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The Effects of Fire and Shrub Cutting on Rare and Endangered Plants in the Ninigret National Wildlife Refuge

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**THE EFFECTS OF FIRE AND SHRUB CUTTING ON RARE AND
ENDANGERED PLANTS IN THE NINIGRET NATIONAL WILDLIFE REFUGE**

BY

AMANDA CLIFTON

**A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
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OF

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Abstract

The decline in rare plant populations and the decrease in size of their native ranges have led to escalating losses of biodiversity. A combination of shrub cutting and fire was applied to an endangered species "hot spot" in southern Rhode Island, USA to determine the effects of these treatments on a group of eight rare herbaceous plant species exposed to ever-increasing encroachment by tall shrubs. Shrub cutting and fire were also applied to a shrub-dominated area adjacent to the hot spot to determine if it was possible to promote establishment and growth of the rare plants in areas in which they were not found in abundance. My analyses focused on the three rare species that were found in greatest abundance within the rare plant area; *Aletris farinosa*, *Platanthera ciliaris*, and *Polygala cruciata*. Fire appeared to have a positive effect on the reproductive output of the endangered orchid *Platanthera ciliaris*; the mean density of inflorescences doubled from 0.70 inflorescences/m² in 2005 to 1.41 inflorescences/m² in 2006 in plots that were burned. However, this difference was not statistically significant. Significant differences in vegetation characteristics were observed between plots in which rare plants were present and plots in which rare plants were absent. *Platanthera* and *Aletris* had negative relationships with woody plant cover, and positive relationships with herbaceous plant cover. The density of *Aletris* was significantly correlated with the density of *Drosera* sp. ($r=0.73$, $P<0.001$), a species indicative of disturbed, nutrient poor environments. Fire had no effect on the cover of woody plants within the rare plant area, however, fire did have an effect on the cover and height of woody plants in adjacent experimental sectors. In 2006, all combinations of shrub cutting and fire decreased the cover and height of woody plants

in these sectors. No rare plants were found in the sector plots adjacent to the rare plant area, but the cut treatment applied to one of these sectors caused the rapid proliferation of the invasive woody vine *Celastrus orbiculatus*. The density of *Celastrus* was an order of magnitude higher in the cut sector than in the control. In an adjacent sector that was both cut and burned, the native shrub *Rhus copallinum* produced a similar rapid response to the treatment. Continued management must now focus on limiting the potential harmful impacts of *Celastrus* while promoting growth and establishment of the rare plants at the site.

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Introduction

The significant loss of rare plant populations and the decrease in size of their historical ranges is a problem both regionally in New England (Farnsworth and Ogurcak 2006) and throughout the world (Kirkpatrick and Gilffeder 1995, Norton and De Lange 2003, Wotavova et al. 2004). There are, however, extant sites that still support relatively large numbers of rare plant populations, thus contributing to locally high levels of biodiversity (Farnsworth and Ogurcak 2006). These areas are often called "hot spots" of biodiversity and are critical to conservation efforts because preservation and management of relatively small areas of land can protect disproportionately large numbers of rare species (Dobson et al. 1997).

One such endangered species "hot spot" exists within the Ninigret National Wildlife Refuge (NNWR) in Charlestown, Rhode Island (Killingbeck et al. 1998). An area just 2,300 m² in size supports an assemblage of at least eight species of plants considered to be rare or endangered in the state of Rhode Island and found at few other localities in the state (Enser 2002). The "endangered species hot spot" at Ninigret contains more individuals of the state-endangered yellow-fringed orchid, *Platanthera ciliaris*, than all of the rest of New England combined (Killingbeck et al. 1998). When the site was first discovered in 1993, it was clear that the relatively small area provided habitat for a variety of biologically important plant species.

When earlier field studies were initiated at the site, it was apparent that, while rare plant density was extremely high within the 2,300m² core of the hot spot, relatively few rare plants existed beyond the boundaries of this area. The curious presence of an abrupt, definitive boundary coupled with an equally abrupt difference

in soil organic matter suggested that anthropogenic disturbance played a key role in the development of vegetation at this site (Killingbeck et al. 1998). However, the limited disturbance history of the site offers limited clues to deduce the profound landscape changes that have occurred in the past 100 years. Additionally, there is even a high degree of uncertainty regarding the species composition and structure of all coastal New England vegetation in presettlement times (Day 1953, Foster and Motzkin 2003, Marks 1983).

While disturbance can lead to the outright destruction and elimination of communities, it can also promote variation in the landscape and, in turn, provide conditions necessary to enhance species richness (Kirkpatrick and Gilfedder 1995). Cultural practices such as mowing, plowing, and burning have perpetuated grasslands and shrublands for hundreds of years by preventing their progression to forested systems (Foster and Motzkin 2003). However, changes in land use have led to the cessation of certain historical disturbance regimes and, in turn, the preservation of habitats that support many rare and unique species of plants (Hall et al. 2002, Latham 2003). It is necessary to reconcile the historical and environmental influences that have impacted the landscape in order to actively conserve these important habitats (Foster 2002, Foster and Motzkin 2003, Neill et al. 2007).

Rare plants are frequently found within anthropogenically-disturbed landscapes (Latham 2003, Zaremba 2004), and much work has been done to explore the relationships between rare plants and disturbance history (Baskin et al. 1997, Clarke and Patterson 2006, Vickery 2001). For many rare North Atlantic coastal plant species, disturbance is necessary to provide the environmental conditions that

favor their existence at a particular site (Clarke and Patterson 2006, Motzkin and Foster 2002). Fire functions as one such critical disturbance in early successional communities and has been shown to promote growth and flowering in some herbaceous plants (Jacobson et al. 1991). Many studies have shown that flowering in orchids and other geophytes is enhanced by fire (Lamont and Runciman 1993, Whelan 1995), and consequently, larger populations are observed after burning (Lunt 1997, Norton and de Lange 2003, Stuckey 1967). Fire can also have indirect effects, one of which is the removal of competing vegetation (Jacobson et al. 1991), which increases both light availability and openings for seedling establishment (Gankin and Major 1964).

Tree and shrub clearing has also been used as a method to promote or restore biodiversity to a system facing increased encroachment of vegetation capable of outcompeting target species (Barbaro et al. 2001). Many rare, herbaceous plants depend on open, short vegetation with patches of bare ground for establishment (Dolman and Southerland 1992). Habitat for low-growing species is often maintained by disturbance or grazing, however, restoration efforts, such as shrub cutting, can simulate such processes (Zobel et al. 1996). In the absence of alternative management, shrubs and trees are likely to dominate communities that were formerly composed of species of shorter stature (Bakker et al. 1996, Bullock and Pakeman 1997).

Previous studies at the Ninigret site offered evidence that shrub cutting and/or fire had a positive effect on at least four species of rare plants (Keller and Killingbeck 2004), yet additional experiments were needed to determine whether continued

frequent, periodic fire would elicit a similar response. To understand how the practice of prescribed burning might change the population dynamics of the rare plants at the site, experimental manipulations including a combination of shrub cutting and fire were utilized at the Ninigret Endangered Species Area (NESA) to reduce light limitation due to shading.

An additional goal of the study was to determine whether areas beyond the margins of the rare plant "hot spot" could be manipulated to provide the conditions necessary for establishment and growth of the rare plants. The experimental design included clearing a shrub-dominated area adjacent to the "endangered species hot spot" with three combinations of shrub cutting and fire to determine how areas harboring few, if any, rare species would respond. The discovery of a number of stems of *Platanthera ciliaris* in 2004 in a mowed firebreak adjacent to the hot spot suggested that such manipulations could be instrumental in increasing the population sizes of at least some of the rare plant species beyond the core area.

The main objective of the study was to determine the efficacy of using shrub cutting and fire to enhance populations of rare plants that might otherwise face shade-induced reductions, or extirpation. This study aimed to address the following specific questions: (1) what are the estimated population sizes for the rare plant species found within the NESA core?; (2) does the application of fire or shrub cutting change the density, percent cover, or number of inflorescences for the rare plants or associated vegetation within the NESA core?; (3) what habitat characteristics are most highly related to the distribution and abundance of the rare species at this site?; and (4) what are the effects of fire and shrub cutting on tall shrubs adjacent to the NESA core, and

does burning, cutting, or scarification promote establishment of rare plants outside of the "hot spot"?

Site Description

The study took place within the Ninigret National Wildlife Refuge, located in Charlestown, Rhode Island (41° 22' N, 71° 40' W). The site is directly adjacent to Ninigret Pond, an inland brackish pond separated from Block Island Sound by a barrier beach. The complete study area within a perimeter firebreak ('site') includes the 2,300m² Ninigret endangered species area "hot spot" (to be referred to as 'NESA core'), and the areas adjacent to the NESA core that were treated in 2005 (to be referred to as 'experimental sectors'). With the addition of the experimental treatment sectors in 2005, the entire site encompasses over 7,300m² including the control sector (1,600 m²) the burn sector (1,200 m²), the cut sector (1,220 m²), and the cut and burn sector (660 m²).

The site is dominated by shrubs, grasses, and many low-growing herbaceous plants. Dominant shrub species include *Myrica pennsylvanica* L. (bayberry), *Clethra alnifolia* L. (sweet pepperbush), *Amelanchier canadensis* (L.) Medik. (shadbush), and *Vaccinium corymbosum* L. (highbush blueberry). Grass species identified at the site include *Andropogon gerardii* Nash. (big blue stem), and *Phalaris arundinacea* L. (reed canary grass), while plants such as *Vaccinium macrocarpon* Ait. (cranberry), *Drosera sp.* L. (sundew), as well as a variety of lichen and moss species are all part of this unique community.

The NESA core supports multiple species of rare plants and has been sampled repeatedly since 1996. The eight known species of rare plants are *Aletris farinosa* L. (colic root; Rhode Island state threatened), *Platanthera ciliaris* (L.) Lindl. (yellow-fringed orchid; Rhode Island state endangered), *Polygala cruciata* L. (Marsh

milkwort; Rhode Island state threatened), *Spiranthes tuberosa* Raf. (little ladies'-tresses, Rhode Island state endangered), *Scleria pauciflora* Muhl. (Carolina whipgrass; Rhode Island state threatened), *Scleria triglomerata* Michx. (whipgrass; Rhode Island state threatened), *Sorghastrum nutans* (L.) Nash (Indian grass; Rhode Island state concern), and *Aristida longespica* Poir. (slimspike three-awn; Rhode Island state concern) (Enser 2002). Additionally, *Platanthera ciliaris* is considered to be regionally rare in New England (Division 2, State Endangered 1, Brumback and Mehrhoff 1996).

Aletris farinosa is one of just five species in the genus *Aletris* that occurs in North America (Sullivan 1973). *Aletris*, part of the family Liliaceae, is a geophyte with fleshy, underground tissues that serve reproductive and storage functions (Rutters et al. 1993). Like *Aletris*, *Platanthera* is a geophyte and part of the family Orchidaceae. *Polygala*, part of the family Polygalaceae, differs as it is an annual plant. The population of *Aletris* within the Ninigret National Wildlife Refuge is one of eight extant populations in the state of Rhode Island (Enser 2002). Including the Ninigret site, *Platanthera* and *Polygala* are documented in just two and three sites, respectively, in Rhode Island.

The Ninigret refuge is the former site of the United States Naval Auxiliary Air Station at Charlestown. Owned and operated by the U.S. Navy from 1943-1973, its primary use was in training Navy pilots for night flights. Due to their close proximity to open water, the runways at this site served to simulate aircraft carrier landing decks. During this time, considerable alterations took place in what is now refuge property, as evidence from pre- and post-base aerial photographs suggests.

Although no runways or buildings covered the rare plant site, observations of debris and remnants of equipment suggest that some type of disturbance took place. Aerial photos indicate that soil removal may have occurred during the U.S. Navy's ownership of the land. Soil samples taken within the rare plant area support this theory (Killingbeck et al. 1998).

