a windspeed of at least 10 mph, and a minimum humidity of less than 50% (Table 3.8). Because MFCSF took wind observations only once during the day, the wind value recorded at 1300 EST was used for the entire day. The lack of a larger data set prevents more precise definition of an average worst day for Martha's Vineyard, but it seems likely that weather conditions that occur five times over the course of two springs are not out of the ordinary.

Modern FARSITE Results

At each of five locations (see Figure 3.5), ten simulations were run for three hours, starting at 1300hrs using the weather data from April 4, 1995. Each simulation included a one percent spotting ignition potential, with spot fire growth enabled. The results of these simulations (Table 3.9) show that the largest fires develop from ignitions in the southwest corner of compartment 8 (Site 1). Fires started here burn primarily through areas of scrub oak and oak woodland/scrub oak (fuel models 31 and 32). The area burned by fires igniting at this location averages 568 acres (230ha) in size and varies from 348 acres (141ha) to 726 acres (294ha), depending on small differences in the ignition site and spot fire ignition patterns. Fires cross the northern boundary of the Forest 90% of the time. The simulated rates of burning in different plant communities on the Forest vary from 7 acres/hr (2.9ha/hr) to 190 acres/hr (76.7ha/hr), with the primary reason for differences being the structure of fuels associated with different vegetation types. Areas with mature, closed canopies (e.g. old plantations and oak woodlands) exhibit greatly reduced rates of spread compared to those with open shrublands. Closed canopies reduce the vigor of the shrub layer which limits fuel loads and depths, and they reduce midflame windspeeds.

Ignitions at site 5 (Figure 3.5), in the south central portion of compartment 30 (mature plantations) result in the smallest fires. This is an area of old plantations (fuel model 35). The average size of a three-hour-long fire started at this location is 21 acres (8.6ha), with a perimeter of 0.6 miles (1.0km). None of the simulated fires ignited at this site crossed the Forest boundary during the three-hour run.

Modeling fire spread requires several assumptions. An objective of the simulations was to determine if fires started on an average worst day would cross the northern and eastern boundaries and move off state land. Although detailed vegetation data exist for the Forest itself, no data exist for areas beyond the Forest boundary. Field observations suggest, however, that the vegetation to the north of the Forest is predominantly oak woodland. Spotting potential into oak woodland is low, but the likelihood of spotting into grass is high. Grassy openings occur around structures, but it was not possible to accurately quantify the location and size of these inclusions. It is these scattered grass areas that provide the greatest probability for spotting and the greatest threat of fire near residences. Because I did not locate each house (and the grassy areas which surround them), simulations were run by classifying all vegetation outside the Forest as grassland. FARSITE effectively predicts ignitions derived from firebrands, but does not accurately predict spread of these subsequent fires (Intermountain Fire Sciences Laboratory, 1998). Therefore, I did not attempt to quantify rates of spread outside the Forest; only if fires could spot across existing fire breaks. Defining all areas outside of the Forest as grassland produces a worst-case scenario, but I felt it was more useful to over–estimate spotting potential rather than to under-estimate the potential danger posed by spotting to residences close to the Forest boundaries.

Historic FARSITE Analysis

Simulated fire behavior using the 1938 and 1952 historic fuels distribution map produced larger burned areas than did simulations run with the modern fuels (Table 3.9). All simulations were run for three hours and for each of the five sites the total acreage burnt in 1938 was approximately twice that burned in 1995.

Modeling 1938 fire behavior

Over 88% of MFCSF was classified as scrub oak on the 1938 vegetation map. This had a profound affect on potential fire behavior. The average area consumed during simulations ignited at site 1 was 927 acres (372ha), or 18% of the total area of MFCSF (based on 1938 Forest boundaries). The lack of fuel breaks (i.e., vegetation with reduced fuel loads) across the landscape allows for elliptical growth of fires (Figure 3.6).

A limitation of FARSITE is that spotting can only occur during crown fires burning through tree canopies. It cannot occur in shrub fuels. Because scrub oak areas did not have canopy trees in 1938, little spotting occurred during the simulations. Fires in scrub oak often produce spot fires however (W. Patterson, pers. comm.), so simulations using 1938 fuels undoubtedly underestimated rates of spread and area burnt.

Modeling 1952 fire behavior

By 1952, the acreage of scrub oak has declined from 4,605 in 1938 to 3,144 in 1952. Oak woodlands by contrast, increased from 90 to 751. As a result, fires would have burned less actively in 1952 than in 1938. Areas of maturing oak woodland in the interior of the Forest would have burned with reduced intensity and rates of spread. Similar areas were virtually absent in 1938 (Figure 3.3). Although these areas are small in 1952, their presence creates a more linear burn pattern with a greater perimeter-to-area ratio compared to 1938.

Although the simulated ignitions from site 1 at the southern edge of the Forest reached the northern boundary, they did so in a less uniform pattern. This is especially important to fire suppression crews who would not be exposed to the broad headfires simulated with 1938 conditions. These uneven headfires, a result of the increasing acreages of oak woodland, would facilitate fire suppression, and might allow crews to extinguish fires that would have previously moved north over the Forest border.

Simulated Fire Behavior in Decadent Pine Plantations

Using standard fuel models 9, 10, 11, and 12 it is possible to suggest how fire behavior will change once plantations begin to break apart (Table 3.10). These four standard fuel models represent fuel types with increasing amount of downed wood. Although the mature plantations do not currently contain abundant downed wood, they could if mortality increased due to disease, weather events (i.e., hurricanes or severe wind storms) or senesce.

A concern of Forest managers is that an increase in dead, downed wood will increase the intensity and rate of spread of fires, making them more difficult to control. Currently, the predicted area burnt per hour in older plantations is low compared to other fuel types on the Forest (Table 3.11); however, if rates of spread were to increase, these areas could require fuels management in order to reduce the risk of large, fast-moving fires developing in these areas.

For rates of spread to increase as these plantations begin to fail, fuel loads will have to rise substantially above current levels (9.9 ton/acre). The only standard fuel model with a high slash load and a higher rate of spread than custom fuel model 34 (old plantations) is FM12 (medium slash). FM 12 has a fuel loading of 34.6 tons/acre. The slow loss of scattered individual stems would not cause fuel loads to rise to the levels represented by FM 12. However, landscape-level disturbances that would create many downed stems could create these high fuel loads. If a severe hurricane were to affect the Forest, fuel loading after the storm might exceed that of fuel model 12 immediately after the storm. This fuel load can, however, be quickly reduced such as after Hurricane Bob in 1991 when fuel loads in plantations that suffered high mortality were quickly reduced by mechanical means (salvage cuts and chipping). Therefore, provided stems are removed after large wind events, fuel loads and rates of spread are not likely to increase as these plantations senesce.

Figure 3.1. Dendrogram used to classify extensively sampled stands into preliminary vegetation classes

Figure 3.2. Distribution of oak stands based on percent canopy cover

Figure 3.3. Land cover maps for MFCSF, MV, MA (1938, 1952, 1995)

, MV, MA

Figure 3.4. Ordination of fuels data by stand for MFCSF

Figure 3.5. FARITE ignition sites for simulations

Figure 3.6. Sample FARSITE simulations using vegetation distribution derived from 1938 and 1952 aerial photos

Table 3.1. Summary information for preliminary vegetation types

Table 3.2. Higher plants identified in or near relevés in MFCSF

2 pages

table 3.2. 2^{nd} page

Table 3.3. Input parameters to BEHAVE

Table 3.4. Comparison of custom fuel models generated by NEWMODEL routine of BEHAVE

Table 3.5. Fire behavior results generated from TESTMODEL routine of BEHAVE compared with standard fuel models

Table 3.6. Acreage by vegetation type from photo interpretation for MFCSF

, Martha's Vineyard

Table 3.7. Annual rates of change (acres/year) between vegetation types, 1938-1995

Table 3.8. Days with potential high fire behavior based on fire weather data for April 1994 and March-April, 1995

Table 3.9. Results of FARSITE simulations for 1938, 1952, 1995 fuels, showing area burnt, fire perimeter and spotting across MFCSF northern boundary

Table 3.10. Comparison of input values for custom and standard fuel models and compiled fire data for FARSITE simulations in old plantations

Table 3.11 Results of FARSITE simulations

Modeling future fire behavior in failing plantations

CHAPTER 4 DISCUSSION

Natural Vegetation Dynamics

The most profound change in vegetation distribution is the increase in importance of the hardwood/scrub oak forest type during the late historical period. This type was not present in 1938 but occupied 533 acres by 1952. It is likely that such a large area could not have been converted into hardwood/scrub oak forest so quickly if the species present in this type - tree and scrub oaks - had not been present as juveniles in 1938. Extensive areas typed as scrub oak and immature hardwoods on the late historical landscape must have contained abundant tree oak saplings in addition to scrub oak. Fires, the most recent in 1930 and 1946, repeatedly killed most above-ground stems, and the resulting vegetation would have been classified, based on its structure, as scrub oak or immature hardwoods. As fire suppression became more effective, coppice oaks would have began to develop into closed forests by 1952.

