Prescribed Fire Monitoring in Vermont Dry Oak Habitats

2023 Report to the Green Mountain National Forest

Regeneration following a prescribed burn on the Dome in the Green Mountain National Forest

Submitted by:

Jay Kelly and Jessica Ray- Raritan Valley Community College

Ryan Rebozo- Vermont Center for Ecostudies

October 2023

DOI: https://doi.org/10.18125/qb154z

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Introduction

The use of prescribed fire as a management strategy for achieving ecological goals in oak forests has gained interest from land managers in recent years as they attempt to address a variety of objectives including attempting to imitate past disturbance regimes, address invasive species, and promote regeneration of target tree species (Hutchinson et al. 2005, Arthur et al. 2012, Brose et al. 2013, Waldrop et al. 2016, Ward et al. 2018). Addressing changes in tree composition as a result of mesophication is often cited as a focus of management efforts in these habitats, yet these processes and confounding effects of herbivory and plant competition are not always well understood at the local level (Kreye et al. 2018, Alexander et al. 2021). Prescribed burning has been hypothesized to benefit the regeneration of oaks by reducing competition, litter depth, or seed predation and increasing light and nutrient availability (Abrams 1992, Brose et al. 2001). However, the benefits of fire for oaks and other hardwoods are highly variable, with the outcomes depending upon initial site conditions, species, timing, size class structure, and other factors, and may also be detrimental or counterproductive to achieving these goals (Brose et al. 2001). Further complicating the expected outcomes from introducing fire disturbance is pressure from invasive species and local deer densities, with their preference for oak and other select hardwood species. As a result, there are many conditions that may influence the likelihood of a prescribed fire obtaining its management goal based on the habitat it is used in.

Dry oak forests are considered an uncommon (S3) natural community in Vermont, though they can be found in each state in the Northeast. These forests often support fire-adapted species and as a result, prescribed burning has become a consideration for managing these forests. Based on empirical-based monitoring results, Southern Vermont has the highest probability for high ungulate browse impacts on forest land in the state and some of the highest probability in New England (McWilliams et al. 2018). Several studies have reported the lack of regeneration in response to fire in the presence of sustained browse pressure except where herbivores were excluded or reduced, even when combined with increased light from canopy gaps (Nuttle et al. 2013, Andruk et al. 2014, Miller et al. 2017, Brose et al. 2001). Tree regeneration can be suppressed with deer densities as low as 6 deer/km2 (Russell et al. 2017), and these declines have resulted in indirect effects on forest breeding birds (Baiser et al. 2008, Rushing et al. 2020, Crystal-Ornelas et al. 2021) and invertebrates (Chips et al. 2015).

Invasive plant species may also profoundly alter ecosystem structure and function in ways that are detrimental to native plants, animals, fungi and ecosystem services (Burghardt et al. 2010, Ashton and Lerdau 2008, Ehrenfeld et al. 2001). Preferential browsing on native species can allow for the establishment of invasive species that then further limit regeneration and recruitment of target species (de la Cretaz and Kelty 1999, Kelly 2019). Limited research has been conducted to date to determine the effectiveness of prescribed burning in this context, where white-tailed deer and invasive plant species may lead to altered trajectories of forest response (Kelly 2019, Richburg et al. 2004, Nuttle et al. 2013).

Study Area

The monitoring described in this report took place at two locations, The Nature Conservancy's Great Ledge Natural Area in Fair Haven VT and the Dome in the Green Mountain National Forest in Pownal VT. The Great Ledge Natural Area is a 960 acre preserve that supports several state-recognized natural communities including approximately 92 acres of Dry Oak habitat. This site does not have a recent history of fire and was included as a satellite control site that represents Dry Oak forest conditions outside of the Dome site.

The Dome is a 2,743’ mountain located near the southwestern corner of the 400,000+ acre Green Mountain National Forest. Over 280 acres of dry oak forest habitat have been identified on the Dome with two variants, heath and beech. While oak remains a dominant component of the canopy, signs of mesophication of the understory are present with other hardwood species becoming more common and few oak seedlings or saplings present (National Forest Service pers. comm.) Maintaining an oak-dominated component of this site has been identified as a priority by the US Forest Service. On May 1st 2022, prescribed fire was introduced in six stands over approximately 127 acres of Dry Oak habitat in an attempt to maintain a fire-adapted plant community and to improve oak regeneration on site, with over 50% of the habitat left unmanaged for comparison. The stated goals of this burn included decreasing fuel load by 30-50%, removing 1-3” of duff from openings, and top kill 70-80% of saplings.