Methods

Data previously obtained at this site (in 1996, 2002, 2003, and 2004; Keller and Killingbeck 2004) were collected from 61 0.5-m² permanent plots distributed throughout the NESA core along 13 transects (Killingbeck et al 1998). Transects were established perpendicular to a northeast/southwest line that bisected the NESA core, and were positioned in randomized locations within eight-meter intervals.

Along each of the 13 transects, permanent sampling plots were established in randomized locations within four-meter intervals in the spring of 2005.

Randomization within each four- and eight-meter segment was achieved by dividing each interval into one-meter units and then choosing by random draw the meter segment at which each plot would be located. All 87 original plots were sampled for the 2005-2006 study.

In 2005, the area of dense woody shrubs beyond the NESA core was divided by five-meter wide firebreaks into four sectors and each sector was given a separate experimental treatment (Figure 1). This experimental design included plots that were cut and burned (Sector D), cut only (sector C), burned only (Sector B), and left untreated (control, Sector A, Figure 2). Treatments for the four sectors were assigned randomly. The original 13 transects were extended approximately 30-40m to the northwest and ended at the perimeter firebreak that surrounds the site. Fifteen new plots were established in each of the four sectors along three expanded transect lines in each sector. The protocol for plot placement explained above was also used to expand the already existing transects and establish a total of 60 new 0.5-m² plots in the densely dominated shrub area beyond the original NESA core.

Five plots on each transect line were distributed randomly at four-meter intervals. Due to constraints imposed by the shape of the cut and burn sector, plot placement deviated slightly from the above design (see Figure 1). If a four-meter interval fell within one meter of a tree, the four-meter interval was skipped and the plot was established within the next four-meter interval.

Geographic coordinates were taken directly over each permanent plot marker, firebreak boundaries and experimental sector boundaries with a Garmin handheld GPS unit, and were imported into ArcMap. All other geospatial data used for the site map were obtained from the Rhode Island Geographic Information System server (RIGIS 1989 and RIGIS 2005).

Fire and shrub-cutting treatments were formally approved by Suzanne Paton (Biologist, USFWS, Ninigret National Wildlife Refuge) and Rick Vollick (USFWS, Northeastern Regional 'Burn Boss') and were applied in spring 2005. Both the cut-only and the cut and burn sectors were mowed in late March 2005 using Brush Hog and Bat Wing mowers. Employees of the U.S. Fish and Wildlife service performed the cut treatments in these two sectors and also mowed three, five-meter wide firebreaks to separate the four new experimental sectors as well as the five-meter wide outer firebreak that surrounds the entire site. The NESA core, the burn sector, and the cut and burn sector were burned on 5 May 2005 by a team of fire management professionals from the U.S. Fish and Wildlife Service.

Temperature sensitive paints (Tempilaq, Tempil Division, Air Liquide America Corporation, South Plainfield, NJ) were deployed in each plot before the 2005 fire to measure the maximum temperature attained during the burn. A series of

five paints with melting points of 200°F, 400°F, 600°F, 800°F, and 1000°F were painted in thin strips on metal tags and were hung 10cm above ground level prior to the burn. Tags were hung in all 61 core plots, in all 15 plots in the cut and burn sector, and all 15 plots in the burn sector. Tags were examined after the burn to determine the maximum temperature attained. Additional visual examination in the field immediately following the burn provided information on the extent of the burned area in each plot based on the percentage of surface area charred in each plot. Each burned plot in the core was assigned one of the following charring coverage classes: A (no charring), B (less than 5% charring), C (5-20% charring), D (20-40% charring), E (40-60% charring), F (60-80% charring) G (80-99% charring) and H (100% charring).

Metal fire exclosures were deployed around 16 plots within the NESA core immediately prior to the burn. These rectangular sheet metal exclosures completely enclosed each 0.5-m² plot and included a 5-cm buffer along all sides of each plot to protect the plants inside. Fire-excused plots were chosen in pairs based on treatments that were applied in 2003. Eight pairs of fire-excused plots were randomly chosen from all pairs of adjacent plots in which one of the plots had been experimentally cut in 2003 while the other in the tandem had not. These fire-excluded plots (9, 10, 18, 19, 21, 22, 31, 32, 34, 35, 45, 46, 48, 49, 60, 61), were also protected from a previous fire treatment in 2003. Charring classes and Tempilaq tags were both used to confirm whether these plots were truly excluded from fire during the 2005 burn.

Topsoil was removed from a group of 15 0.5-m² plots in the 2005 growing season to determine if the removal of topsoil plays a role in rare plant emergence or establishment. These scarified plots were created to mimic what appeared to be the removal of topsoil in the NESA core while the entire site was under U.S. Navy ownership over 50 years ago. The soil was removed to a depth of approximately 25 cm from 15 plots in the cut and burned sector. Each new scarified plot was offset from an established plot by one meter.

Collection of plant species data took place in August and September in both 2005 and 2006 within 0.5-m² PVC quadrats that were placed over each aluminum or steel pipe that marked the northwest corner of each of the plots. The 87 plots original plots, as well as the 60 new plots and 15 scarified plots were sampled. Measurements for the eight rare plant species in all 162 plots included density (number of stems) and dominance (percent cover), numbers of stems with inflorescences, and maximum height of inflorescences. All plots were also assessed for the number and percent cover of the carnivorous sundew *Drosera* spp., percent cover of mosses, percent cover of lichens, percent cover and mean height of herbaceous and graminaceous species, percent cover and mean height of woody species, and percent cover of unvegetated soil. Collectively, these latter parameters were thought to be indicative of the recent disturbance history of this site (Brewer 1999, Eldridge et al 2000, Juniper et al 1989, Sedia and Ehrenfeld 2003). Sampling of the scarified plots took place in the summer of 2006 to determine if scarification on the periphery of the NESA core would promote the establishment of rare plant species.

All plant nomenclature follows Gleason and Cronquist (1991) except for *Platanthera ciliaris* (Brumback and Mehrhoff 1996).

Statistical Analyses

Within the NESA core, plots were segregated between those burned and those not burned in 2005. Plots considered to be burned were those with a cover class of B (at least 5% charring) or higher and one or more melted Tempilaq paint strips. Plots considered to be unburned in 2005 were those with a charring class of A (no charring) or B (less than 5% charring), and unmelted Tempilaq paints.

Associated organisms and plot characteristics were analyzed based on two categories of plots: plots in which rare plants were present, termed occupied plots, and plots in which rare plants were absent, termed unoccupied plots. All burned and unburned plots were included in this analysis.

The Lilliefors test was used to determine whether data were normally distributed. Probabilities of differences among treatments were generated with the Kruskal-Wallis statistic to test for differences among burn cover classes and maximum temperatures attained during the burn. Tests for an interaction between year and treatment were generated by comparing the change in burned plots between years and the change in unburned plots between years using the Wilcoxon rank-sum test. The Wilcoxon rank-sum test was also used to test for pairwise differences among burned and unburned plots and habitat characteristics in plots occupied and unoccupied by rare plants.

Percent cover of lichens, moss, unvegetated soil, and *Drosera* (referred to collectively as “indicators”) were thought to be potential indicators of past

disturbance that may have facilitated the colonization of the NESA core by rare plants. Cover and mean height of both herbaceous and woody plants were referred to collectively as “vegetation characteristics.” Correlations between the rare plants and indicators were generated from a Pearson correlation matrix. Regression analyses were completed on woody and herbaceous vegetation and rare plant density, number of inflorescences, and cover, and adjusted coefficients of determination were reported.

Statistical analyses of the rare plant data were completed for *Aletris*, *Platanthera* and *Polygala* (Figure 3). All other species were not conducive to statistical testing due to their extremely low numbers or absence within the NESA core plots. Data on the abundance of these species were generated by active searches within the entire NESA core.

Statistical analyses were completed with SYSTAT software (Wilkinson 1992).

Results

Estimated population sizes

Six of the eight rare species known to exist at the site were documented during the 2005 and 2006 growing seasons (Table 1). Overall, every rare species observed increased in density from 2005 to 2006. *Sorghastrum* and *Aristida* were not found within the NESA core despite an active search both years. *Spiranthes*, while found in 2006, was not observed in the NESA core in 2005. Since data collection began at the site in 1996, estimated populations of all rare plant species have been highly variable between years and between plots within the NESA core (see Appendix B).

Effects of fire within the NESA Core

Burned plots within the NESA core were subjected to a range of intensity and coverage by the 2005 fire (Table 2). High charring did not necessarily denote a high intensity burn. Maximum temperature attained during the burn and charring cover class had no significant effect on the density, number of inflorescences or percent cover of *Aletris*, *Platanthera*, or *Polygala* in either 2005 or 2006 ($P > 0.05$, Kruskal-Wallis).

In 2005, maximum temperature was significantly related to both mean height of herbaceous plants and the amount of unvegetated soil present, which were both significantly higher in plots reaching 1,000°F than in plots reaching all lower temperatures ($P < 0.001$, Kruskal-Wallis). Woody plant cover and mean height were not related to maximum temperatures attained during the burn or by the extent of charring observed in either 2005 or 2006 ($P > 0.05$, Kruskal-Wallis).

In 2005 and 2006, there was no difference in the density of *Aletris*, *Platanthera*, or *Polygala* between burned and unburned plots ($P>0.05$; Wilcoxon Rank Sum Test, Figure 4). Density of *Aletris* inflorescences was significantly higher in unburned plots than in burned plots in both 2005 ($P=0.032$; Wilcoxon Rank Sum Test) and 2006 ($P=0.016$; Wilcoxon Rank Sum Test, Figure 5). The number of inflorescences of *Platanthera* in burned plots doubled from 0.7 inflorescences/m² in 2005 to 1.4 inflorescences/m² in 2006 (Table 3), however, this difference was not statistically significant. In unburned plots, the number of inflorescences of *Platanthera* was 1.1/m² in both 2005 and 2006. No significant differences in *Polygala* flowering were detected between 2005 and 2006 in either burned or unburned plots ($P>0.05$; Wilcoxon Rank Sum Test, Figure 5).

Percent cover of *Aletris* followed a similar pattern as the density of *Aletris*; plots that were unburned had a higher coverage than plots that were burned, however, this difference was not statistically significant (Figure 6). For plots that were burned, the percent cover of *Platanthera* was higher in 2006 (3.6% cover) than in 2005 (1.2% cover; Table 3). *Polygala* had a relatively low coverage in both burned and unburned plots, and differences were not significant in either year of the study ($P>0.05$ Wilcoxon Rank Sum Test).

Significant year-to-year differences were observed in both the density of *Aletris* and the percent cover of *Platanthera* (Table 3). The percent cover of *Platanthera* and the density of *Aletris* were both higher in 2006 than in 2005 when averaged across all 61 plots.

Burned and unburned plots were evaluated for significant differences in the change between years of density of stems, density of inflorescences, and percent cover of *Aletris*, *Platanthera*, and *Polygala*. The between year change in density, number of inflorescences, and percent cover in burned plots was not statistically different from the between year change in unburned plots for *Aletris*, *Platanthera*, or *Polygala* ($P>0.05$; Wilcoxon Rank Sum test, Figure 7).

Significant differences were observed in the percent cover of *Drosera* and unvegetated soil in burned and unburned plots in 2005 (Figure 8). The amount of unvegetated soil was significantly higher in burned plots in 2005 than in unburned plots ($P=0.003$; Wilcoxon Rank Sum Test). However, this effect had disappeared by 2006, as the amount of unvegetated soil in burned plots (10.5% cover) in 2006 was not statistically different from that in unburned plots in 2005 or 2006 (Table 4). In 2006, *Drosera* cover in burned plots was not significantly different than in unburned plots (Figure 8). However, in 2005 *Drosera* cover was significantly higher in unburned plots than in burned plots ($P=0.024$; Wilcoxon Rank Sum Test). Differences in percent cover of lichens and moss were not significant between any combination of year and treatment ($P>0.05$; Wilcoxon Rank Sum Test).