The presence of "ancient oak stools" suggests that coppice growth of oaks has been occurring on the Forest for centuries (Foster and Motzkin, 1999). Species present on the Forest have simply resprouted after fires and cutting. The dominant species in these stands - tree oaks, scrub oaks, huckleberry, blueberry, and bracken fern – are all capable of regenerating vegetatively after fire. Except in the case of fires that burn severely and destroy root systems, species capable of resprouting would have a competitive advantage over those relying on seedling regeneration such as white pine.

Frequent disturbances are also suggested by the lack of pitch pine forest and the presence of pitch pine-scrub oak barrens during the first half of the 20th century. Frequent fires favor shrubby vegetation - young pitch pine and shrubby oaks - over woodlands and forests. Young pitch pine stands develop into pitch pine forests in the absence of disturbance, but the development of these forests is not evident during the early 20th century.

Plantation Development: 1938-1995

The planting and tending of timber species dominated forest management during 1938-1995. The acreage of plantations increased from 83.3 acres (34 ha) in 1938 to 1,269 acres (514 ha) in 1995. Although many of these plantations are now beginning to fail, the 1995 data do not indicate conversion of plantations to native vegetation. The implications of future mortality in plantations are discussed in Chapter 5.

Changing Fire Behavior in the Forest

Simulations of historic fire behavior are not based entirely on historic data. No data exist on fuel loads for historical vegetation. Stands were assigned to fuel models based on canopy characteristics, and I assumed that stands from 1938 and 1952 that had canopy characteristics similar to 1995 stands, would have similar fuel characteristics. Although this is not necessarily the case, this assumption is the best available for estimating historical fuel levels. Although one might assume higher fuel loads in the late 1990's due to the long period without fire, Nelson (2002) reports that barrens fuel loads return to near pre-burn conditions within five years of a fire, so surface fuel bed conditions may not have differed substantially in 1938 and 1952 versus 1995.

Predicted fire behavior, using assumed fuel distributions for 1938 and 1952, suggests a declining impact of fire through time. This is best illustrated by comparing simulated rates of consumption (area burned) at different periods during the history of the Forest (Table 3.9). Each of the five sites chosen for fire simulations showed a decrease in area burned from 1938 to 1995. Weather and topography were held constant, so only changes in fuels distribution could cause decreased burning. Although fire exclusion has been cited as a cause for recent increases in fire activity in the West (Pyne, 1999), this apparently is not the case on Martha's Vineyard. Rather, the conversion of early developmental types such as scrub oak and young plantations into mature oak woodlands and mature plantations has lead to decreased fire activity on the landscape.

Simulated area burned has decreased in the past 70 years, but the potential for catastrophic fires remains. All of the 1995 fires started on sites 1-4 crossed the northern boundary of the

Forest in less than three hours. Areas of scrub oak and young plantations have sparse canopies, and this creates fire behavior that promotes spotting. Although the risk of catastrophic fires may be lower, recent residential development along the northern boundary of the Forest means that should a large fire develop, there is a greater potential for damage than there was 70 years ago.

Fire Regimes

The changing role of fire on MFCSF since 1938 is best examined by defining two unique fire regimes for the period (Table 4.1). The presence of fire on the Forest is a result of human activity, and the boundary between the two regimes is a result of a change in human behavior. The modern fire regime begins when advancements in fire prevention and suppression reduced the incidence of large fires on the plain.

The division between the two fire regimes is distinct. Prior to 1955, approximately 8,500 acres burned on the Central Plain every decade. Since 1955, only about 600 acres per decade have burned (Table 1.1).

Late Historic Fire Regime (1850 - ~1955)

The late historic period spans the time between the decline of agriculture on the Vineyard (1850-1920) and the inception of modern fire suppression (ca. 1955). Frequent, large fires characterize this period. These fires were common throughout the spring and summer (Table 1.1). Fires larger than 1,000 acres occurred an average of once every five years during this period (Foster and Motzkin, 1999). These fires were likely intense, with high rates of spread. They typically consumed all, or most, above-ground vegetation. The lack of modern fire suppression equipment contributed to the fact that these fires burned more area than fires in the late 20th century.

Frequent fires prevented the maturing of oak woodlands from what was typed as “scrub oak” or “immature hardwoods” in 1935. These types are characterized by large 1- and 10-hour fuel loads but little 100-hr fuels. Accumulation of fine, flashy fuels (litter and flammable shrubs) promoted high intensity fires with low residence times during the spring.

Fires during this period (1850-1955) killed above-ground stems, but root stock and rhizomes probably remained largely intact. Although the severity of these fires was greater than is observed for fires in the later 20th century, most fires in the late historic period likely did not consume the organic soil layer. The presence of mature coppice stems in the modern vegetation community is evidence of this.

If oak root stocks had been killed and large areas of mineral soil exposed, pitch pine, a species that requires exposed mineral soil to establish (Ledig and Little, 1979), might now occupy more acreage than it does. Compared to most of the sandplain communities in New England, pitch pine is uncommon on MFCSF. It is seldom found in modern, oak-dominated stands, and pitch pine dominated-stands occupy less than 235 acres (95ha) of the Forest (Figure 4.1).

During the late historic period, the combination of young stands of low stature and short fire return intervals produced a feed-back mechanism that maintained immature stands susceptible to large, fast-moving fires. Although many stands contained tree oak species that could have developed into forests, frequent fires prevented this from occurring.

Modern Fire Regime (~1955-present)

Infrequent, small, relatively low intensity fires characterize the modern fire regime. These fires are typically less than 10 acres in size and have a return interval of many decades. Fires during this modern era occur during all months of the year, with the primary cause of ignition assumed to be arson (Varkonda, pers comm.). Advancements in fire suppression equipment and the maturing forest vegetation have combined to keep most of these fires small. Since 1955, only four fires have burned 100 acres (42ha) or more, with only the December, 1965 fire burning as many as 1,200 acres (500ha). None of the six fires I observed during 1998-1999 consumed all 1-hr fuels nor did they kill all canopy stems. The Forest has not experienced a large fire that has killed canopy stems and created open-stand conditions during the past 50 years. This lack of fire has affected vegetation structure and the likelihood of large fires in the future.

A common perception of both natural resource professionals and the public on Martha's Vineyard is that it is only a matter of time before large-scale fires return to the Forest. This may or may not be the case. Although it is true that large fires were present on the Forest in the past, the lack of fire in the past 50 years has fundamentally changed fuel beds, stand structure and the role of fire on MFCSF. Without fire, 27% of the Forest's vegetation has developed into mature oak woodlands. The closed canopies of these stands serve to limit the development of large, intense fires. Fuels sampling shows that the fine loads in these stands are less than in early developmental types such as scrub oak. The modification of the fire regime was due to human intervention but, even if fire suppression were curtailed, it would be less likely today to result in the return of large, intense fires than in the past (Fig 4.2).

Although those areas labeled as high fire danger on Figure 4.2 could still support large, intense fires, the landscape-level continuity of these stands is reduced from 1938. The development of the oak woodlands has effectively created barriers that would limit the development of large-scale fires. Intense fires can still develop in pockets of highly flammable vegetation, i.e., scrub oak, but they are less likely to spread unchecked across the plain as in the past.

The positive correlation between vegetation development and decreased fire behavior is a barrier to the possible return of the late historic fire regime. In order to break this cycle, it would be necessary to expend a great deal of energy to implement a fire program that would, through prescribed fire and mechanical treatments, recreate the early developmental types capable of supporting large fires.