Elevations differed between the control sites, with sampling locations located at approximately 740 – 840’ elevation at Great Ledge Natural Area, and 1400 – 2400’ at Green Mountain National Forest. Burn and control plots at GMNF were at identical elevations with similar moderate sloping conditions. Burn plots at GMNF were 15±1% slope, and control sites were 17±1% slope. Aspect differed slightly, with burn sites being oriented SW on average (235 8) and control sites being SSE (169 8), but with roughly similar amounts of solar radiation given their general southerly orientation. Monitoring sites at the Great Ledge Natural Area were randomly selected using ArcGIS in the portions of the natural area identified as Dry Oak habitat and averaged 251.4 meters apart. Sites selected on the Dome were a subset of those used to monitor both the burn and control sides by the forest service and had a minimum of 250m between sites.

Scope of Work

The goal of this project was to complement and expand upon the existing monitoring at stands in the GFMNF to include full phase 3 FIA monitoring, local deer density estimates, and develop species lists for local bird species richness and vascular plants. Our primary goal is to contribute data that will establish a baseline for monitoring the variables described above, allow for a comparison of burned vs. unburned plots and other comparable dry oak forests, and inform additional surveys focused on responses to prescribed fire.

Methods

FIA Methods

Field data were collected in August 2022 at pre-determined sampling locations provided by USFS staff at GMNF, and in June 2023 at random points in Dry Oak habitat generated by VCE at the Great Ledge Natural Area (GLNA). At each sampling location, four 7.3 m radius subplots were established following FIA protocols, with a single plot located at the center point and others located 36.6 m from center at 0, 120 and 240 degrees. A total of 11 plots were measured at GMNF (5 burned, 6 control) and six plots at GLNA. Data collection followed FIA Phase 3 protocols with some minor modifications, including measurements of:

1) Tree dbh for all stems greater than 4” in the 7.3 m radius subplots;

2) Tree seedling (<1" dbh) densities, sapling (1-4" dbh) densities and sapling dbh by height class in a 2.1 m radius microplot located 3.65 m at 90 degrees from center. Height classes followed McWilliams et al. (2015) for studying deer browse impacts on tree regeneration, including 0-6", 6-12", 1 – 3', 3 – 5', 5 – 10', >10';

3) Line intercept for percent cover of woody shrubs, lianas, and large tree seedlings (>1' tall) on three radial transects at 30, 150 and 270 degrees, including only the last 5 m of transect length to avoid double counting vegetation patches at the center of the plot. The tallest shrubs were measured at the beginning and end of the transect segments;

4) Percent cover of non-woody species and ground cover, density of small tree seedlings (<1' tall), and canopy cover using a densiometer in three 1 m^2 vegetation plots near the limits of each transect. The tallest herbaceous plants were also measured in each plot along with each herbaceous species encountered in the plot;

5) Percent cover and decay class of coarse woody debris (CWD) and counts of fine woody debris (FWD) in three different size classes (<0.25", 0.25-0.99", 1-2.99" dbh) using line intercept, and measurements of duff and litter depth at the ends of each transect. The smaller FWD was collected from 5.5 – 7.3 m, and 1 -2.99" size class from 4.3 – 7.3 m;

6) For all vegetation, instances of browse damage, insect herbivory or burn damage or mortality were noted.

Duff layer samples were collected to measure bulk density as a proxy for compaction. We collected two duff samples per plot using 10 cm diameter standard soil corer at the full depth of the duff layer. We removed the litter layer before collecting duff samples. Soil moisture content was determined by first weighing 10 gram subsamples, then drying the samples for 6 hours at 70°C before reweighing. Collected soil was manually homogenized prior to analysis.

Statistical Analyses

Data for each variable were summarized by subplots and non-parametric Kruskal-Wallis tests were conducted in SAS-JMP 10.0 to determine whether differences existed between the means of burned and control plots at confidence intervals of 0.95.

Deer Density Methods

We conducted infrared surveys for white-tailed deer (*Odocoileus virginianus*) by drone or sUAS (small unmanned aerial system) to obtain estimates of local deer population size and density at the Dome and The Great Ledge Natural Area. We used an Autel EVO II Dual drone with FLIR 640 Thermal Sensor, which was flown at night when greater contrast between ground and deer body temperatures enabled enhanced visibility. All flights were conducted with an FAA-certified pilot aided by a visual observer trained and certified for night-time operations. Each mission was flown in public airspace (Class G) at ≤400 feet above ground level, in compliance with federal regulations for night-time operations.