The between year decrease in cover of *Drosera* in unburned plots was significantly greater than the between year decrease in burned plots ($P=0.01$; Wilcoxon rank sum test, Figure 9). The between year decrease in unvegetated soil in burned plots was significantly different than the between year increase in unburned plots ($P=0.001$, Wilcoxon Rank Sum Test).

Herbaceous cover increased more from 2005 to 2006 in burned than in unburned plots ($P=0.001$; Wilcoxon Rank Sum Test, Figure 9). Herbaceous cover was significantly lower in burned than in unburned plots in 2005 ($P=0.001$; Wilcoxon Rank Sum Test), however, that effect had disappeared by 2006 (Figure 10). In burned plots, herbaceous height was significantly higher than in unburned plots during both years of the study ($P=0.023$, 2005 and $P=0.035$, 2006; Wilcoxon Rank Sum Test).

The height of woody plants increased more from 2005 to 2006 in burned than in unburned plots ($P=0.007$, Wilcoxon Rank Sum Test, Figure 9). For burned plots in 2006, mean woody plant height (46.3cm) was not significantly different from unburned plots in 2005 (60.3cm) and 2006 (51.3cm; Table 4). There was no significant change in woody plant cover between 2005 and 2006, and no difference between burned and unburned plots (Figure 10).

Significant changes were observed between 2005 and 2006 in unvegetated soil, herbaceous plant cover, and woody plant cover when considering all 61 plots within the NESA core (Table 4). The percent cover of woody plants and unvegetated soil significantly decreased from 2005 to 2006, while the percent cover of herbaceous plants significantly increased from 2005 to 2006.

Plots categorized as 'not burned' in 2005 were those that were enclosed within sheet metal fire exclosures, or that were unburned simply because the natural course of the fire missed them. The density, cover and number of inflorescences of *Aletris*, *Platanthera*, and *Polygala* in the unburned, unexclosed plots were not significantly different from the unburned, exclosed plots (Table 5). Fire exclosed plots were

further segregated by those in which shrubs had been cut in 2003 and those that were uncut in 2003. In 2005, the density, cover, and number of inflorescences of *Aletris*, *Platanthera*, and *Polygala* in plots that were cut in 2003 were not significantly different from uncut plots (Table 5). However, in 2006 the number of inflorescences of *Platanthera* was significantly higher in cut plots than in uncut plots ($P=0.04$; Wilcoxon Rank Sum Test, Table 5).

Percent cover of unvegetated soil was significantly higher in fire exclosed plots than in unexclosed, unburned plots in both 2005 ($P=0.007$; Wilcoxon Rank Sum Test) and 2006 ($P=0.039$; Wilcoxon Rank Sum Test, Table 6). In 2006, percent cover of woody plants was significantly lower in fire exclosed plots than in unexclosed, unburned plots ($P=0.026$; Wilcoxon Rank Sum Test). There were no significant differences in the fire exclosed plots between those that were cut in 2003 and those uncut in 2003 for all vegetation and plot characteristics (Table 6).

Vegetation and habitat characteristics inside the NESAs core

The mean percent cover of *Drosera*, lichens and moss was significantly different in plots occupied by *Aletris* and *Platanthera* than in plots unoccupied by those species ($P<0.01$; Wilcoxon Rank Sum Test, Figure 11). Cover of unvegetated soil did not differ significantly between occupied and unoccupied plots for any of the rare plants. In plots unoccupied by *Aletris*, mean *Drosera* and lichen cover was near 0% in 2005. The difference in percent cover of *Drosera* between plots occupied and unoccupied by *Aletris* was highly significant ($P<0.001$) in both 2005 and 2006. The percent cover of woody plants differed significantly between plots occupied and unoccupied by *Aletris*, but not by those occupied and unoccupied by *Platanthera* or

Polygala (Figure 12). In 2006, the mean height of both herbaceous and woody vegetation was significantly lower in plots occupied by either *Aletris* or *Platanthera* than in plots unoccupied by these species.

Density of *Aletris* had a positive relationship with the density of *Drosera* in 2005 ($r=0.73$, $P<0.001$) and 2006 ($r=0.57$, $P<0.001$). Density and cover of both *Aletris* and *Platanthera* were negatively related to woody plant cover in 2005 and 2006 (Table 7). In 2006, woody cover accounted for 31% of the variance in *Aletris* density, and 21% of the variance in *Platanthera* density. *Aletris* density, number of inflorescences and cover all were positively related to herbaceous plant cover (Table 7). *Platanthera* density and cover were positively related to herbaceous cover. Herbaceous cover explained 30% of the variance in *Aletris* density and 21% in *Platanthera* density in 2006. Density, cover, and inflorescence abundance in *Polygala* were not significantly related to the cover of woody or herbaceous plants ($P>0.05$, data not included).

Platanthera and *Aletris* density were highly correlated with one another as well as with *Drosera* density in 2005, however, *Polygala* density was not correlated with the density of any other rare plant or *Drosera* (Bartlett Chi-square statistic: 74.727, $df=6$, $P=0.000$). Similar results were seen for all three rare plants and *Drosera* in 2006 (Bartlett Chi-square statistic: 50.106, $df=6$, $P=0.000$). None of the rare plants were significantly correlated with any of the other indicator variables which included lichen cover, moss cover, and unvegetated soil cover. The number of plots that contained rare plants did not differ significantly between years ($P>0.05$;

Wilcoxon Rank Sum), and plots unoccupied by a particular rare plant tended to remain unoccupied for both years of the study (Appendix B).

Effects of fire, shrub cutting, and scarification in the experimental sectors

No rare plants were recorded in newly established plots outside of the NESA core in either 2005 or 2006. However, treatments had significant effects on other species. Density of the invasive woody vine *Celastrus orbiculatus* (Oriental bittersweet) was significantly higher in the cut sector in 2006 than in any other sector ($P < 0.001$, Kruskal-Wallis test, Figure 13). In 2006, the density of *Celastrus* in the cut sector (11.6 stems/m²) was an order of magnitude higher than in the control sector (0.1 stems/m²).

The woody shrub *Rhus copallinum* (winged sumac) was extremely abundant in the cut and burn sector, and density was significantly higher there than in any other sector (Figure 13). In the cut and burn sector, the density of *Rhus* remained high in 2006 (14.4 stems/m²), and like *Celastrus* in the cut sector, was an order of magnitude higher than in the control (0.4 stems/m²).

The cut sector had the highest cover of herbaceous vegetation (56%) among all experimental sectors in 2005 (Figure 14). It also had the lowest cover of woody vegetation (30%), although this was not statistically different from the cut and burn sector. The control sector had higher woody plant cover (71%, both years) and higher woody plant height (102 cm in 2005, 88 cm in 2006) than all other sectors in both 2005 and 2006. Mean height of herbaceous plants was higher in the control (54cm) than in all other sectors except the burn sector in 2005, however, that difference had disappeared by 2006 (Figure 14). In 2005, the burn sector and the cut and burn sector

differed significantly in mean height of herbaceous and woody vegetation, however, by 2006 the difference in mean height of woody vegetation was no longer significant.

No rare plants were found in the scarified plots established in the cut and burn sector in 2005. In the mowed firebreak that surrounds the site, four *Aletris* plants were found in 2005, and six *Aletris* plants were found in 2006.

Discussion

Long-term trends in rare plant populations

Since data collection began at the site in 1996, estimated populations of all rare plant species have experienced large fluctuations from year to year. However, some patterns are evident. For example, the number of inflorescences produced by *Platanthera* in the NESA core has increased every year since 2003, the year in which the first prescribed burn took place at the site (Keller and Killingbeck 2004). In 2005, the density of *Platanthera* stems fell to the lowest level since data collection began, yet twice as many inflorescences were produced that year than in 2004. The number of inflorescences produced by *Aletris* and *Polygala*, and the density of stems of *Polygala* peaked in 2004, while the density of *Aletris* and *Platanthera* stems peaked in 2003 (Keller and Killingbeck 2004). Such observed fluctuations set in the framework of the experimental treatments implemented in the NESA core have provided insights into the effects of fire on the most abundant of the rare species growing there.

Response of rare plants to fire

Past studies on geophyte populations and their response to fire have described increases in flowering or aboveground stem production following a burn (Lamont and Runciman 1993, Verboom et al. 2002). Specifically, fire has been utilized to promote flowering in forbs such as *Aletris lutea* in the southeastern U.S. (Carter et al. 2004, Platt et al. 1988). Such a response from *Aletris farinosa* at Ninigret was not discerned in 2005 or 2006, as no significant increase in stem density, cover, and number of inflorescences of *Aletris* was detected in burned plots.

The extent and timing of the burn in 2005 may offer explanations as to why *Aletris* did not respond positively to this treatment. It is possible that the fire was applied too late in the growing season for *Aletris* to respond in 2005. At the time of the May burn, the basal rosettes of the plant were already above ground and it may have been too late for the plants to immediately benefit from the effects of the fire. Charring was observed on the basal rosettes of some *Aletris* stems, but such charring was minimal and it did not seem as though these individuals were killed by the burn.

It is likely that a combination of both uneven distribution of the fire relative to the distribution of the plants within the NESA core and the timing of the burn contributed to the lack of an increase of *Aletris* in burned plots during this study.

The high heterogeneity influenced the ability to determine significant changes in *Platanthera* as a result of the burning treatment. The increases in reproductive output and percent cover of *Platanthera* were not statistically significant, however, trends overall suggest that burning may have had a positive effect. This would support similar results in other investigations in the response of rare orchids to fire (Norton and Delange 2003, Wotavova et al. 2004). Like *Aletris*, *Platanthera* is a geophyte with underground storage for future growth and reproduction. It is believed that disturbances such as fire can stimulate growth and reproduction in orchids (Stuckey 1967, Whelan 1995). Due to the high incidence of rarity in the family Orchidaceae, not only in New England (Brumback and Mehrhoff 1996, Enser 2002) but also in many other parts of the world (Kirkpatrick and Gilfedder 1995, Lunt 1997, Silvertown et al. 1994), the suggestion that fire may stimulate reproductive output is an important consideration.

Fire did not have any statistically significant effects on the stem density, cover or inflorescence production of *Polygala cruciata*. Of the 61 plots within the NESA core, only 10 plots in 2005, and 14 plots in 2006 were occupied by *Polygala*. This low density, coupled with high variability in the dataset, made it difficult to detect relationships between *Polygala* and other rare plants and associated organisms at the site. However, trends point toward higher densities of *Polygala* in burned plots and further study may be important in understanding these trends.

Research on fire and rare plants has been increasing since the 1980's and more rapidly since the early 1990's (Hassl and Spackman 1995). Such research is vital to the conservation of some rare plant populations and fire is a recommended tool for increasing rare plant populations (Jacobson et al. 1991), yet it is difficult to elucidate effects without long-term monitoring of at least three years (Menges 1986). The best course of action toward the recovery of an endangered plant species is a comprehensive management plan that assesses the biological status and demographics of the plant in question, and also includes guidelines for management and recovery (Schemske et al. 1994). Presently, one such plan exists for *Platanthera* (Sharp 2004). Once found in greater numbers in New England, only 10 extant sites with populations of *Platanthera* still remain (out of 41 historic populations). Of the 10 populations still considered extant in New England, two are relatively stable, two have shown decline, and six have not been found in recent surveys (Sharp 2004). Fire may be an important tool in efforts to restore vigor to those populations facing extirpation.

Response of NESA core vegetation to fire

In examining the effects of fire on the herbaceous and woody vegetation inside the NESA core, it was apparent that the burn did not reduce cover of woody plants or height of herbaceous plants. Differences that were observed in burned plots, specifically cover of herbaceous plants and height of woody plants, were short-lived. By the year after the burn, cover of herbaceous plants and height of woody plants had both increased to effectively negate the differences observed in 2005 after the burn. This suggests that the fire did not kill a significant amount of the woody plants inside the NESA core. Results from this study and others (Briggs et al. 2002, Glasgow and Matlack 2007, Heisler et al. 2003) suggest that responses of woody shrubs to fire are much weaker by the second year after a prescribed burn, necessitating a continuation of prescribed fire if long-term reductions in woody vegetation are a goal.