Future Vegetation dynamics

Native Vegetation

The species composition and structure of native vegetation of MFCSF appears to be changing more slowly than in the past. Stand types with the greatest potential for change, immature hardwoods and pitch pine/scrub oak thicket stands, now comprise <30 acres (0.6%) of the Forest (Table 3.6). The lack of wide-spread fires since 1946 has contributed to a reduced rate of vegetation change. Stands will continue to age but future changes in structure, as from immature hardwoods to oak woodland, will be minimal.

The distribution of pitch pine on the Forest will continue to decline. Most pitch pine stands are >50 years old (W. Patterson, unpublished data), and vegetative regeneration of pitch pine is now unlikely as its ability to resprout from the root collar diminishes with size and age (Carey, 1994). Where they occur, pitch pine may survive for another 50-100 years or more, but as individual stems die, oaks are more likely to take their place in the canopy.

Unlike the conifer plantations, white pine is not present in the understories of pitch pine forests. The pitch pine stands of MFCSF have a well-developed shrub layer of huckleberry and blueberry. This shrub layer, and the litter it generates, creates a deep litter layer that is not conducive to the establishment of white pine seedlings.

Mature Plantations

The older plantations are likely to deteriorate over the next 50 years. Unlike the native species which dominate the natural vegetation, conifers planted at MFCSF do not have the ability to resprout and they do not occur naturally on coastal sandplain soils. Most of the old plantations will eventually break up due to environmental stress, windthrow, or disease. Baring catastrophic wind storms, some of the healthier white pine may remain standing for decades. When stands do break up, they will be replaced by native and/or invasive non-conifer species.

White pine regeneration is common in older pine plantations where canopy covers have declined. These saplings are generally less than 20 ft. in height, and are shading out other understory species. As the canopy declines further, these saplings may mature into a second cohort of canopy pines. Where this occurs, white pine could persist for several centuries. This process appears to be occurring in compartment 31. The northeastern quarter of the compartment contains white pine planted in the early 1900s. Many of these older stems are dying and the area is now typed as young plantation (a second cohort of white pine).

Some of the failing plantations contain a number of invasive species (Table 4.2). This is especially true of scotch pine stands in compartment 30. Unlike areas planted to red pine, these scotch pine plantations developed a closed canopy before senescing. Native species common in other stands (scrub and tree oaks, huckleberry, and blueberry) were unable to survive, so when these stands began to break up, the understory was only sparsely vegetated. Species invading these stands – poison ivy, blackberry, shining sumac, and black cherry – are rarely found elsewhere on the Forest.

Young Plantations

Many of the younger plantations, including white spruce in the east and southwest portions of the Forest are unlikely to develop fully closed canopies because of slow growth rates and wide spacing. However, these species may persist in these areas for another 50 or more years. Many of these areas were planted 30-40 years ago, but the heights of trees are typically less than 20 ft. This group of plantations includes some red pine stands planted at spacings of 10 ft. by 10 ft. Native species still dominate the understories of most of these plantations.

Red pine planted was planted at narrower spacings in compartment 14 and stands have achieved canopy closure. These closed canopies could shade out native understory species in the future. Although *Diplodia pinea*, a fungal pathogen, infects red pine plantations on the Forest, most of the stands currently infected are 60-70 years old. The younger red pine stands may continue to develop, but they might also, as was the case with the older plantations, begin to senesce in 20-30 years. The fate of these plantations after senescence will likely replicate that of current scotch pine plantations – they will be invaded by a host of species not normally found in barrens vegetation. These plantations comprise 450 acres (182ha) or 8.8% of the Forest, with class A or B (>40%) canopy cover and class 1 or 2 (0 ft. – 40 ft.) canopy height. They currently present the greatest risk for loss to native vegetation on MFCSF. Once these plantations shade out the native vegetation, restoration of understories will be much more difficult. If planted pines are removed now, understory species currently present may quickly restore the stands to native vegetation.

Implications for Fire Regimes

The decreasing rate of change in vegetation suggests that the modern fire regime (i.e., many fires impacting small acreages) will continue to define the role of fire on the Forest in the future. Stands with mature canopies will increasingly dominant the landscape and their presence will prevent the development of fast moving, high intensity fires observed during the Late Historic period. Private development adjacent to the Forest will necessitate fire suppression and prevent the development of landscape-level fires. The potential for landscape-level fires, especially during the early spring, will continue to be a concern, but the fires are likely to be less frequent than before ca. 1955.

Figure 4.1. Pitch pine forests on MFCSF

Figure 4.2. Highly flammable vegetation

Table 4.1. Comparison of fire regimes for central Martha's Vineyard

Table 4.2. Species found primarily in plantations and disturbed areas.

CHAPTER 5 APPLICATIONS FOR MANAGEMENT

A goal of vegetation management on MFCSF is to reduce the potential for catastrophic wild fires. Reducing fuel depths and loading would reduce flame heights, rates of spread, and fire intensity. In so doing, the risk to people and structures on adjacent properties would be contained and reduced. Currently, two methods for reducing fire danger on the Forest are being examined: prescribed fire and mechanical treatment.

Prescribed Fire

Dunwiddie and Caljouw (1990) studied coastal heathland and grasslands on Nantucket Island and found that burning in alternate years increased graminoid cover at the expense of shrubs. Growing season burns, as well as mowing during the growing season, were more effective than dormant season burns (Rudnicky et al., 1997). A benefit of prescribed fire as a management tool is the fact that fire has been present on the Martha's Vineyard landscape for millennia (Stevens, 1996), so native flora and fauna are adapted to its effects. Thus, fire is viewed by some as "natural", even though most prehistoric fires were, as has been the case during the historic period, ignited by humans (Stevens, 1996).

Although there is a great deal of published research on prescribed burning elsewhere, studies in the Northeast are just beginning to bear fruit. In addition to the works of Dunwiddie and Caljouw (1990) and Rudnicky et al. (1997), Matlack et al. (1993) found that late winter fires in the New Jersey Pine Barrens killed all above-ground stems of huckleberry (*Gaylussacia baccata*), but that this species resprouts rapidly. Similar resprouting is observed when stems are clipped instead of burned. Mid-summer burns increase the length of time needed for regeneration of huckleberry as stored carbohydrates in roots are seasonally depleted and the plants resprout less vigorously (Droege, 1996). During these growing season burns, typically in late July and early August, mean monthly temperatures are at their highest and precipitation is lower than average on Martha's Vineyard (Storm Fax, 1990). This combination favors plants with less non-photosynthetic structural tissue, such as graminoids. Although weather conditions in late summer are sometimes conducive to fire, Rudnicky et al. (1997) found that lower live fuel and fine fuel moisture levels make it easier to ignite fires in the spring than in the summer.

Prescribed fire is not without its drawbacks. Although it is possible to treat large areas relatively quickly, the treatment may not be uniform over the entire area (Chandler et al., 1983) and the risk of escaped fires exists. On MFCSF, one of the chief concerns regarding the use of prescribed fire is the large amount of development directly to the north and east of the Forest (i.e., downwind of areas potentially treated with prescribed fire) (DEM, 1994). Employing prescribed burning requires a well-trained crew and reliable weather conditions. These constraints often limit the number of days that prescribed fire can be employed.

Mechanical Treatment

Although mechanical treatment does not substantially reduce fuel loads; it does alter fuel structure and has the advantage of generally being safer than prescribed burning in terms of risk of damage to surrounding property. Mechanical treatments reduce fuel bed depth by compacting fuels near the ground. The two mechanical treatments commonly employed on MFCSF are harrowing and mowing. Both compact fuel beds, but harrowing is more controversial because it exposes mineral soils which can lead to the establishment of invasive, exotic species. It is also true, however, that most rare plant species on the Forest occur in previously disturbed (harrowed and repeatedly mowed) firebreaks (Foster and Motzkin, 1999).

A potential problem with disk harrowing is that production rates can decrease by 50% or more with the presence of canopy trees (Roby and Green, 1976). Between one-fourth and one-half of the existing maintained firebreaks (30-60 ha) on MFCSF contain mature pitch pine that would have to be cleared before harrowing could be employed.