Surveys were conducted on April 25, 2023 at The Great Ledge Natural Area and April 26, 2023 at GMNF and. This is within a seasonal window that provides the most conservative estimates of annual deer densities, i.e., after the fall/winter season when deer numbers are driven to their lowest numbers in the year from hunting, vehicle collisions, harsh winter conditions, and prior to the birth of fawns in May. Preflight planning included the identification of suitable launch points, flight hazards, access, and airspace regulations via aerial photography, aeronautical maps, and field visits to each site. Sufficient launch points were identified to ensure that all areas were adequately covered based on the range limitations of the drone.

Flights were conducted in transects to ensure proper coverage of the entire area. Transects were spaced an average of roughly 500 feet apart. All observations of deer and search areas were recorded and mapped in real-time using the Autel Explorer and ArcCollector App. When deer were spotted, the drone was kept in a hover position until an accurate count was obtained. If necessary, the drone was moved to a lower position (≥200') and/or different angles to get a better vantage for accurate counting or positive identification. This procedure was repeated until the entire study area was surveyed. Densities from the drone surveys were later calculated by dividing the total deer found by the search area covered by the drone.

To obtain the most accurate estimate possible, we also implemented several additional quality control measures. If herds of deer were found close to a prior location where deer were previously observed, the drone was flown back to the vicinity of the first observation to see if they were still present. If absent from the original location, then the second observed herd was not counted in order to avoid double-counting (i.e., to account for the fact that the first herd observed may have moved to the new position). Secondly, when deer herds were noted to be moving in a certain direction during the observation, then the area of habitat that they were moving towards was surveyed next in order to ensure that deer were not double-counted. If observed objects could not be positively identified, the data was excluded from our analysis. All these controls ensured the results to be as robust and conservative as possible.

Deer observations were spatially plotted in ArcMap. The kernel density tool was used to display a heat map of the density at each study site, which creates heat maps of local densities based on the densities of points within predetermined search radius. We utilized a search radius based on estimates of deer home range sizes, or the extent to which deer move throughout the year, which themselves are dependent on various factors, including sex, food availability, weather conditions, hunting pressures, land cover (forested, suburban, urban, exurban, rural, etc.), breeding patterns and other factors (Etter et al. 2018, Innes 2013, Kilpatrick et al. 2001, Williams et al. 2008). Studies on home range sizes of whitetail deer show major variation throughout their range, from between 0.14 – 11.7 square miles (Innes 2013). However, in the Mid-Atlantic and New England regions, deer home ranges tend to be much smaller, including approximately 1.0 mi^2 in agricultural and heavily forested land covers (Sparrowe and Springer 1970, Tierson et al. 1985), 0.4 mi^2 in exurban areas (Storm et al. 2007), and 0.17 mi^2 in suburban areas (Kilpatrick and Spohr 2000). Because both study sites are dominated by forested landscapes, we used a search radius that represented 1 mi^2 home range size to be conservative. However, it is important to keep in mind that some densities may be underestimated as some deer within this area as deer may have a larger home range size.

ARU Sampling Methods

Six Wildlife Acoustics Song meter SM4 autonomous recording units (ARUs) were deployed on the Dome from May 11, 2023 to June 23, 2023 in order to develop a bird species list for the site that will complement other descriptive variables collected as part of this monitoring project. These units were programmed to record for two hours centered around sunrise and two hours centered around sunset for each day they were deployed. Units were affixed to trees at a height of approximately 2m in an array spaced +/- 250m apart. The location of each unit is listed in Appendix 3. Timing of deployment coincides with the nesting period for many species and the resulting list can be useful in identifying species that may be nesting on site. Audio files were read using BirdNET Analyzer with the following analysis parameters- 0.0s time overlap, 1.0 sensitivity, 0.1 minimum confidence in identification and 4 threads. The list of potential species used to aid in the identification of the audio files was generated from eBird data for the Lat/Long of the site and the weeks during which the units were deployed. A list of species recorded and identified with the minimum confidence level is listed in Appendix 6.