Legacy effects from shrub-cutting treatments in fire exclosed plots in 2003 were not significant in 2005 or 2006 for herbaceous or woody vegetation. This suggests that the shrub cutting treatments, which were applied once before the initiation of this study, were not effective in controlling coverage or height of the vegetation inside the NESA core in the long-term. Others have observed this effect after shrub-cutting treatments were applied in an effort to reduce competition between rare plants and competing vegetation (Barbaro et al. 2001, Gordon 1996, Muller 2002). However, the mean height of the vegetation was significantly lower in the unburned plots than in the burned plots, despite the fact that no past treatments had taken place in 13 of the unburned plots. This limited the ability to test for differences between burned and unburned plots within the NESA core, as these groups were inherently different before the treatment was applied. The fact that the differences

existed despite the fact that no manipulations had occurred in many of the unburned plots gives merit to the theory that disturbance history has played a role in the present day distribution of plants and habitat characteristics at the site.

Trends in vegetation and habitat characteristics in the NESa core

Discovering what makes a particular environment suitable for the rare plants that inhabit it has always been a challenge (Clarke and Patterson 2006, Motzkin and Foster 2002, Schemske et al. 1994). Certain habitat variables were important in determining whether or not rare plant species grew in a particular plot within the NESa core. Coverage and stem density of *Drosera* was highly correlated with, and had significant, positive relationships with the density of stems of both *Aletris* and *Platanthera*. In 2005 and 2006, nearly all plots that contained *Aletris* contained *Drosera* as well. The presence of *Drosera* is indicative of disturbed, nutrient poor environments (Brewer 1999) and slightly acidic, hydric environments (Juniper et al. 1989). Such environmental characteristics may be important for the establishment, growth, or persistence of *Aletris* and *Platanthera*.

Overall, plots containing 40-50% cover of herbaceous plants and less than 30-40% cover of woody plants were most likely to have at least one rare plant species growing in them. Both *Aletris* and *Platanthera* had positive relationships with cover of herbaceous plants and negative relationships with cover of woody plants. These trends underscore the potential influence of common species on the abundance and distribution of rare species.

It has been observed that light limitations and competitive interactions with surrounding species have been important in excluding many orchid species from sites

in which they have occurred historically (Wotavova et al. 2004). At Ninigret, there was no difference in percent cover of woody vegetation in plots that were occupied by *Platanthera* than in plots that were not occupied by *Platanthera*. This suggests that the mere presence of woody vegetation did not preclude the presence of *Platanthera*. However, the mean height of the woody vegetation was significantly lower in plots that were occupied by *Platanthera* than in plots that were not occupied by *Platanthera*. This result supports the theory that disturbances which limit the height of surrounding vegetation, including certain historic management regimes, are vital to the persistence of the rare orchid species found within disturbed sites (Lunt 1997).

Whether woody or herbaceous, the mean height of vegetation in plots containing rare plants in 2005 was less than 25-35 cm, which was not significantly different from the mean height of the entire NESA core in 2005. In 2006 the mean height of vegetation in plots containing rare plants (30-40cm) was lower than the mean height of vegetation at the site overall. The increase in height of woody plants in 2006 in burned plots may have contributed to this difference. However, relationships between *Aletris*, *Platanthera*, and *Polygala* and mean height of the surrounding vegetation were weak or non-existent in 2006. Consequently, impacts from the increase in height of the woody vegetation were not detected. Impacts may be observed in the future if significant increases in height of the vegetation continue because local extinctions of orchid species apparently caused by increasing levels of shade have occurred in other parts of Rhode Island (Stuckey 1967).

The properties of the soil inside the NESA core are most likely one of the keys to explaining the unique nature of the NESA core. For example, the presence of *Drosera* is indicative of recently disturbed habitats with high light availability and low soil fertility (Brewer 1999, Givnish et al. 1984). The tight association between *Drosera* and both *Aletris* and *Platanthera* may be a function of both high light and low fertility. Both *Platanthera* and *Scleria* sp. were associated with nutrient poor environments in conservation plans for each species (Sharp 2004, Zaremba 2004). In addition, organic matter in the soil of the NESA core was 50% lower than in areas adjacent to the NESA core (Killingbeck et al. 1998).

The extended persistence of shrubs growing at abnormally low heights has been suggested to indicate the presence of an environmental limiting factor (Latham 2003). Woody shrubs are a major component of the NESA core, yet many are low growing and do not prevent the co-occurrence of rare plants. Some plots within the NESA core harbor low-growing herbaceous and woody plants that have been unaltered by experimental manipulations and of these plots, many contain high densities of *Aletris* and *Platanthera*. Therefore, it is possible that the soil fertility limited the growth of herbaceous and woody vegetation thus allowing high light penetration. This in turn may have produced optimal conditions for the rare plants that exist in the NESA core.

Treatment effects outside of the NESA core

The manipulations implemented in the shrub-dominated area outside the NESA core did not promote rapid colonization by any of the rare plants. However, the treatments did have major impacts on other species. The cut treatment clearly

facilitated the growth of *Celastrus orbiculatus*, an invasive woody vine. Reductions in the cover of tall shrubs caused by the treatment most likely promoted the increase in density and cover of *Celastrus*. Disturbances, in general, contribute to the spread of *Celastrus* by increasing light availability and reducing competition for resources (McNab and Loftis 2002). Greenberg et al. (2001) have proposed a “sit and wait” strategy for the mechanism by which *Celastrus* establishes and spreads. This strategy involves growing and persisting within an undisturbed, closed canopy until a disturbance opens up the canopy, allowing for rapid growth and proliferation (Greenberg et al. 2001).

The introduction of disturbance to the experimental sectors initiated a rapid increase in growth of *Celastrus* and clearly indicates that cutting shrubs in the absence of fire may contribute to future increases in this nonnative species. Studies suggest *Celastrus* will spread rapidly after a sufficient disturbance (Silveri et al. 2001) and can be highly correlated with scarified, exposed soils (McNab and Loftis 2002, Silveri et al. 2001). *Celastrus* has a rapid, prolific, and consistent annual rate of production of seeds that have both high viability and high germination rates (Ellsworth et al. 2004). The rapid response of *Celastrus* to the cut treatment indicates that buried seeds were likely the source of the increase in density. *Celastrus* seeds are thought to be spread primarily by birds (McNab and Loftis 2002), and the source of the seeds could have come from other parts of the NNWR that support mature *Celastrus* plants. A significant increase in *Celastrus* stem density in 2006 suggests that the growth and spread of this invasive could continue and eventually impact the adjacent NESA core if it is not controlled.

Rather than promoting the growth of *Celastrus*, the adjacent experimental sector that was both cut and burned was immediately dominated by *Rhus copallinum* after the 2005 burn. *Rhus* demonstrated the same rapid growth and colonization in response to the cut and burn treatment as *Celastrus* did to the cut treatment, despite the fact that *Celastrus* is invasive to Rhode Island and *Rhus* is a native woody shrub. Some shrub species are typically the first to grow back after disturbance due to their ability to re-sprout and spread by rhizomes (Glasgow and Matlack 2007). Consequently, plant species with clonal growth forms are common in many disturbed habitats (Hartnett 1987). Although it is unknown whether the profusion of *Rhus* was primarily from seed germination or re-growth from rhizomes, the very low densities of *Rhus* in the control sector suggest that germination from seed may have been a major source of this species in the cut and burned sector.

The lack of *Celastrus* stems in the cut and burn sector is difficult to explain. There seems to be no published literature focused on the effects of fire on *Celastrus*, but in this study, the differences in *Celastrus* density between the burned sectors and the cut-only sector suggest that fire may have a negative impact on this species. One possible mechanism for such an effect would be a reduction in seed viability caused by high temperatures.

While major differences in the cover of woody plants between burned and unburned plots did not occur in the NESA core, major differences were found in the experimental sectors. By the 2006 growing season, the percent cover and height of woody plants had not reached the pre-burn levels of the control. While differences existed in 2005 between the cut, cut and burn, and burn sectors, these three sectors

were no different from each other by 2006. This suggests that the preliminary cut treatment applied immediately before the burn treatment in the cut and burn sector was not effective in controlling woody plants any more than the burn only treatment, by 2006. Also, the application of the cut treatment before the burn may have promoted the proliferation of *Rhus* in the cut and burn sector, since the high densities of *Rhus* were not seen in the burn only sector.

The scarified plots introduced into the cut and burn sector had no immediate impact on rare plant growth or establishment. However, it is possible that such growth may take longer than the two growing seasons of the study.

Management implications

Continued prescribed burning is recommended inside the NESAs core. Scheduling of a future burn should occur, if possible, before *Aletris* emerges at the site to see if a difference in timing of the burn would have a more positive effect on *Aletris*. While no positive effects on the rare plants were detected statistically in response to the 2005 burn, it also does not appear that they were negatively impacted by burning.

Woody plant cover may have negative impacts on both *Aletris* and *Platanthera* inside the NESAs core. Continued management of the site should attempt to reduce woody plant cover, especially in plots containing over 35% cover of woody plants. While no significant relationships were detected between *Aletris*, *Platanthera*, and *Polygala* and mean height of the surrounding vegetation inside the NESAs core, trends show important distinctions in the height of vegetation between those plots that were occupied by rare plants and those that were not. Continued prescribed burning

inside the NESA core is recommended, however, large-scale mechanical shrub cutting by itself is not recommended due to the potential for increasing *Celastrus* density inside the NESA core. Small-scale shrub-cutting treatments applied by hand may help to curb woody plant growth, possibly during years in which fire is not applied. However, cutting treatments should be applied in one to two year intervals since this study has shown that effects on shrubs over two years after a cutting treatment are negligible.

This study has documented that *Celastrus* density has increased dramatically in response to shrub cutting. This treatment was aimed at managing rare and endangered plants at NNWR, instead, the shrub cutting treatment may now put rare plants in jeopardy if the *Celastrus* is not controlled. Great care must be taken to identify the best possible management strategies that concurrently limit the proliferation of the invasive *Celastrus* and promote growth and flowering of the rare plants. While no significant rare plant growth occurred outside of the NESA core, such a result may take longer than the two growing seasons of the study, and future prescribed burning in areas immediately adjacent to the NESA core is recommended.

Table 1

Estimated population sizes for rare species and *Drosera* in the NESA core (2,300m²).

Numbers for both *Scleria* species and *Spiranthes* were generated from an active search, while numbers for all other plants were extrapolated from plot data.

Sorghastrum nutans and *Aristida longespica* were not found in the NESA core in either year, and *Spiranthes tuberosa* was not found in the NESA core in 2005.