Data from Cape Cod National Seashore (CCNS) suggest that summer mowing can be an effective alternative to harrowing for controlling shrub density and fuel depth (Patterson, pers. comm; Del'Orfano, 1996). Relevés sampled on MFCSF show that annually mowing areas of scrub oak (*Q. ilicifolia, Q. prinoides*) reduces fuel height without the introduction of weedy species. Although fuel heights are reduced, the fuel load is typically not reduced sufficiently to stop fires from crossing a buffer (Table 5.1). A limitation of mowing is that it requires a terrain without stumps or holes that could jam the mower. In order to safely mow many of the firebreaks on MFCSF, extensive work must be done to remove stumps and to fill in erosion gullies (J. Varkonda, pers. comm.).

Modeling Management Techniques

FARSITE simulation modeling was used to determine the relative effectiveness of a variety of firebreak options that the Department of Environmental Management is currently considering for MFCSF. These options include a mineral soil fire break [200 ft. (61 m.) wide] and a managed fuel zone [500 ft. (152 m.) wide] around the northern and eastern borders of the State Forest (DEM, 1994).

Using FARSITE with the modern fuels map, I determined the potential effectiveness of possible management techniques in stopping, or slowing headfires on MFCSF. FARSITE was used to determine what combination of buffers and managed fuel zones reduced rates of spread to a level where fire fighting personnel could reach the fire scene and set up control lines before fires could move across the Forest boundary.

Present-Day Fire Behavior

Methods

Exterior buffer zones

Given the prevailing SW winds during those months when fire danger is highest, the northern and eastern borders of the Forest are the most likely to be breached by fires (Appendix H). The effectiveness of eight different combinations of bare soil and managed fuels in stopping fires from crossing these lines was examined. A 200 ft. no fuel buffer was created in FARSITE. Creation of this buffer has already begun on the northern boundary. The simulated buffer was tested alone and in combination with a 500 ft. wide managed fuel zone. Seven different custom fuel models were created using data collected on MFCSF (Woodall, 1998 and this study) and at

Cape Cod National Seashore (CCNS) (Del'Orfano, 1996; Patterson, unpublished data). These custom fuel models represent a range of management options: prescribed burning scrub oak once (BSO), burning oak woodland once (BOW), summer mowing scrub oak every two (MSO2) and three years (MSO3), burning every third winter (BW3) and burning every third summer (BS3), as well as no fuel (NF). All the custom fuels models except the BW3 and BS3, which were derived from data collected at CCNS, were created from data collected on MFCSF.

Each treatment was applied to a 500 ft. buffer inside a 200 ft. no fuel zone along the northern and eastern boundaries of the Forest. Each option was tested by simulating ignitions in FARSITE at sites 1, 2, and 3 (Fig 5.1). Ten simulations were run at each site using April 4, 1995 weather conditions (Table 3.8). The simulations were run for six hours starting at 1300 hrs. The goal of these simulations was to determine if a fire would cross the buffers and move on to private property. If the fire crossed the boundary, the elapsed time since the fire was ignited was recorded. The percentage of fires that crossed the boundary as well as the average time it took to cross were calculated for each management option at each site (Table 3.9).

Interior fire breaks

The ability of interior fire breaks to impede the spread of fires was examined using different methods. Unlike the simulated ignitions used to evaluate the effectiveness of the exterior fire breaks, which consumed hundreds of acres of vegetation prior to reaching the break, the interior ignitions were placed 0.5 mile (0.8 km.) and 0.25 mile (0.4 km.) upwind of the breaks. These fires consumed fewer acres. In order to facilitate the comparisons between sites, all the simulations were run in scrub oak vegetation.

Breaks 50, 100, 150, 200, and 400 ft. were evaluated to determine if they would prevent fires from crossing into other compartments and how long it might take for fires to cross the breaks. Although the smaller breaks may not stop fires from spotting across, they might slow these fires down and allow for suppression crews to assemble and fight the fire. These simulations were run using the same weather and simulation conditions (April 4, 1995) as the exterior breaks. Ten simulations were run at each site and the results were averaged.

Results

Exterior Fire Breaks

None of the buffers stopped the simulated fires from spotting over the line and onto private property (Table 5.1). The spotting potential from the ignitions from all three sites under similar weather conditions rendered the combined 700 ft. break (200 ft. no fuel and 500 ft. managed fuel) inadequate. Fuel zones wider than 500 ft. were not examined as the cost for these breaks would be prohibitive (Roby and Green, 1976). Although no one of the above fuel management scenarios stopped fires from crossing the Forest boundaries, all lengthened the time it takes for fires to cross, especially for site 1. This site is important as it represents an area next to the Edgartown - West Tisbury Road with high public access. It is also close to the sites where the 1930 and 1942 fires initiated. The no fuel option, although difficult and costly from a management standpoint, increased the time to crossing by 40 minutes compared to all other options.

Interior Fire Breaks

The results of the interior fire break simulations (table 5.2) show that none of the breaks stopped fires from spotting into other compartments nor did an increase in the width of the break slow the spread of these fires across the lines. Because I had defined fuel types for the Forest, these simulated fires spotted into actual fuels rather than the grassland fuel type used to evaluate spotting for the exterior break simulations.

Discussion

Exterior Fire Breaks

It is clear that when spotting potential is high, managed fuel zones alone will not prevent fires from moving off the Forest. But breaks do appear to have some value, at least in context of these simulations. The 200 ft. no fuel zone allows suppression crews to safely assemble, and it creates a zone that will prevent head fires from moving off the Forest directly. Fires only cross the boundary by spotting.

A 500 ft. managed fuel zone further reduces the risk to personnel and allows more time to fight a fire, although it is unclear if these benefits are worth the cost of creating and maintaining a managed fuel zone. Creating a 500 ft. zone along the northern and eastern boundaries of MFCSF would require the treatment of 428 acres (173 ha.). Periodic at least once every five years would be required. Maintaining this zone would likely require additional personnel to be assigned to the Forest.

Interior Fire Breaks

The inability of interior fire breaks less than 400 ft. in width to stop or slow the spread of fires suggests that increasing the width of the existing 100-foot-wide breaks would not be cost effective. Creating two east/west fire breaks across the Forest 400 ft. in width would involve the treatment of more than 371 acres (150 ha.) with little or no effect on simulated fire behavior. Although widening the existing fire breaks would not reduce the spread of fires on MFCSF, widening would allow for greater access and safer escape routes for suppression crews. But ignitions started when weather conditions are similar to those used in these simulations are likely to result in fires that can not be stopped along interior fire breaks. These buffers would, however, facilitate the use of prescribed fires ignited during less hazardous weather conditions, to manage interior fuels

Management Recommendations

The transition matrices and FARSITE simulations indicate that although many of the old plantations will begin to fall apart in the next 50 years, the fire danger in these areas will not increase substantially. The intensity of fires ignited in these failed plantations will be higher due to an increase in 100-hr fuels, but rates of spread will be low (Table 3.10). Thus fuels management in these plantations is of lower priority compared to external breaks. Relevé data suggest that these plantations contain many non-native species, and additional work is needed to determine effective means of restoring native vegetation to these areas (Foster and Motzkin, 1999). Young plantations, especially those where the probability of canopy closure is great, should be managed to prevent the disappearance of the native understory. This management will likely require the thinning or removal of planted species. The rates of spread in these young plantations is less than that in the scrub oak and oak woodland/scrub oak areas that are likely to revegetate these areas if the conifers are removed, and as these plantations mature, rates of spread will decrease further. Thus managers should weigh the benefits these plantations yield as areas of reduced fire behavior with the disadvantages of creating areas dominated by non-native species.

CONCLUSIONS

The purpose of this study was to determine how vegetation and fire have interacted on the central Martha's Vineyard sandplain in the past and how they are likely to interact in the future. By using historical accounts, aerial photos, vegetation sampling and computer modeling I have characterized the relationships between vegetation and fire.

Historical accounts suggest that fire has been present on the Martha's Vineyard landscape for hundreds of years, and that both Native Americans and Europeans contributed to the frequent burning of the central plain. The modern vegetation of the plain is an artifact of this disturbance regime. It is difficult to characterize the effect of fire on the landscape prior to the 19th century except to state that fire was present and did influence vegetation dynamics. In the absence of fire, sandplain vegetation would likely develop as mature oak forests. This does not appear to have occurred on the central plain during the past 400 years of occupation by humans of European origin. Fire has apparently contributed to keeping vegetation as oak shrublands and woodlands.