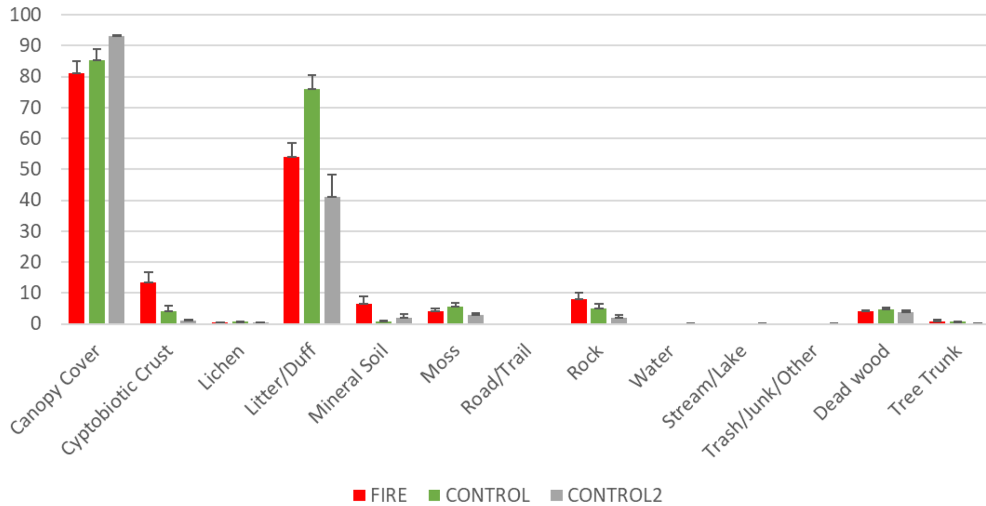
Results

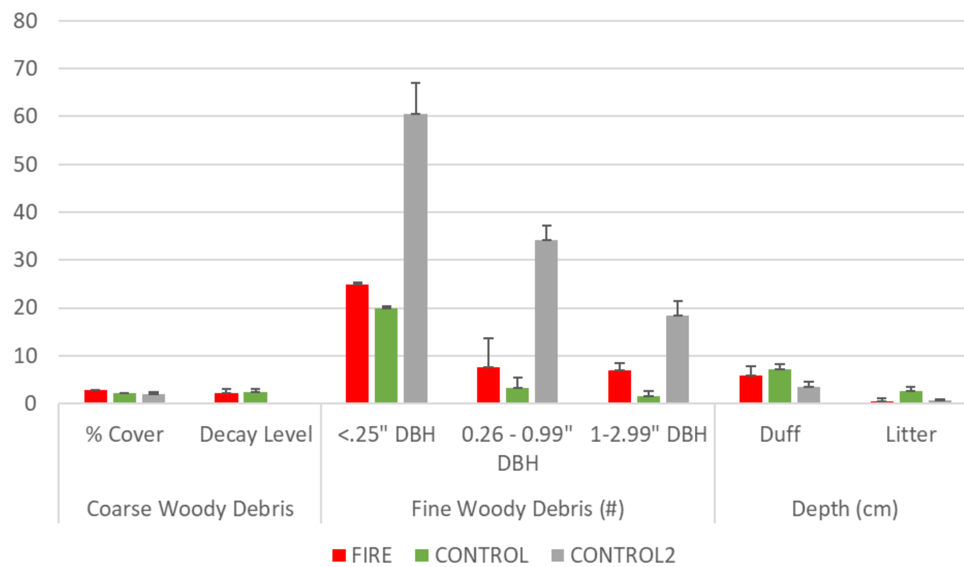
Physical Site Conditions

Ground and canopy cover measurements in vegetation plots (Figure 1) indicated significant differences between burned and control sites at GMNF for percent cover of mineral soil (7% burned vs. 1% control, p = 0.0334), cryptobiotic crust (15% vs. 4%, p = 0.0187), and litter/duff (54% vs. 76%, p = 0.0004). No differences existed for canopy cover (81% vs. 85%, p = 0.4152), lichen (0.4% vs. 0.6%, p = 0.5825), moss (4% vs. 6%, p = 0.2144), rock (8% vs. 5%, p = 0.1078), dead wood (4% vs. 5%, p = 0.6625), or tree trunks (0.8% vs. 0.7%, p = 0.7683). Measurements of woody debris, duff and litter found significant differences in 0.25-0.99" fine woody debris (8% vs. 3%, p = 0.0.0175), 1-2.99" fine woody debris (7% vs. 2%, p=0.0056), and litter depth (0.5 cm vs. 2.6 cm, p < 0.0001), but not coarse woody debris cover (3% vs. 3%, p = 0.541) or state of decay (2.3 vs. 2.4, p = 0.6764), <0.25" fine wood debris (25% vs. 20%, p = 0.8063) or duff depth (6cm vs. 7cm, p = 0.2792). Average bulk density of the duff layer across all GMNF sites was 3.23 g/cc (n=22). There was no significant difference (p>0.05) between bulk densities at burned (μ=3.29) and control plots (μ= 3.14).