		2005	2006
<i>Aletris farinosa</i>			
	stems	28,807	33,481
	inflorescences	2,187	1,961
<i>Platanthera ciliaris</i>			
	stems	15,082	26,620
	inflorescences	1,961	3,016
<i>Polygala cruciata</i>			
	stems	15,157	16,666
	inflorescences	10,256	6,108
<i>Scleria pauciflora</i>			
	stems	3,224	4,859
	inflorescences	1,855	2,652
<i>Scleria triglomerata</i>			
	stems	698	841
	inflorescences	310	407
<i>Spiranthes tuberosa</i>			
	stems	—	55
	inflorescences	—	55
<i>Drosera</i> spp.			
	stems	117,338	272,380
	inflorescences	72,092	145,239

Table 2

Range of maximum temperatures reached in NESA core plots that were burned in 2005 and the number of plots within the NESA core for which those temperatures were reached. Charring range indicates the mean range of charring that occurred at each maximum temperature. Numbers in paranthesis are standard errors for mean charring range.

maximum temp. reached	# of plots reaching each temp.	mean charring class
No Melting	8	43-62% (8)
200°F	8	61-78% (12)
400°F	8	78-97% (3)
600°F	3	80-99% (0)
800°F	7	80-99% (0)
1000°F	3	67-86% (7)

Table 3: Mean density of stems, density of inflorescences, and % cover for *Aletris*, *Platanthera*, and *Polygala* in all 61 plots in the NESA core (first set of paired rows). Plots were further broken down by treatment type based on whether they were burned in 2005 (middle set of paired rows) or unburned in 2005 (last set of paired rows). The number of plots in each dataset is indicated in parenthesis in the left-hand column. Significant differences for all NESA core plots between years are indicated by asterisks (* $P < 0.05$, ** $P < 0.01$). Significant differences between treatments are shown in Figures 4-6. Standard error of the mean is given in parenthesis.

	year	<i>Aletris</i>			<i>Platanthera</i>			<i>Polygala</i>		
		stems/m ²	inflorescences/m ²	% cover	stems/m ²	inflorescences/m ²	% cover	stems/m ²	inflorescences/m ²	% cover
Core Plots (61)	2005	12.5 (1.3)	0.9 (0.2)	5.3 (1.2)	6.6 (0.5)	0.9 (0.1)	1.6 (0.4)	6.6 (1.4)	4.5 (0.9)	0.5 (0.2)
	2006	14.5 (1.3)	0.8 (0.2)	4.7 (1.1)	11.3 (0.7)**	1.3 (0.1)	3.5 (0.6)*	7.6 (1.1)	2.7 (0.5)	0.3 (0.1)
<i>Burned in 2005</i> (37)	2005	8.1 (1.2)	0.3 (0.1)	2.7 (0.8)	5.5 (0.6)	0.7 (0.1)	1.2 (0.3)	9.1 (2.2)	5.7 (1.4)	0.6 (0.3)
	2006	9.5 (1.3)	0.6 (0.2)	3.0 (1.0)	10.7 (0.9)	1.4 (0.2)	3.6 (0.9)	9.4 (1.6)	3.3 (0.8)	0.5 (0.2)
<i>Unburned in 2005</i> (24)	2005	19.3 (2.5)	1.9 (0.4)	9.2 (2.5)	8.3 (1.0)	1.1 (0.2)	2.3 (0.7)	2.7 (0.8)	2.6 (0.8)	0.3 (0.2)
	2006	22.3 (2.6)	1.3 (0.3)	7.4 (2.1)	12.4 (1.2)	1.1 (0.2)	3.3 (0.7)	4.8 (1.4)	1.7 (0.6)	0.2 (0.1)

Table 4: Mean density and/or cover for *Drosera*, lichens, unvegetated soil ('unveg'), moss, herbaceous and woody plants in all 61 plots in the NESA core (first set of paired rows). Plots were further broken down by treatment type based on whether they were burned in 2005 (middle set of paired rows) or unburned in 2005 (last set of paired rows). The number of plots in each dataset is indicated in parenthesis in the left-hand column. Significant differences for all NESA core plots between years are indicated by asterisks (* $P < 0.05$, ** $P < 0.01$). Significant differences between treatments are shown in Figures 7-8. Standard error of the mean is given in parenthesis.

	year	<i>Drosera</i>		lichens	unveg	moss	herbaceous plants		woody plants	
		stems/m ²	% cover	% cover	% cover	% cover	% cover	mean height (cm)	% cover	mean height (cm)
Core Plots (61)	2005	25.5 (6.6)	2.3 (0.7)	1.5 (0.6)	14.2 (1.7)	4.3 (1.3)	37.7 (2.9)	34.4 (2.6)	44.8 (2.9)	46.8 (5.6)
	2006	59.1 (12.2)	1.1 (0.2)	1.3 (0.5)	9.7 (1.2)*	4.9 (0.9)	50.6 (3.4)**	32.3 (2.1)	38.9 (3.3)***	48.3 (2.9)
<i>Burned in 2005</i> (37)	2005	25.2 (4.7)	1.0 (0.4)	1.4 (0.7)	19.2 (2.3)	4.8 (2.1)	29.1 (2.6)	39.3 (3.5)	46.8 (3.3)	38.1 (2.3)
	2006	84.1 (11.9)	0.9 (0.3)	1.3 (0.7)	10.5 (1.5)	5.3 (1.4)	47.9 (3.8)	35.5 (2.9)	39.9 (3.5)	46.3 (2.8)
<i>Unburned in 2005</i> (24)	2005	90.7 (14.7)	4.5 (1.5)	1.8 (1.1)	6.5 (1.7)	3.6 (1.2)	51.0 (5.2)	26.7 (3.5)	41.7 (5.6)	60.3 (13.5)
	2006	170.9 (24.8)	1.3 (0.4)	1.4 (0.7)	8.3 (2.2)	4.3 (0.9)	54.6 (6.4)	27.3 (2.6)	37.3 (6.6)	51.3 (6.4)

Table 5: Mean density, inflorescences, and % cover of *Aletris*, *Platanthera*, and *Polygala* in plots that were not burned in 2005. Both the 2005 and 2006 datasets for unburned plots were categorized based on the presence or absence of a metal enclosure deployed before the 2005 burn. The plots that were exclosed were categorized based on whether they were cut or uncut in 2003. The number of plots in each dataset is indicated in parenthesis in the left-hand column. Significant differences in pairwise comparisons are indicated by asterisks (* $P < 0.05$). All other pairwise relationships between paired rows are not significant. Standard error of the mean is given in parenthesis.

		<i>Aletris</i>			<i>Platanthera</i>			<i>Polygala</i>		
		stems/m ²	Inflorescences/m ²	% cover	stems/m ²	Inflorescences/m ²	% cover	stems/m ²	Inflorescences/m ²	% cover
2005										
	Unexclosed plots (11)	16.2 (3.9)	2.9 (0.7)	9.1 (4.0)	9.6 (2.1)	1.5 (0.4)	3.0 (1.5)	1.1 (0.5)	0.9 (0.5)	0.1 (0.1)
	Fire exclosed plots (13)	22.0 (3.3)	1.1 (0.2)	9.3 (3.4)	7.1 (0.7)	0.8 (0.2)	1.7 (0.5)	4.0 (1.5)	4.0 (1.5)	0.5 (0.4)
	cut in 2003 (6)	19.0 (4.6)	1.0 (0.3)	5.2 (2.3)	7.7 (1.2)	1.3 (0.3)	1.5 (0.7)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	uncut in 2003 (7)	24.6 (4.9)	1.1 (0.3)	12.9 (5.8)	6.6 (0.9)	0.3 (0.1)	1.9 (0.8)	7.4 (2.6)	7.5 (2.6)	0.9 (0.7)
2006										
	Unexclosed plots (11)	20.7 (3.9)	1.6 (0.6)	10.5 (4.2)	11.5 (1.9)	1.3 (0.4)	3.7 (1.3)	5.5 (2.1)	2.5 (1.3)	0.2 (0.1)
	Fire exclosed plots (13)	27.8 (3.6)	1.1 (0.2)	5.6 (1.6)	14.6 (1.7)	0.9 (0.2)	3.2 (0.8)	5.1 (2.0)	1.1 (0.4)	0.2 (0.1)
	cut in 2003 (6)	20.7 (4.6)	0.3 (0.2)	4.3 (1.9)	11.7 (1.6)	1.7 (0.3)	2.3 (0.8)	8.0 (4.0)	0.7 (0.3)	0.2 (0.2)
	uncut in 2003 (7)	26.3 (5.6)	1.4 (0.4)	5.1 (2.4)	14.6 (2.7)	0.3 (0.1)*	3.3 (1.4)	1.1 (0.6)	1.1 (0.6)	0.1 (0.1)

Table 6: Mean density, cover, and/or height for all other organisms and habitat variables sampled in plots that were not burned in 2005. Both the 2005 and 2006 datasets for unburned plots were categorized based on the presence or absence of the metal exclosure deployed before the 2005 burn. The plots that were exclosed were categorized based on whether they were cut or uncut in 2003. The number of plots in each dataset is indicated in parenthesis in the left-hand column. Significant differences in pairwise comparisons are indicated by asterisks (* $P < 0.05$, ** $P < 0.01$). All other pairwise relationships between paired rows are not significant. Standard error of the mean is given in parenthesis.

		<i>Drosera</i>	Lichen	Unveg	Moss	Herbaceous plants		Woody plants		
		stems/m ²	% cover	% cover	% cover	% cover	mean height (cm)	% cover	mean height (cm)	
2005										
	Unexclosed plots (11)	84.0 (26.4)	3.8 (2.7)	1.0 (0.9)	0.9 (0.6)	3.3 (1.5)	49.1 (9.0)	18.4 (2.8)	50.0 (9.1)	77.5 (26.7)
	Fire exclosed plots (13)	96.5 (16.5)	5.1 (1.6)	2.5 (1.9)	11.2 (2.5)**	3.9 (1.9)	52.7 (6.1)	33.8 (5.4)	34.6 (6.7)	45.6 (10.0)
	cut in 2003 (6)	122.0 (31.0)	5.2 (2.3)	4.9 (3.7)	10.8 (3.6)	1.8 (0.9)	54.2 (5.5)	35.8 (7.1)	31.7 (7.4)	35.5 (4.8)
	uncut in 2003 (7)	74.6 (14.8)	5.0 (2.2)	0.1 (0.1)	11.4 (3.4)	5.7 (3.4)	51.4 (10.6)	32.1 (8.1)	37.1 (10.7)	54.3 (18.1)
2006										
	Unexclosed plots (11)	94.8 (29.4)	1.0 (0.6)	0.1 (0.1)	4.1 (1.1)	4.2 (1.1)	44.1 (10.3)	23.2 (3.6)	51.4 (10.3)	60.0 (11.5)
	Fire exclosed plots (13)	230.0 (36.9)	1.7 (0.6)	2.5 (1.3)	11.8 (3.9)*	5.1 (1.5)	66.4 (6.8)	27.7 (3.1)	22.7 (7.1)*	44.5 (6.9)
	cut in 2003 (6)	175.0 (41.6)	0.7 (0.2)	4.3 (2.3)	14.2 (6.4)	3.5 (1.6)	65.8 (7.1)	31.7 (4.8)	21.7 (7.9)	38.3 (6.3)
	uncut in 2003 (7)	288.6 (60.0)	2.3 (0.9)	0.9 (0.7)	10.0 (4.5)	5.0 (2.4)	61.4 (13.0)	30.0 (5.5)	28.6 (12.3)	48.6 (10.7)

Table 7: Adjusted coefficients of determination from regression analyses describing the relationships between % cover and height of both woody and herbaceous plants and percent cover, density (stems/m²), and inflorescence abundance (inflorescences/m²) of *Aletris* and *Platanthera*. All relationships with woody plant cover were negative, all relationships with herbaceous plant cover were positive, and all relationships with mean height of both woody and herbaceous plants were negative. N=61 throughout.

		<i>Aletris</i>			<i>Platanthera</i>		
		% cover	stems/m ²	inflorescences/m ²	% cover	stems/m ²	inflorescences/m ²
Herbaceous plant cover (%)	2005	0.378***	0.290***	0.135**	0.190***	0.128**	0.035
	2006	0.087*	0.296***	0.037	0.077*	0.215***	0.027
Herbaceous plant height (cm)	2005	0.149***	0.190***	0.087*	0.038	0.000	0.000
	2006	0.028*	0.087*	0.003	0.000	0.000	0.000
Woody plant cover (%)	2005	0.202***	0.233***	0.032	0.071**	0.110**	0.009
	2006	0.142***	0.308***	0.085	0.036**	0.210***	0.012
Woody plant height (cm)	2005	0.021	0.031	0.000	0.024	0.090	0.000
	2006	0.017	0.090*	0.024	0.021	0.103*	0.053

Ninigret Endangered Species Area

NESA core and experimental sectors

Figure 1: Map of the study area indicating the location of the NESA Core and the four experimental sectors adjacent to the Core

Insert a: location of study area within RI

Insert b: close up of the study area adjacent to Ninigret Pond

Figure 2: Plot numbers and designations for all 147 plots (with 2003-04 RIDOT Orthophoto)

Platanthera ciliaris

Aletris farinosa

Polygala cruciata

Figure 3: Images of *Aletris farinosa*, *Platanthera ciliaris*, and *Polygala cruciata*. Images of *Aletris* and *Platanthera* were taken at the Ninigret site.