Analysis of historical vegetation data, as depicted on aerial photos, shows that the majority of the sandplain was occupied by shrubby oak as recently as 1938. Computer modeling of fire behavior shows that these early successional, shrubby stands would have supported large, catastrophic fires. Such fires occurred as recently as 1930 and 1946. Tree oaks would not have remained as saplings without fires at intervals of <20-40 years. This is evident in the rapid transition of these areas to oak woodlands after 1946.

Examination of modern vegetation data from aerial photos and vegetation surveys shows that there have been landscape-level changes in vegetation during the past 70 years. Human ignition sources still exist but a concerted effort to suppress all wildfires on the Plain has effectively removed fire as a landscape-level process. This change in disturbance regime has allowed young stands to develop, and oak woodland rather than scrub oak is now the dominant vegetation type. This change in vegetation has affected potential fire behavior. Mature oak woodlands are less likely to support large-scale fires than shrubby oaks. The potential still exists, under extreme weather conditions, for catastrophic fires, but the probability of these fires occurring has decreased from historic levels. These changes will impact future vegetation/fire interactions.

The rate of vegetation change is slowing. Many of the remaining scrub oak stands are in frost pockets and are unlikely to develop into oak woodlands, even with the complete removal of fire from the landscape. The continued existence of flammable fuels in these stands will result in a continued risk of fires. Fire hazard in these areas can be partially mitigated by the construction of fire breaks within and downwind of these shrub stands.

Computer simulations show that creating a buffer around the northern and eastern boundaries of the Forest will slow the movement of large fires onto private property. Although no fire break will stop all fires, the movement of fire off the Forest could be slowed substantially by well maintained breaks. Breaks might will allow trained suppression crews to control fires before they cross the Forest boundary and threaten private property. They would also facilitate the implementation of a prescribed fire program within the Forest by reducing the risk of escaped fires.

Fire has been and will remain a component of the Martha's Vineyard landscape. The large fires of the 19th and early 20th centuries cannot be allowed to reoccur as they would cause great damage to private property. Steps can be taken to reduce the threat of such fires, and this study provides guidance on how and where to undertake fire hazard reduction fuel management activities.

Figure 5.1. Ignition sites for exterior buffer simulations

Table 5.1. Exterior fire break simulations, FARSITE

Table 5.2. Interior fire break simulations, FARSITE

APPENDIX A. Planting record for MFCSF, 1926-1965

APPENDIX B. Fire effects on the common species of MFCSF
Manuel F. Correllus State Forest, Dukes County, Massachusetts

Each of the most common species on MFCSF - pitch pine (*Pinus rigida*), white pine (*P. strobus*), white oak (*Quercus alba*), post oak (*Q. stellata*), black oak (*Q. velutina*), scrub oak (*Q.* i*licifolia* and *Q. prinoides*), huckleberry (*Gaylussacia baccata*), blueberry (*Vaccinium angustifolium*, *V. vaccilans*), bracken fern (*Pteridium aquilinum*), sweet fern (*Comptonia peregrina*), wintergreen (*Gaultheria procumbens*), and little bluestem (*Schizachyrium scoparium*) - respond to fire in different ways.

Mature pitch pine (*P. rigida*) can withstand occasional fire due to its thick bark. After those fires which result in stem mortality, young (<20 years of age) pitch pine can resprout vegetatively from the root collar (Carey, 1992, Ledig and Little, 1979). Pitch pine is the only northeastern pine with this adaptation. After those fires which kill both above ground stems and the root collars, pitch pine can regenerate from seed shed from cones provided there is exposed mineral soil (Ledig and Little, 1979). Pitch pine is shade intolerant and cannot regenerate under a mature canopy (Wright and Bailey, 1982).

White pine (*P. strobus*) is moderately fire tolerant (Carey, 1993). Mature individuals can typically survive low-intensity fires as the species self-prunes and has a deep rooting system but saplings are fire intolerant (Wendel and Smith, 1990). The historic fire regime of white pine forests in the eastern United States incorporates stand-initiating fires at intervals longer than 150 years with frequent low-intensity fires (Heinselman, 1973). Although white pine is not native, there are over 265.3 acres (107.4 ha) of white pine plantations on MFCSF. These plantations provide an ample seed source and white pine is found in the understory of most failing plantations, regardless of the canopy species, as well as in oak woodlands.

Oaks are generally fire tolerant. This is due in part to thick bark and ability to resist rotting after scarring. Oaks can resprout from the root collar as well as survive occasional drought better than other tree species. Fire also serves to reduce competition from shade-tolerant species such as red maple (*Acer rubrum*) (Abrams, 1992). The deep root system as well as a lower water potential threshold for the closure of stomata allows oaks to photosynthesize under conditions that would force other trees to halt photosynthesis (Abrams, 1992). A decline in fire in the Eastern United States in the past century can be correlated with a decline in oak, although this has not been documented for New England (Abrams, 1992). There are three tree-oak species found on MFCSF, white oak (*Q. alba*), post oak (*Q. stellata*), and black oak (*Q. velutina*). The responses of these species to fire are similar, but not identical.

White oak (*Q. alba*) is generally more fire resistant than other oaks (Tirmenstein, 1991). Although white oak is semi shade tolerant it cannot regenerate from seed under parent trees, but requires an open seed bed (Tirmenstein, 1991). Regeneration after fire is typically vegetative, with sprouts from existing root collars having an advantage of stored carbohydrates over sprouts from seed. White oak acorns are not resistant to fire (Garren, 1943). "Average" intensity fires typically kill all white oak acorns due to high moisture levels in the seed (Garren, 1943). For seed germination to occur, both mineral soil and a close seed source must be present. A return interval of less than eight years can eliminate white oak from a site (Little and Moore, 1949).

Post oak (*Q. stellata*) is moderately fire resistant and has excellent drought resistance (Carey, 1992; Stransky, 1990). The species exhibits slower growth rates than most oaks and is commonly over-topped in the absence of disturbance (Stransky, 1990). Post oak can sprout vigorously from the root collar of stems less than 10 in. DBH and therefore regular burning tends to increase post oak dominance on a site (Thor and Nichols, 1974; Stransky, 1990). Post oak forests in the mid-west have been found to be former savannas, comprised of grassland and scattered oaks, that succeeded to post oak forest after the removal of fire (Johnson and Risser, 1975)

Black oak is less shade tolerant than white oak and does not have the drought tolerance of post oak (Johnson, 1992; Carey, 1992). Black oak is typically found on drier southern and western exposures. On extremely dry sites, such as those at MFCSF, black oak forests succeed only slowly into mesophytic oak woodlands. Low nutrient requirements allow black oak to persist on poor sites. Nutrients do not typically accumulate in the soils of these sites, as black oak leaf litter is nutrient poor (Olson, 1958).

Bear oak (*Q. ilicifolia*) and dwarf chestnut oak (*Q. prinoides*) are the two scrub oaks found on MFCSF. Dwarf chestnut oak is typically shorter (< 3ft) while bear oak can reach heights of (10-20ft). Both species are common in combination with tree oaks and in barrens without an overstory. Although both species are present in barrens, bear oak is more common and it is the dominant species on MFCSF. Both species sprout vigorously from root collars after cutting or fire (J. Varkonda, pres. comm.). These scrub oaks tend to form dense thickets in the barrens that retain dead stems and twigs as suspended necromass. This suspended fuel dries faster than downed wood and increases fire behavior. Scrub oak barrens exhibit the most extreme fire behavior of all sandplain vegetation types found on MFCSF (DEM, 1994).