Figure 4: Mean densities for the three rare plant species found in greatest abundance within the NESa core in 2005 (a) and 2006 (b). White bars show mean densities of *Aletris*, *Platanthera*, and *Polygala* for plots that were burned in 2005 and black bars show mean densities for plots not burned in 2005. Pairwise comparisons did not show significant differences ($P > 0.05$, Wilcoxon Rank Sum Test). Error bars indicate standard error of the mean.

Figure 5: Mean densities of inflorescences for the three rare plant species found in greatest abundance within the NESA core in 2005 (a) and 2006 (b). White bars show mean densities of *Aletris*, *Platanthera*, and *Polygala* inflorescences for plots that were burned in 2005 and black bars show mean densities for plots not burned in 2005. Asterisks indicate significant differences in pairwise comparisons (* $P < 0.05$, Wilcoxon Rank Sum Test). Error bars indicate standard error of the mean.

Figure 6: Mean percent cover for the three rare plant species found in greatest abundance within the NESAs core in 2005 (a) and 2006 (b). White bars show mean percent cover of *Aletris*, *Platanthera*, and *Polygala* for plots that were burned in 2005 and black bars show mean densities for plots not burned in 2005. Pairwise comparisons did not show significant differences ($P > 0.05$, Wilcoxon Rank Sum Test). Error bars indicate standard error of the mean.

Figure 7: Mean change between 2005 and 2006 in the density of stems (a), inflorescences (b), and percent cover (c), for *Aletris*, *Platanthera*, and *Polygala* in burned plots (white bars) and unburned plots (black bars). Positive values indicate an increase between years and negative values indicate a decrease. Error bars show standard error of the mean.

Figure 8: Mean percent cover of *Drosera*, lichens, unvegetated soil, and moss within the NESA core in 2005 (a) and 2006 (b). White bars show mean percent cover in plots that were burned in 2005 and black bars show mean percent cover for plots not burned in 2005. Asterisks indicate significant differences in pair-wise comparisons (* $P < 0.05$, ** $P < 0.01$, Wilcoxon Rank Sum Test). Error bars indicate standard error of the mean.

Figure 9: Mean change between 2005 and 2006 in percent cover of *Drosera*, lichens, unvegetated soil, and moss (a) and herbaceous and woody cover and height (b) for burned plots (white bars) and unburned plots (black bars). Positive values indicate an increase between years and negative values indicate a decrease. Significant differences between the change in burned and unburned plots are indicated with asterisks (** $P < 0.01$, *** $P < 0.001$, Wilcoxon Rank Sum Test). Error bars show standard error of the mean.

Figure 10: Mean cover and height of herbaceous and woody vegetation within the NESA core in 2005 (a) and 2006 (b). White bars show mean values in plots that were burned in 2005 and black bars show mean values for plots not burned in 2005. Asterisks indicate significant differences in pairwise comparisons (*** $P < 0.001$, * $P < 0.05$, Wilcoxon Rank Sum Test). Error bars show standard error of the mean.

Figure 11: Mean percent cover of *Drosera*, lichens, moss, and unvegetated soil in the NESA core in 2005 and 2006 for plots in which *Aletris*, *Platanthera* and *Polygala* were present (white bars) or absent (black bars). Asterisks indicate differences (*** $P < 0.001$; ** $P < 0.01$; * $P < 0.05$, Wilcoxon Rank Sum Test).

Figure 12: Mean percent cover and height of herbaceous and woody vegetation in the NESA core in 2005 and 2006 for plots in which *Aletris*, *Platanthera* and *Poylgala* were present (white bars) or absent (black bars). Asterisks indicate differences (*** $P < 0.001$; ** $P < 0.01$; * $P < 0.05$, Wilcoxon Rank Sum Test).

Figure 13: Mean densities of *Celastrus* and *Rhus* in the experimental treatment sectors adjacent to the NESA core. Bars show mean values for the cut and burn sector, the cut sector, the burn sector, and the control sector for both 2005 (a) and 2006 (b) data. Different letters indicate significant differences ($P < 0.05$, Wilcoxon Rank Sum Test) in pairwise comparisons, while asterisks indicate significant differences in groupwise comparisons (** $P < 0.01$; * $P < 0.05$, Kruskal-Wallis Test). Error bars show standard errors of the mean.

Figure 14: Mean cover and height of herbaceous and woody vegetation in experimental treatment sectors adjacent to the NESA core. Bars show mean values for the cut and burn sector, the cut sector, the burn sector, and the control sector for both 2005 (a) and 2006 (b) data. Different letters indicate significant differences ($P < 0.05$, Wilcoxon Rank Sum Test) in pairwise comparisons, while asterisks indicate significant differences in groupwise comparisons (*** $P < 0.001$; ** $P < 0.01$; * $P < 0.05$, Kruskal-Wallis Test). Error bars show standard errors of the mean.

Appendix A

Charring Classes and Max Temps for unburned plots in the NESA core (2005)

Plot #	Charring Class	Max Temp (°F)
1 A		0
2 A		0
3 A		0
4 A		0
5 A		0
9 B		0
13 A		0
14 A		0
18 B		0
21 A		0
22 A		0
31 A		0
32 A		0
34 A		0
35 A		0
39 A		0
45 A		0
46 A		0
48 B		0
49 B		0
53 A		0
54 A		0
56 A		0
61 B		0

Charring Classes and Max Temps for burned plots located in the NESA core (2005)

Plot #	Charring Class	Max Temp (°F)
6 G		400
7 G		600
8 G		400
10 C		0
11 E		0
12 E		0
15 G		800
16 G		400
17 G		800
19 E		0
20 B		200
23 G		400
24 F		0
25 F		0
26 E		0
27 G		1000
28 E		0
29 F		0
30 G		800
33 G		200
36 G		600
37 G		200
38 G		0
40 G		200
41 G		200
42 G		400
43 G		400
44 E		200
47 G		600
50 E		0
51 G		800
52 G		200
55 G		400
57 G		800
58 G		800
59 G		800
60 F		400

Appendix B

NESA core raw data for rare plants in 2005. Numbers are per 0.5m² plot.

YEAR	PLOT	ALFA_N	ALFA_I	ALFA_C	PLCI_N	PLCI_I	PLCI_C	POCR_N	POCR_I	POCR_C
2005	1	19	1	10	12	3	5	6	5	1
2005	2	0	0	0	0	0	0	0	0	0
2005	3	0	0	0	0	0	0	0	0	0
2005	4	12	7	30	2	0	1	0	0	0
2005	5	0	0	0	3	3	1	0	0	0
2005	6	0	0	0	0	0	0	0	0	0
2005	7	0	0	0	0	0	0	0	0	0
2005	8	2	0	1	4	0	1	0	0	0
2005	9	23	2	15	6	1	5	18	18	1
2005	10	3	0	1	3	0	1	0	0	0
2005	11	12	1	10	6	0	1	0	0	0
2005	12	28	3	25	4	2	5	0	0	0
2005	13	4	4	5	4	2	1	0	0	0
2005	14	0	0	0	0	0	0	0	0	0
2005	15	0	0	0	0	0	0	0	0	0
2005	16	1	0	1	5	0	5	3	3	1
2005	17	0	0	0	0	0	0	37	27	5
2005	18	9	1	10	3	0	1	8	8	5
2005	19	0	0	0	3	1	5	0	0	0
2005	20	1	0	0	4	1	1	0	0	0
2005	21	28	0	10	7	0	1	0	0	0
2005	22	0	0	0	5	0	1	0	0	0
2005	23	5	0	5	0	0	0	58	30	5
2005	24	18	0	10	6	2	5	8	2	1
2005	25	3	0	1	1	0	1	0	0	0
2005	26	29	0	10	5	0	1	0	0	0
2005	27	0	0	0	0	0	0	0	0	0
2005	28	0	0	0	0	0	0	0	0	0
2005	29	0	0	0	0	0	0	18	8	5
2005	30	4	0	0	5	0	1	44	34	5
2005	31	15	1	5	2	0	1	0	0	0
2005	32	30	0	25	4	0	1	0	0	0
2005	33	1	0	1	0	0	0	0	0	0
2005	34	0	0	0	0	0	0	0	0	0
2005	35	0	0	0	6	2	5	0	0	0
2005	36	0	0	0	6	2	1	0	0	0
2005	37	9	0	5	10	0	1	1	1	1
2005	38	12	0	10	13	2	5	0	0	0
2005	39	0	0	0	0	0	0	0	0	0
2005	40	0	0	0	0	0	0	0	0	0
2005	41	0	0	0	0	0	0	0	0	0
2005	42	0	0	0	0	0	0	0	0	0
2005	43	0	0	0	12	1	0	0	0	0
2005	44	0	0	0	4	0	0	0	0	0
2005	45	13	2	15	6	1	1	0	0	0
2005	46	24	1	40	5	0	5	0	0	0
2005	47	0	0	0	0	0	0	0	0	0
2005	48	0	0	0	0	0	0	0	0	0
2005	49	1	0	1	2	1	1	0	0	0
2005	50	11	1	5	0	0	0	0	0	0
2005	51	4	0	5	1	0	1	0	0	0
2005	52	2	0	5	0	0	0	0	0	0
2005	53	13	4	20	11	0	10	0	0	0
2005	54	0	0	0	0	0	0	0	0	0
2005	55	0	0	0	0	0	0	0	0	0
2005	56	41	0	35	21	0	15	0	0	0
2005	57	0	0	0	0	0	0	0	0	0
2005	58	0	0	0	0	0	0	0	0	0
2005	59	0	0	0	5	1	5	0	0	0
2005	60	5	1	5	4	1	5	0	0	0
2005	61	0	0	0	0	0	0	0	0	0

ALFA = *Aletris farinosa* stems/0.5m² plot (N), inflorescences/0.5m² plot (I), and percent cover/0.5m² plot (C)

PLCI = *Platanthera ciliaris* stems/0.5m² plot (N), inflorescences/0.5m² plot (I), and percent cover/0.5m² plot (C)

POCR = *Polygala cruciata* stems/0.5m² plot (N), inflorescences/0.5m² plot (I), and percent cover/0.5m² plot (C)

NESA core raw data for rare plants in 2006

YEAR	PLOT	ALFA_N	ALFA_I	ALFA_C	PLCI_N	PLCI_I	PLCI_C	POCR_N	POCR_I	POCR_C
2006	1	22	0	30	16	3	10	22	14	1
2006	2	4	0	1	0	0	0	0	0	0
2006	3	0	0	0	0	0	0	0	0	0
2006	4	32	6	20	13	0	10	8	0	1
2006	5	0	0	0	5	0	1	0	0	0
2006	6	0	0	0	0	0	0	0	0	0
2006	7	0	0	0	11	1	5	0	0	0
2006	8	3	0	1	13	3	10	6	0	1
2006	9	34	1	15	22	0	10	4	4	1
2006	10	8	0	5	13	1	10	28	16	5
2006	11	10	0	10	9	0	5	0	0	0
2006	12	28	0	15	9	2	10	0	0	0
2006	13	5	0	5	7	1	5	0	0	0
2006	14	0	0	0	0	0	0	0	0	0
2006	15	0	0	0	0	0	0	0	0	0
2006	16	7	0	5	9	2	5	18	14	1
2006	17	0	0	0	0	0	0	38	22	5
2006	18	9	0	10	5	0	1	0	0	0
2006	19	0	0	0	0	0	0	0	0	0
2006	20	0	0	0	9	0	5	0	0	0
2006	21	17	0	10	10	0	5	0	0	0
2006	22	0	0	0	8	1	5	0	0	0
2006	23	7	0	5	0	0	0	13	0	1
2006	24	16	0	5	9	2	5	32	5	1
2006	25	6	0	1	4	1	1	18	1	1
2006	26	29	0	10	9	1	5	0	0	0
2006	27	0	0	0	0	0	0	0	0	0
2006	28	0	0	0	0	0	0	0	0	0
2006	29	0	0	0	0	0	0	3	0	1
2006	30	4	0	1	9	1	5	7	3	1
2006	31	26	0	5	2	0	1	24	2	1
2006	32	31	2	10	7	0	1	0	0	0
2006	33	0	0	0	0	0	0	0	0	0
2006	34	0	0	0	0	0	0	0	0	0
2006	35	0	0	0	11	2	5	0	0	0
2006	36	0	0	0	10	4	5	0	0	0
2006	37	10	0	5	14	0	30	10	0	0
2006	38	16	0	5	13	1	5	0	0	0
2006	39	0	0	0	0	0	0	0	0	0
2006	40	0	0	0	0	0	0	0	0	0
2006	41	0	0	0	0	0	0	0	0	0
2006	42	0	0	0	1	1	1	0	0	0
2006	43	0	0	0	21	0	10	0	0	0
2006	44	0	0	0	0	0	0	0	0	0
2006	45	18	1	10	5	1	1	0	0	0
2006	46	18	2	1	8	0	5	0	0	0
2006	47	0	0	0	1	0	1	0	0	0
2006	48	0	0	0	1	0	1	0	0	0
2006	49	1	0	1	5	1	1	0	0	0
2006	50	16	5	10	6	0	1	0	0	0
2006	51	3	1	1	8	3	5	0	0	0
2006	52	1	1	1	4	2	1	0	0	0
2006	53	23	1	35	10	3	5	0	0	0
2006	54	0	0	0	0	0	0	0	0	0
2006	55	0	0	0	4	1	5	0	0	0
2006	56	28	2	25	12	0	10	0	0	0
2006	57	0	0	0	0	0	0	0	0	0
2006	58	0	0	0	1	0	1	0	0	0
2006	59	0	0	0	1	0	1	0	0	0
2006	60	12	4	30	9	0	1	0	0	0
2006	61	0	0	0	2	1	1	0	0	0

ALFA = *Aletris farinosa* stems/0.5m² plot (N), inflorescences/0.5m² plot (I), and percent cover/0.5m² plot (C)

PLCI = *Platanthera ciliaris* stems/0.5m² plot (N), inflorescences/0.5m² plot (I), and percent cover/0.5m² plot (C)

POCR = *Polygala cruciata* stems/0.5m² plot (N), inflorescences/0.5m² plot (I), and percent cover/0.5m² plot (C)

Appendix C

NESA core raw data for all other plants and variables in 2005

YEAR	PLOT	DROS_N	DROS_C	LICH_C	UNVG_C	MOSS_C	HERB_C	HERB_H	WOOD_C	WOOD_H
2005	1	45	5	0	5	0	55	20	40	48
2005	2	0	0	0	0	0	15	35	85	60
2005	3	0	0	0	5	0	55	30	40	45
2005	4	0	0	10	0	10	70	15	30	30
2005	5	30	1	0	0	5	75	20	25	30
2005	6	0	0	0	40	0	50	65	10	45
2005	7	0	0	0	50	0	40	50	10	45
2005	8	0	0	0	30	0	40	20	30	38
2005	9	52	5	0	5	5	70	20	20	50
2005	10	32	1	0	0	5	25	10	75	30
2005	11	0	0	10	10	5	30	20	35	35
2005	12	4	1	25	10	5	60	10	15	30
2005	13	2	1	0	0	1	30	15	70	45
2005	14	0	0	0	0	0	0	0	100	300
2005	15	0	0	0	5	0	25	70	70	40
2005	16	0	0	0	10	0	40	50	50	30
2005	17	0	0	0	35	0	40	65	25	30
2005	18	95	15	0	20	0	50	10	25	20
2005	19	0	0	0	10	40	15	35	85	35
2005	20	0	0	0	0	60	10	20	85	40
2005	21	105	10	25	10	5	70	10	5	18
2005	22	0	0	0	25	5	40	65	30	35
2005	23	33	1	0	10	0	40	30	50	30
2005	24	74	10	5	15	1	30	20	40	30
2005	25	49	5	1	20	1	10	20	70	25
2005	26	85	5	5	10	15	30	20	40	35
2005	27	0	0	0	50	0	15	90	35	25
2005	28	0	0	0	0	0	50	30	50	40
2005	29	0	0	0	20	30	20	50	30	25
2005	30	0	0	1	50	1	10	50	40	40
2005	31	52	5	5	25	1	50	20	25	25
2005	32	76	10	0	5	25	80	20	15	35
2005	33	0	0	0	25	1	45	65	40	40
2005	34	0	0	0	10	0	15	25	85	160
2005	35	0	0	0	20	0	40	50	40	35
2005	36	0	0	0	20	0	40	60	30	40
2005	37	0	0	0	10	1	20	60	60	40
2005	38	80	5	1	30	1	30	30	25	20
2005	39	0	0	0	0	0	10	12	90	200
2005	40	0	0	0	20	1	10	70	70	50
2005	41	0	0	0	15	0	20	60	65	40
2005	42	0	0	0	10	0	30	50	60	45
2005	43	0	0	0	25	0	40	70	35	30
2005	44	0	0	1	40	0	5	40	50	30
2005	45	200	15	0	5	5	65	30	30	50
2005	46	38	5	0	0	5	85	25	15	30
2005	47	0	0	0	10	1	10	10	70	100
2005	48	0	0	1	15	0	20	60	70	50
2005	49	9	1	1	5	0	65	60	25	35
2005	50	110	10	1	20	0	40	10	20	20
2005	51	0	0	0	15	0	10	25	50	40
2005	52	0	0	0	20	5	15	20	65	30
2005	53	95	5	0	0	5	75	20	25	35
2005	54	0	0	0	0	0	75	20	25	35
2005	55	0	0	0	15	0	20	24	65	40
2005	56	290	30	1	0	15	80	15	20	25
2005	57	0	0	0	35	0	15	25	50	60
2005	58	0	0	0	10	0	30	40	60	60
2005	59	0	0	0	15	0	40	40	45	38
2005	60	0	0	0	0	5	75	30	25	40
2005	61	0	0	0	0	0	35	45	65	50

DROS = Drosera stems/0.5m² plot (N), and percent cover/0.5m² plot (C)

LICH = lichen percent cover in each 0.5m² plot (C)

UNVG = unvegetated soil percent cover in each 0.5m² plot (C)

MOSS = Moss percent cover in each 0.5m² plot (C)

HERB = Herbaceous vegetation %cover (C), and mean height (H) for each 0.5m² plot

WOOD = Woody vegetation %cover (C), and mean height (H) for each 0.5m² plot

Appendix C

NESA core raw data for all other plants and variables in 2006

YEAR	PLOT	DROS_N	DROS_C	LICH_C	UNVG_C	MOSS_C	HERB_C	HERB_H	WOOD_C	WOOD_H
2006	1	198	5	0	10	5	70	30	20	60
2006	2	0	0	0	5	5	5	20	90	80
2006	3	0	0	0	0	10	45	40	55	50
2006	4	0	0	0	0	5	90	35	10	35
2006	5	0	0	0	5	1	75	25	20	30
2006	6	0	0	0	20	0	40	80	40	80
2006	7	0	0	0	10	0	80	85	10	60
2006	8	185	5	0	5	0	65	60	30	50
2006	9	285	5	1	15	0	75	30	10	50
2006	10	220	5	0	0	10	40	20	60	50
2006	11	0	0	5	10	10	65	35	25	45
2006	12	0	0	25	5	5	80	20	15	40
2006	13	0	0	0	5	5	25	35	70	65
2006	14	0	0	0	0	0	0	0	100	150
2006	15	0	0	0	0	0	40	60	60	70
2006	16	0	0	0	0	0	30	40	70	45
2006	17	0	0	0	15	0	70	65	15	40
2006	18	95	1	5	30	0	55	20	15	30
2006	19	0	0	0	0	15	15	30	85	60
2006	20	0	0	0	5	40	40	20	55	55
2006	21	45	1	15	5	1	80	20	15	45
2006	22	0	0	0	5	10	80	50	15	45
2006	23	95	1	0	5	5	75	35	20	40
2006	24	82	1	0	10	5	70	20	25	40
2006	25	122	1	0	20	1	30	25	50	50
2006	26	125	5	0	5	5	85	20	10	35
2006	27	0	0	0	15	0	65	60	20	50
2006	28	0	0	0	0	0	55	50	45	65
2006	29	0	0	5	5	30	55	45	40	40
2006	30	42	1	1	10	10	70	25	20	35
2006	31	85	1	5	45	5	50	20	5	35
2006	32	380	5	0	0	15	95	15	5	30
2006	33	0	0	0	5	15	80	40	15	35
2006	34	0	0	0	0	0	15	20	85	110
2006	35	0	0	1	15	0	65	45	20	30
2006	36	0	0	1	10	0	60	45	30	45
2006	37	225	5	0	5	5	50	30	45	25
2006	38	210	5	5	10	10	80	15	10	15
2006	39	0	0	0	10	0	5	10	85	100
2006	40	0	0	0	20	1	10	30	70	55
2006	41	150	1	1	15	0	55	25	30	30
2006	42	0	0	0	5	0	50	45	45	50
2006	43	0	0	0	25	0	45	45	35	30
2006	44	0	0	5	25	0	15	20	60	35
2006	45	125	1	0	5	10	80	35	15	20
2006	46	250	5	0	0	10	95	25	5	30
2006	47	0	0	0	5	10	25	15	60	65
2006	48	0	0	0	20	0	15	50	65	45
2006	49	270	1	5	5	0	80	45	15	35
2006	50	80	5	1	20	0	65	20	15	25
2006	51	20	1	0	15	0	50	20	35	25
2006	52	0	0	0	25	10	25	15	40	25
2006	53	38	1	0	0	5	70	25	25	30
2006	54	0	0	0	5	0	20	15	75	30
2006	55	0	0	0	0	0	20	25	80	50
2006	56	280	5	1	5	10	80	20	15	30
2006	57	0	0	0	40	0	15	50	45	40
2006	58	0	0	0	0	0	25	30	75	100
2006	59	0	0	0	15	0	25	20	60	50
2006	60	0	0	0	10	10	10	30	30	65
2006	61	0	0	0	10	5	40	25	60	65

DROS = Drosera stems/0.5m² plot (N), and percent cover/0.5m² plot (C)

LICH = lichen percent cover in each 0.5m² plot (C)

UNVG = unvegetated soil percent cover in each 0.5m² plot (C)

MOSS = Moss percent cover in each 0.5m² plot (C)