The common shrubs of MFCSF are adapted to frequent fire. Huckleberry (*Gaylussacia baccata*) is a significant constituent in most stands on MFCSF. Seedlings are rare and regeneration is typically from existing rootstock (Reiners, 1965). Huckleberry thrives on acidic, coarse textured well-drained, low nutrient soils (Carey, 1994; Reiners, 1965). Most fires will kill all above ground stems but the root systems and rhizomes can survive crown fires in oak-pine barrens, so long as the fires are not severe (Dosmann et al., 1991). Huckleberry leaves, which are deciduous, contain volatile compounds that promote the spread of summer fires. Low bush blueberries (*Vaccinium angustifolium, V. vaccilans*) are found throughout out the Forest in every vegetation type. Fire promotes regeneration of these species from rhizomes (Bourgeron et al., 1988; Tirmenstein 1991). Blueberry rhizomes are more resistant to fire than huckleberry (Eaton and White, 1960). Bracken fern is common in the understory of most stands on MFCSF. Vegetative propagation is most common and fire has been shown to increase species abundance (Crane, 1990). Bracken fern (*Pteridium aquilinum*) has also been shown to promote fire through the production of fine flashy fuels, and be promoted by fire as it regenerates rapidly after a burn (Crane, 1990).

Sweet fern (*Comptonia peregrina*) occurs sparsely in most stands on MFCSF. Sprouting from rhizomes is common and can greatly increase sweet fern dominance after fire or disking (Snyder, 1993). Sweet fern is drought and salt tolerant and can fix nitrogen (Snyder, 1993). Prairie chickens in the Midwest have been observed using sweet fern thickets for cover (Hamerstrom, 1939).

Wintergreen (*Gaultheria procumbens*) is an evergreen rhizomatous shrub commonly found in those stands, both oak and pine, with mature canopies (Coladonato, 1994). The roots extend less than 1 inch into the soil (Flinn and Pringle, 1983). Wintergreen berries are one of the few fruits that persist into the winter and are a favorite food of the eastern chipmunk. The shallow rooting of wintergreen does not allow the species to survive fires that remove the organic layer (Flinn and Pringle, 1983). Motzkin et al. (1999) found that 19^{th} century plowing removed wintergreen from sandplain sites in the Connecticut Valley, and that recovery of populations has been slow.

Little bluestem (*Schizachyrium scoparium*) is an erect, perennial, grass that is well adapted to dormant season burns (Uchytil, 1989). Carbohydrates are stored below ground in the root system and shoots can resprout from insulated root crowns (Ewing and Engle, 1988). Summer fires greatly reduce cover as the apical meristem is exposed (Anderson and Claude, 1955; Abrams and Hulbert, 1987). Seeds from burnt areas have a higher germination rate than seeds from unburned areas (Ehrenreich and Aikman, 1963).

APPENDIX C. Field procedures downed-woody fuels inventory procedures

Manuel F. Correllus State Forest

Dukes County, Massachusetts

1996-1998

Supervisor - William Patterson

Field Workers- 1996 Andrew Finton and Beth Bardon

1997 Tom Warhol, Eric Brischler, and Adam Mouw

1998 Adam Mouw and Nate Goard

I. Equipment

A. Measuring devices

1. DBH tapes (2)
2. 100’ tapes, marked in feet and tenths on one side, meters on the other (2)
3. yard stick, marked in feet and inches
4. go-no-go gauges with increments that correspond to time lag classes (2)
5. spherical densiometer concave
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 40cm (1600cm^2) frame made from 1/2" PVC pipes

7. blank data sheets

8. paper bags for vegetation samples

II. Selecting and locating a plot

A. select stands that approximate the dominant vegetation types of the Forest

B. locate plot on Forest map and determine route to approach it

C. attempt to begin survey at center of plot

III. Downed Woody Fuels Inventory

A. Based on the presence of roads, trails, and changing forest types, select direction (N-S or E-W) for transects

1. four transects lines, 100 feet apart

2. five points on each transect, each 100 feet apart

B. Measure 150 feet from plot center in a direction perpendicular to transects (to avoid sampling through the plot center, which is fairly well trampled by now). This is point #1.

C. At each point:

1. use the densiometer to measure percent cover of all vegetation above waist height

2. use the Cruz-all to count how many trees are "in" a variable radius plot with a basal area factor of 10.

3. look at the second hand of a watch. Sampling plane will extend 50 feet in a direction at which the second hand points PLUS the bearing of the transects line.

(a) example: transect runs west at 270 degrees. Your second hand is on the 3. 3 X 30 degrees = 90 degrees. 90 degrees plus 270 degrees = 360 degrees. Your sampling plane should run at a bearing of 360 degrees, or true north.

(b) example: transect line runs north south at 180 degrees. Your second hand is on the 10. 10 X 30 degrees = 300 degrees

(c) 300 degrees plus 180 degrees = 480 degrees. 480 degrees minus 360 degrees = 120 degrees. Your sampling plane should run at a bearing of 120 degrees.

(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. Intersections 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

b) 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.

c) 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. Intersections should be divided into size classes.

i) 1/4 to 1 inch diameter

ii) 1-3 inch diameter

iii) 3+ diameter

b) 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

b) 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

(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 intersection between the sampling plane and any dead, unrooted woody material larger than three inches in diameter and below nine feet. 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

(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

E. Move along the transect to the next point, 100 feet away from the first, and repeat.

F. The goal is to sample 20 points/line per stand.

40 X 40 cm Biomass Plot Procedure

Manuel F. Correllus State Forest

Dukes County, Massachusetts

1998

Supervisor - William Patterson

Field Workers - 1998 Adam Mouw and Nate Goard

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

(4) 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”

1m X 1m Biomass Plot Procedure.

Manuel F. Correllus State Forest

Dukes County, Massachusetts

1998

Supervisor - William Patterson

Field Workers - 1998 Adam Mouw and Nate Goard

I. At ten randomly placed plots in each stand measure basal diameter all scrub oak stems to nearest 1/2 cm

   A. Measure all scrub oaks stems rooted within the plot

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

      1. Determine where the stems cross a vertical projection of the plot boundaries

      2. Measure every at this point, do not measure basal diameters

II. Laboratory procedures

   A. Enter all data into a 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)

Stand Survey Procedure.

Manuel F. Correllus State Forest

Dukes County, Massachusetts

1998

Supervisor - WilliamPatterson

Field Workers - 1998 Adam Mouw and Nate Goard

I. Selecting and locating a plot

A. select stands that approximate the dominant vegetation types of the Forest

B. locate plot on Forest map and determine route to approach it

C. attempt to begin survey at center of plot

II. Relevé

A. Walk around 10m radius circle and record all species present and the strata in which they appear (grass and forbs, low shrub, high shrub, and canopy)

B. For each species and each strata assign a cover class

1. 1 (>1%)
2. 2 (1%-5%)
3. 3 (5%-25%)
4. 4 (25%-50%)
5. 5 (50%-75%)
6. 6 (75%-100%).

III. Vegetation survey

A. Record average height of each vegetation layer from a plot 0.6m in radius to the nearest 10cm.

1. For grasses and forbs measure the average height of the layer to the nearest 5cm.
2. For low shrubs measure the average height of the layer to the nearest 5 cm.
3. For high shrubs, measure the average height of the layer to the nearest 5 cm.
4. In future studies, determine the average height of the shrub layers as a whole as 70% of the maximum high shrub height.

B. Record the average height to the base of the live crown and total tree height to the nearest 5 ft.

C. Determine basal area using a Cruz-all with either a 5 or 10 ft^2/acre BAF so that at least ten stems are sampled.

1. Record species of each stem sampled
2. For oaks, determine if the stem is part of a coppice stump
3. For pines record if the stem is live or dead.

D. Proceed to the next plot using the random-bearing method

1. Make note of any species encountered not noted in the relevé
2. Make note of fire scars, cut stumps, and other evidence of disturbance
3. In plantations, make note of spacing and trend of planted rows as well as evidence as to the planting method such as furrows.

APPENDIX D. Data sheets for extensive field surveys.

APPENDIX E. Aerial photo vegetation classification key

APPENDIX F. TESTMODEL outputs from BEHAVE

Pg 2

Pg 3

Pg 4

Pg 5

APPENDIX G. Weather data collected at 1300hrs. at MFCSF headquarters for April 1994 and March-April, 1995.

APPENDIX H. Transition matrices

Appendix H, Table 1. Transition matrix for vegetation development, derived from 1938 and 1995 aerial photos. Data represent changes (in acres) of vegetation classification between 1938 and 1995 aerial photo interpretation

Appendix H. Table 2. Transition matrix for vegetation development, derived from 1938 and 1952 aerial photos. Data represent changes (in acres) of vegetation classification between 1938 and 1952 aerial photo interpretation

Appendix H. Table 3. Transition matrix for vegetation development, derived from 1952 and 1995 aerial photos. Data represent changes (in acres) of vegetation classification between 1952 and 1995 aerial photo interpretation

APPENDIX I. Reordered AGGLOM data.

Page 1.

Appendix I, Reordered AGGLOM data (page 2)

Bibliography

Abrams, M. D. 1992. Fire and the development of oak forests. BioScience Vol. 42, No. 5. Pp 346-353.

________ and L. C. Hulbert. 1987. Effect of topographic position and fire on species composition in tallgrass prairie in northeast Kansas. American Midland Naturalist. 117(2): 442-445.

Adams, M. B. 1992. The state forest; wasteland in the woodland. New Agenda for hope. Martha's Vineyard Magazine. Fall/ Holiday. Pp. 13-19

Anderson, H. E. 1982. Aids to determining fuel models for estimating fire behavior. USDA For. Serv. Gen. Tech. Rep. INT-122, 22p. Intermt. For. And Range Exp. Stn., Ogden, Utah.

Anderson, K. L. and C. L. Fly. 1955. Vegetation-soil relationships in Flint Hills bluestem pastures. Journal of Range Management. 8: 163-169.

Andrews P. L. 1986. BEHAVE: fire behavior prediction and fuel modeling system, --BURN subsystem, part 1. USDA Forest Service General Technical Report INT-194. Odgen, UT

________ and C. H. Chase. 1989. BEHAVE: fire behavior prediction and fuel modeling system –BURN subsystem, part 2. USDA Forest Service General Technical Report INT-260. Odgen, UT.

Boose, E. R., D. R. Foster, M. Fluet. 1994. Hurricane impacts to tropical and temperature forest landscapes. Ecological Monographs, 64(4). pp369-400.

Bourgeron, P. S., A. M. Kratz, T. Weaver, and N. Weidman. 1988. Bibliography of Montana vegetation description. Great Basin Naturalist. 48(3): 301-401

Burgan R. E. and R. C. Rothermal. 1984. BEHAVE; fire behavior prediction and fuel modeling subsystem – FUEL subsystem. USDA Forest Service General technical report INT-167. Intermountain Forest and Range Experiment Station, Odgen, UT. 126pp.

Bromely, S. W. 1935. The original forest type of southern New England. Ecological Monographs 5:61-89.

Brown, J. K. 1974. Handbook for inventorying downed woody material. USDA Forest Service General Technical Report INT-16. Ogden, UT. 24pp.

Carey, J. H. 1994. *Gaylussacia baccata.* In: Fischer, W. C., compiler. The Fire Effects Information System [Data base]. Missoula, MT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Intermountain Fire Sciences Laboratory

________ 1993. *Pinus strobus*. In: Fischer, W. C., compiler. The Fire Effects Information System [Data base]. Missoula, MT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Intermountain Fire Sciences Laboratory

________ 1992. *Quercus velutina*. In: Fischer, W. C., compiler. The Fire Effects Information System [Data base]. Missoula, MT:U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Intermountain Fire Sciences Laboratory.

________ 1992. *Quercus stellata*. In; Fischer, W. C., compiler. The Fire Effects Information System [Data base]. Missoula, MT; U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Intermountain Fire Sciences Laboratory

________ 1992. *Pinus rigida*. In: Fischer, W. C., compiler. The Fire Effects Information System [Data base]. Missoula, MT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Intermountain Fire Sciences Laboratory.

Chandler, C., P. Cheney, P. Thomas, L. Trabaud, and D. Williams. 1983. Fire in Forestry. Wiley-Interscience Publication, John Wiley & Sons, New York, New York, vol.1,2.

Chokkalingam, U. 1995. Recent disturbance-mediated vegetation change at Cape Cod National Seashore. M.S. thesis, University of Massachusetts, Amherst. 127pp.

Clark J.S. and W. A. Patterson, III. 1985. The development of a tidal marsh; upland and oceanic influences. Ecol Monogr 55:189-217.

Coladonato, M. 1994. *Gaultheria procumbens*. In: Fischer, W. C., compiler. The Fire Effects Information System [Data base]. Missoula, MT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Intermountain Fire Sciences Laboratory.

________ 1990. *Pteridium aquilinum*. In: Fischer, W. C., compiler. The Fire Effects Information System [Data base]. Missoula, MT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Intermountain Fire Sciences Laboratory.

Cryan, J. F. 1985. Retreat in the barrens. Defenders, Jan/Feb. 18-29pp.

Day, G. 1953. The Indian as an ecological factor in the Northeastern forests. Ecology 34:329-346.

Del'Orfano, M. 1996. Fire behavior prediction and fuel modeling of flammable shrub understories in northeastern pine-oak forests. M.S. Thesis, Worcester Polytechnic Institute. Worcester. MA.

DEM. 1994. An ecosystem management plan for the Manuel F. Correllus State Forest. Draft unpublished report.

________ 1999. Vegetation measurements in firebreak areas on Manuel F. Correllus State Forest. Report on file with the DEM. 17pp.

Dosmann, M. G., W. A. Patterson, III, E. Stack, and C. Caljouw. 1991. Fire regime of a Massachusetts scrub oak-pitch pine barren. In: Proceedings, 17th Tall Timbers fire ecology conference; 1989 May 18-21; Tallahassee, FL. Tallahassee, FL: Tall Timbers Research Station: 409-410. Abstract.

Droege, **M. F.** 1996. The seasonal variation in total available carbohydrates in rhizomes of huckleberry (*Gaylussacia baccata*) and its implications for fire management. Unpublished Masters' Thesis, University of Massachusetts, Amherst, Department of Forestry and Wildlife Management. 64pp.

Dunwiddie, P. W. 1994. Martha's Vineyard landscapes: the nature of change. Vineyard Conservation Society, Massachusetts. 60pp.

________ and C. Caljouw. 1990. Prescribed burning and mowing of coastal heathlands and grasslands in Massachusetts. Ecosystem Management: Rare Species and Significant Habitats. New York State Museum Bulletin 471. 1990 pp. 271-275.

Eaton, E. L. and R. G. White. 1960. The relation between burning dates and the development of sprouts and flower buds in the lowbush blueberry. American Society for Horticultural Science. 76: 338-342.

Ehrenreich, J. H. and J. M. Aikman. 1963. An ecological study of the effect on certain management practices on native prairie in Iowa. Ecological Monographs. 33(2): 113-130.

Ewing, A. L. and D. M. Engle. 1988. Effects of late summer fire on tallgrass prairie microclimate and community composition. American Midland Naturalist. 120(1): 212-223.

Finton, A. D. 1998. Succession and plant community development in pitch pine-scrub oak barrens of the glaciated northeast United States. Unpublished Master's Thesis, University of Massachusetts. 179pp.

Flinn, M. A. and J. K. Pringle, 1983. Heat tolerance of rhizomes of several understory species. Canadian Journal of Botany. 61: 452-457.

________ and R. W. Wein. 1977. Depth of underground plant organs and theoretical survival during fire. Canadian Journal of Botany. 55: 2550-2554.

Foster, D. R. 1992. Land-use history (1730-1990) and vegetation dynamics in central New England, USA. Journal of Ecology, 80. Pp 753-772.

________ and G. Motzkin. 1999. Historical influences on the landscape of Martha's Vineyard: perspectives on the management of the Manuel F. Correllus State Forest. Harvard Forest Paper No. 23. Harvard University Press. 48pp.

Garren, K. H. 1943. Effects of fire on vegetation of the southeastern United States. Botanical Review. 9: 617-654.

Goldstein, P. Z. Grassland insects on Marta's Vineyard. 217-236. In: Grasslands of North America. 1997. Ed. P. D. Vickery and P. W. Dunwiddie. Massachusetts Audubon Society, Lincoln Massachusetts. 297 pp.

Hamerstrom, F. N., Jr. 1939. A study of Wisconsin prairie chicken and sharp-tailed grouse. Wilson Bulletin. 51(2): 105-120.

Heinselman, M. L. 1973. Fire in the virgin forests of the Boundary Waters Canoe Area, Minnesota. Quaternary Research. 3: 329-382

High Performance Systems, Inc. 1998. Stella program information, untitled information package. 15pp.