HERB = Herbaceous vegetation %cover (C), and mean height (H) for each 0.5m² plot

WOOD = Woody vegetation %cover (C), and mean height (H) for each 0.5m² plot

Appendix D

Data for all plots outside of the core for 2005

Sector	Plot #	UNVG_C	MOSS_C	HERB_C	HERB_H	WOOD_C	WOOD_H	CEOR_N	CEOR_C	RHCO_N	RHCO_C
Control	62	0	0	5	30	95	200	0	0	0	0
Control	63	0	0	30	20	70	50	0	0	0	0
Control	64	0	0	35	40	65	65	0	0	0	0
Burned	65	0	0	30	35	70	55	0	0	0	0
Burned	66	30	0	50	50	20	40	0	0	0	0
Burned	67	15	0	30	20	55	60	0	0	3	1
Burned	68	20	0	10	70	60	65	0	0	1	5
Cut	69	40	0	20	25	40	30	0	0	0	0
Cut	70	35	0	15	40	50	40	0	0	0	0
Cut	71	60	0	5	40	30	48	0	0	0	0
Cut&Burned	72	35	0	40	42	25	30	0	0	2	1
Cut&Burned	73	35	0	15	35	50	65	0	0	4	15
Cut&Burned	74	5	0	15	15	80	50	0	0	15	75
Control	75	0	0	0	0	100	300	-	-	-	-
Control	76	0	0	10	30	90	70	-	-	-	-
Control	77	0	0	80	30	20	24	-	-	-	-
Control	78	0	0	70	25	30	42	-	-	-	-
Control	79	0	0	0	0	100	65	-	-	-	-
Control	80	0	0	10	20	90	80	-	-	-	-
Control	81	0	0	10	15	90	95	-	-	-	-
Control	82	0	0	1	58	99	50	-	-	-	-
Control	83	0	0	90	35	10	20	-	-	-	-
Control	84	0	0	25	30	75	60	-	-	-	-
Control	85	0	0	15	35	85	80	-	-	-	-
Control	86	0	0	20	30	80	80	-	-	-	-
Control	87	0	0	20	18	80	350	-	-	-	-
Cut&Burned	88	20	0	40	20	40	40	0	0	4	20
Cut&Burned	89	10	0	15	18	75	75	0	0	17	75
Cut&Burned	90	10	0	30	20	60	30	0	0	11	30
Cut&Burned	91	20	0	10	20	70	45	0	0	9	25
Cut&Burned	92	45	0	25	24	30	38	0	0	8	25
Cut&Burned	93	20	0	30	28	50	50	0	0	12	45
Cut&Burned	94	45	0	30	28	25	25	0	0	3	5
Cut&Burned	95	20	0	10	25	70	55	0	0	17	5
Cut&Burned	96	25	0	50	42	25	35	0	0	7	1
Cut&Burned	97	70	0	10	20	20	15	0	0	17	2
Cut&Burned	98	65	0	5	20	30	20	0	0	19	25
Cut&Burned	99	50	0	10	30	40	35	0	0	10	5
Cut&Burned	100	70	0	0	0	30	20	0	0	1	1
Cut&Burned	101	60	0	15	12	25	5	0	0	0	0
Cut	102	95	0	0	0	5	5	0	0	1	1
Cut	103	70	0	1	20	30	15	0	0	0	0
Cut	104	10	0	75	30	15	40	6	15	0	0
Cut	105	0	0	95	25	5	10	4	5	0	0
Cut	106	0	0	90	40	10	40	5	10	0	0
Cut	107	5	0	75	55	20	15	0	0	0	0
Cut	108	5	0	15	10	80	55	0	0	0	0
Cut	109	10	0	80	10	10	25	0	0	0	0
Cut	110	0	0	30	80	20	40	0	0	0	0
Cut	111	0	0	90	35	50	10	1	1	0	0
Cut	112	5	0	60	25	35	30	0	0	0	0
Cut	113	60	0	5	5	40	70	0	0	1	1
Cut	114	25	0	10	15	50	40	0	0	0	0
Cut	115	20	0	60	40	5	20	4	10	0	0
Cut	116	20	0	70	30	10	15	0	0	0	0
Cut	117	5	0	80	25	15	20	2	5	0	0
Burned	118	15	0	1	30	85	65	0	0	8	70
Burned	119	10	0	30	60	60	80	0	0	3	50
Burned	120	45	0	5	20	50	45	0	0	1	10
Burned	121	60	0	0	0	40	25	0	0	0	0
Burned	122	15	5	15	25	70	55	0	0	7	5
Burned	123	15	0	40	40	45	35	0	0	0	0
Burned	124	30	0	40	55	30	45	0	0	3	1
Burned	125	35	0	50	65	15	70	0	0	2	1
Burned	126	5	0	5	25	90	55	0	0	5	5
Burned	127	15	0	10	25	75	45	0	0	1	1
Burned	128	60	0	20	25	20	35	0	0	0	0
Burned	129	20	0	30	40	50	30	0	0	0	0
Burned	130	40	0	10	35	50	55	0	0	2	1
Burned	131	20	0	15	40	65	50	1	0	8	25
Burned	132	20	0	60	45	20	50	0	0	4	1
Control	133	5	20	20	35	75	60	0	0	0	0
Control	134	0	15	35	90	60	70	0	0	0	0
Control	135	10	0	15	80	75	85	0	0	0	0

Control	136	80	0	5	20	95	150	0	0	0	0
Control	137	0	0	20	90	80	120	0	0	0	0
Control	138	0	0	20	90	90	80	0	0	0	0
Control	139	0	0	5	15	95	130	0	0	0	0
Control	140	5	0	20	80	75	100	0	0	0	0
Control	141	75	0	5	30	90	170	0	0	1	1
Control	142	1	50	20	15	90	90	0	0	1	1
Control	143	10	0	60	80	25	70	0	0	0	0
Control	144	10	0	10	60	90	150	0	0	0	0
Control	145	30	0	40	50	40	30	0	0	0	0
Control	146	5	0	15	50	70	90	0	0	1	1
Control	147	75	0	5	20	20	140	0	0	0	0

UNVG = unvegetated soil percent cover in each 0.5m² plot (C)

MOSS = Moss percent cover in each 0.5m² plot (C)

HERB = Herbaceous vegetation %cover (C), and mean height (H) for each 0.5m² plot

WOOD = Woody vegetation %cover (C), and mean height (H) for each 0.5m² plot

CEOR = *Celastrus orbiculatus* stems/0.5m² (N) and % cover (C) for each 0.5m² plot

RHCO = *Rhus copallina* stems/0.5m² (N) and %cover C for each 0.5m² plot

Appendix D

Data for all plots outside the core in 2006

Sector	Plot #	UNVG_C	MOSS_C	HERB_C	HERB_H	WOOD_C	WOOD_H	CEOR_N	CEOR_C	RHCO_N	RHCO_C
Control	62	0	0	0	0	100	250	0	0	0	0
Control	63	0	0	10	70	90	80	0	0	0	0
Control	64	0	0	30	80	70	90	0	0	0	0
Burned	65	0	0	95	50	5	30	0	0	0	0
Burned	66	0	0	60	50	40	35	1	1	0	0
Burned	67	0	0	40	35	60	65	0	0	3	5
Burned	68	5	0	25	70	70	65	0	0	1	5
Cut	69	0	0	60	45	40	65	0	0	0	0
Cut	70	0	0	90	35	10	40	3	1	0	0
Cut	71	40	0	25	50	35	55	0	0	0	0
Cut&Burned	72	0	0	60	30	40	40	6	5	2	1
Cut&Burned	73	0	0	55	60	45	55	0	0	3	15
Cut&Burned	74	5	0	30	35	65	60	10	10	12	40
Control	75	0	0	0	0	100	300	—	—	—	—
Control	76	0	0	10	30	90	70	—	—	—	—
Control	77	0	0	80	30	20	24	—	—	—	—
Control	78	0	0	70	25	30	42	—	—	—	—
Control	79	0	0	0	0	100	75	—	—	—	—
Control	80	0	0	10	25	90	80	—	—	—	—
Control	81	0	0	10	15	90	95	—	—	—	—
Control	82	0	0	5	50	95	50	—	—	—	—
Control	83	0	0	85	15	15	20	—	—	—	—
Control	84	0	0	25	35	75	60	—	—	—	—
Control	85	0	0	15	35	85	80	—	—	—	—
Control	86	0	0	20	30	80	80	—	—	—	—
Control	87	0	0	15	25	85	350	—	—	—	—
Cut&Burned	88	50	0	20	30	30	35	0	0	2	5
Cut&Burned	89	5	0	50	30	45	65	5	1	13	60
Cut&Burned	90	5	0	30	15	65	45	0	0	13	30
Cut&Burned	91	0	0	15	15	85	70	0	0	5	30
Cut&Burned	92	15	0	50	25	35	35	0	0	9	35
Cut&Burned	93	5	0	35	30	55	70	2	1	7	25
Cut&Burned	94	10	0	75	25	15	40	4	1	7	20
Cut&Burned	95	0	0	20	30	80	75	0	0	11	25
Cut&Burned	96	0	0	35	45	65	35	0	0	7	20
Cut&Burned	97	15	35	50	30	35	30	0	0	15	30
Cut&Burned	98	60	10	15	15	25	40	0	0	13	45
Cut&Burned	99	15	0	10	35	75	65	0	0	5	30
Cut&Burned	100	45	0	15	25	40	35	3	1	1	1
Cut&Burned	101	30	0	60	15	10	15	0	0	0	0
Cut	102	85	0	15	25	0	0	0	0	0	0
Cut	103	45	20	20	5	30	35	1	1	0	0
Cut	104	0	0	85	55	15	40	19	15	0	0
Cut	105	0	0	100	35	0	0	15	10	0	0
Cut	106	0	0	100	45	0	0	8	10	0	0
Cut	107	0	0	100	50	0	0	0	0	0	0
Cut	108	0	0	30	15	70	100	3	10	0	0
Cut	109	0	0	70	25	30	30	0	0	0	0
Cut	110	0	0	85	40	15	40	11	5	0	0
Cut	111	0	0	85	20	15	30	2	10	0	0
Cut	112	15	0	65	35	20	30	5	5	0	0
Cut	113	20	0	5	10	75	85	0	0	1	1
Cut	114	0	0	30	25	70	55	0	0	0	0
Cut	115	15	0	100	55	0	0	9	10	0	0
Cut	116	5	0	80	45	15	50	11	10	2	1

Cut	117	0	0	80	45	20	40	3	5	0	0
Burned	118	15	0	1	30	85	65	0	0	6	70
Burned	119	10	0	35	65	55	80	4	1	3	5
Burned	120	35	0	5	35	60	45	0	0	1	5
Burned	121	45	0	10	10	45	30	2	1	0	0
Burned	122	10	0	20	30	70	60	0	0	5	5
Burned	123	0	0	95	60	5	20	0	0	0	0
Burned	124	0	0	90	45	10	60	3	1	1	1
Burned	125	0	0	40	65	60	75	0	0	0	0
Burned	126	0	0	15	30	85	60	0	0	2	5
Burned	127	0	0	5	15	95	110	0	0	0	0
Burned	128	0	0	85	60	15	30	0	0	1	1
Burned	129	0	0	60	70	40	70	1	1	3	20
Burned	130	10	0	60	70	30	55	0	0	0	0
Burned	131	0	0	55	50	45	80	7	5	5	40
Burned	132	0	0	80	70	20	60	0	0	3	20
Control	133	10	15	80	35	20	50	0	0	0	0
Control	134	0	0	30	70	70	70	0	0	0	0
Control	135	0	0	35	95	65	65	0	0	0	0
Control	136	0	0	0	0	100	180	1	1	0	0
Control	137	0	0	0	0	100	120	0	0	0	0
Control	138	0	0	5	70	95	85	0	0	0	0
Control	139	0	0	5	10	95	90	0	0	0	0
Control	140	0	0	20	70	80	100	0	0	0	0
Control	141	0	0	5	25	95	120	0	0	1	1
Control	142	0	15	25	40	75	150	0	0	1	1
Control	143	0	0	45	50	60	65	0	0	0	0
Control	144	10	0	30	40	60	100	0	0	0	0
Control	145	30	0	40	50	40	30	0	0	0	0
Control	146	5	5	10	50	70	90	0	0	1	10
Control	147	60	0	20	25	20	150	0	0	0	0

UNVG = unvegetated soil percent cover in each 0.5m² plot (C)

MOSS = Moss percent cover in each 0.5m² plot (C)

HERB = Herbaceous vegetation %cover (C), and mean height (H) for each 0.5m² plot

WOOD = Woody vegetation %cover (C), and mean height (H) for each 0.5m² plot

CEOR = *Celastrus orbiculatus* stems/0.5m² (N) and % cover (C) for each 0.5m² plot

RHCO = *Rhus copallina* stems/0.5m² (N) and %cover C for each 0.5m² plot

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