Intermountain Fire Sciences Laboratory. 1998. FARSITE 3.0 documentation. Missoula, MT

Johnson, F. L. and P. G. Risser. 1975. A quantitative comparison between an oak forest and an oak savanna in central Oklahoma. Southwestern naturalist, 20(1); 75-84.

Johnson, P. S. 1992. Oak overstory/reproduction relations in two xeric ecosystems in Michigan. Forest Ecology and Management. 48: 233-248.

Ledig, F. T. and S. Little. 1979. Pitch pine (Pinus rigida Mill.): ecology, physiology, and genetics. In:, Forman, R. T. T., ed. Pine Barrens: Ecosystem and landscape. New York: Academic Press, Inc.: 347-371.

Little, S. 1998. Fire and plant succession in the New Jersey Pine Barrens. In: Pine barrens ecosystem and landscape. Ed. R. T. T. Forman. Rutgers University Press, New Jersey. 601pp.

________ and E. B. Moore. 1949. The ecological role of prescribed burns in the pine-oak forests of southern New Jersey. Ecology. 30(2): 223-233.

Matlack, G., R., D. J. Gibson, and R. E. Good. 1993. Regeneration of the shrub *Gaylussacia baccata* and associated species after low-intensity fire on an Atlantic coastal plain forest. American Journal of Botany 80(2): 119-126.

Melton, M. 1989. The Keetch/Byram Drought Index: A guide to fire conditions and suppression problems. Fire Management Notes 50(4):30-34.

Milne, B. T. 1985 Upland vegetational gradients and post-fire succession in the Albany Pine Bush, New York. Bulletin of the Torrey Botanical Club 112:21-34.

Motzkin, G., D. R. Foster, A. Allen, J. Harrod, and R. Boone. 1996. Controlling site to evaluate history: vegetation patterns of a New England sand plain. Ecological Monographs 66(3).

________, G., W. A. Patterson, III, and N. E. R. Drake. 1993**.** Fire history and vegetation dynamics of a *Chamaecyparis thyoides* wetland on Cape Cod, Massachusetts. J Ecol 81:391-402.

________, ________ , and D. R. Foster. 1999. A historical perspective on pitch pine-scrub oak communities in the Connecticut valley of Massachusetts. Ecosystems, 2:255-273.

Mueller-Dombois D. and H. Ellenberg. 1974. Aims and methods of vegetation ecology. New York; John Wiley and Sons.

National Advanced Resource Technology Center. 1997. Fireregimes: Applying Ecological Principles to Manage Wildland Fire.

Oldale, R. N. and R. A. Barlow. 1986. Geologic map of Cape Cod and the Islands, Massachusetts. U. S. Geological Survey Map I-1763, Reston, Virginia.

Oliver, C. D. and B. C. Larson. 1996. Forest stand dynamics. John Wiley and Sons, Inc. New York, New York. 519pp.

Olson, J. S. 1958. Rates of succession and soil changes on southern Lake Michigan sand dunes. Botanical Gazette. 119(3): 125-170.

Olsvig, L. S. 1980. A comparative study of northeastern pine barren vegetation. Ph.D. Thesis, Cornell Univeristy. 479pp.

Patterson, W. A. III. 1999. Post-fire development and potential fire behavior for the Waterboro Barrens, Southwestern Maine. Report submitted to the Maine Chapter, The Nature Conservancy. 19pp.

________ and K. E. Sassaman. 1988. Indian fires in the prehistory of New England. In: Holocene human ecology in northeastern North America. Ed G. P. Nicholas. Plenum Publishing Corp. Pp. 107-133.

________, K. E. Saunders, and L. J. Horton. 1983. Fire regimes of Cape Cod National Seashore. USDI NPS North Atlantic region Office of Scientific Studies Report OSS83-1.

Pyne, S. J. , P. L. Andrews, and R. D. Laven. 1996. Introduction to wildland fire. John Wiley and Sons, Inc. New York, New York. 769pp.

Reiners, W. A. 1965. Ecology of a heath-shrub synusia in the pine barrens of Long Island, New York. Bulletin of the Torrey Botanical Club. 92(6): 448-464.

Richardson, J. B. 1985. Prehistoric man on Martha’s Vineyard. Oceanus 28: 35-42.

Rivers, W. H. 1997. Coming Full Circle: Restoring Sandplain Grassland Communities in the State Forest on Martha's Vineyard, Massachusetts. 79-84. In: Grasslands of North America. 1997. Ed. P. D. Vickery and P. W. Dunwiddie. Massachusetts Audubon Society, Lincoln Massachusetts. 297 pp.

Roby, G. A. and L. R. Green. 1976. Mechanical methods of chaparral modification. U.S. Dep. Agric., Agric. Handb. 487. 46pp.

Rudnicky, J. L., W. A. Patterson III, and R. P. Cook. 1997. Experimental Use of Prescribed Fire for Managing Grassland Bird Habitat at Floyd Bennett Field, Brooklyn New York. 99-118. In: Grasslands of North America. 1997. Ed. P. D. Vickery and P. W. Dunwiddie. Massachusetts Audubon Society, Lincoln Massachusetts. 297 pp.

Ruffner, C. M and W. A. Patterson III. 1999. Fire History of the Upper Cape Cod region, southeastern Massachusetts.

Schweitzer D. F. and T. J. Rawinski. 1988. Northeastern pitch pine/scrub oak barrens. Eastern Heritage Task Force, The Nature Conservancy, Boston, Massachusetts, USA.

Snyder, S. A. 1993. Comptonia peregrina. In: Fischer, W. C., compiler. The Fire Effects Information System [Data base]. Missoula, MT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Intermountain Fire Sciences Laboratory.

Soil Conservation Service. 1986. Soil Survey of Dikes County, Massachusetts. 144pp.

Stevens, A. 1996. The paleoecology of coastal sand plain grasslands on Martha's Vineyard, Massachusetts. Ph.D. thesis, University of Massachusetts, Amherst.

STORMFAX Inc. 1999. Climatological data from Martha's Vineyard, 1961-1990. www.stormfax.com

Stransky, J. J. 1990. Quercus stellata. In: Burns, R. M. and B. H. Honkala. tech. coord. Agric. Handb. 654. Silvics of North America. Vol.2. hardwoods. Washington, DC; U.S. Department of Agriculture, Forest Service: 738-743.

Thor, E. and G. M. Nichols. 1974. Some effects of fires on litter, soil, and hardwood regeneration. In: Proceedings, annual Tall Timbers fire ecology conference; 1973 March 22-23; Tallahassee, FL. No. 13. Tallahassee, FL: Tall Timbers Research Station: 317-329.

Tirmenstein, D. A. 1991. *Quercus alba*. In: Fischer, W. C., compiler. The Fire Effects Information System [Data base]. Missoula, MT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Intermountain Fire Sciences Laboratory

________1991. *Vaccinium angustifolium*. In: Fischer, W. C., compiler. The Fire Effects Information System [Data base]. Missoula, MT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Intermountain Fire Sciences Laboratory

Uchupi, E. and R. N. Oldale. 1994. Spring sapping origin of the enigmatic relict valleys of Cape Cod and Martha's Vineyard and Nantucket Islands, Massachusetts. Geomorphology 9;83-95.

Uchytil, R. J. 1989. *Schizachyrium scoparium*. In: Fischer, W. C., compiler. The Fire Effects Information System [Data base]. Missoula, MT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Intermountain Fire Sciences Laboratory.

Wendel, G. W. and H. C. Smith. 1990. *Pinus strobus* L. eastern white pine. In: Burns, R. M. and B. H. Honkala, technical coordinators. Silvics of North America. Volume 1. Conifers. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture, Forest Service: 476-488.

Whitaker, R. H. 1979. Vegetational relationships of the Pine Barrens. Pages 315-331. In: R. T. T. Forman, editor. Pine barrens: ecosystem and landscape. Academic Press, New York, New York, USA.

Woodall, C. A. 1998. Prescribed fire behavior and custom fuel modeling in the pitch pine-scrub oak barrens and pine-oak forests of New England. 33pp.

Wright, H. A. and A. W. Bailey. 1982. Fire ecology: United States and southern Canada. New York: John Wiley & Sons. 501p.