Comparison of GLNA to GMNF control plots found significantly lower litter (0.7 cm, p = 0.0028) and duff (4 cm, p = 0.0482) depth at GLNA, and 3 – 11 x more fine woody debris. Ground cover, coarse woody debris and canopy cover were not significantly different between these sites except for lower amounts of leaf litter/duff cover (41%, p = 0.0016), moss (3%, p = 0.0495) and rock (2%, p = 0.0217). Decay level of coarse woody debris was not recorded at GLNA. No differences existed between average slope and aspect of the control sites.

Figure 1. Canopy and Ground % Cover (Left) and Woody Debris and Litter Depth (Right). "Fire" = burned areas at GMNF, "Control" = unburned areas at GMNF, "Control 2" = unburned areas at Great Ledge Natural Area.





Vegetation Structure

Various measurements of vegetation structure (Figure 2) showed significant differences between burned and control plots, including tallest shrub (13 cm vs. 85 cm, $p < 0.0001$), and live tree basal area (4.3 ft2 vs. 6.6 ft2, $p = 0.0102$), but not basal area of dead trees (0.1 ft2 vs. 0.2 ft2, $p = 0.0620$) or tallest non-woody plant (14 cm vs. 20 cm, $p = 0.1509$). Tree densities decreased in burn plots for 4-9.9” dbh size class (6 vs. 11, $p = 0.0012$), but not for canopy trees >10” dbh (3 vs. 3, $p = 0.2707$). Taller size classes of seedlings in the microplots also declined in burn plots, including height classes of 1 – 3’ (3 vs. 6, $p = 0.0177$), 3 – 5’ (0.1 vs. 1.7, $p < 0.0001$), 5 – 10’ (0.2 vs. 1.5, $p = 0.0047$), and >10’ (0.6 vs. 1.6, $p = 0.0218$). No difference was found in density of dead trees (0.5 vs. 1, $p = 0.0937$), or the smaller seedling size classes of 0 – 6” (24 vs. 18, $p = 0.6797$) or 6 – 12” (10 vs. 10, $p = 0.9905$).

Tree mortality (%) in all understory size classes was greater in burn plots, but was significantly greater only at 1 – 3’ (32% vs. 5%, $p = 0.02347$), 3 – 5’ (89% vs. 8%, $p < 0.0001$), and 5 – 10’ (80% vs. 20%, p =

0.0011). Browse damage was greater in control plots, but there was no significant difference in any size class.

Cumulative percent cover of shrubs (22% vs. 84%, $p < 0.0001$) and herbs (9% vs. 15%, $p = 0.0133$) decreased significantly in burn plots (Figure 3). Within these categories, the % cover of forbs (1.1% vs. 1.7%, $p = 0.0219$), ferns (2% vs. 6%, $p = 0.0208$), and ericaceous shrubs (13% vs. 54%, $p = 0.0013$) all decreased significantly in burn plots compared to controls, and no difference was found with viburnums or graminoids.

Understory structure differed significantly between the GLNA and GMNF control plots. There was significantly less shrub cover in the GLNA controls (44%) compared to GMNF controls ($p = 0.0041$), for example, but no difference in shrub height. There was significantly less % cover of ericaceous shrubs (9%, $p < 0.0001$), but greater cover of viburnums (4%, $p = 0.0005$). There was also less cover of fern species (0.4%, $p < 0.0001$), but greater cover of graminoids (6%, $p < 0.0001$). There was significantly less percent cover for each of the dominant species of large tree seedlings (>1' tall, <1" dbh), including *Acer rubrum, Quercus* spp., *Fagus grandifolia, Hamamelis virginiana, Sassafras albidum*, but not for *Amelanchier* and "other" trees. Herbaceous cover was greater at GLNA (28%, $p = 0.0076$) and herb height was also greater (29 cm, $p = 0.0059$). There was no difference in basal area of trees. In terms of tree seedling size class structure, there were more seedlings <6" tall (36, $p = 0.0335$), and less large saplings >10' tall (0.2, $p = 0.0003$), but no differences otherwise.

Browse damage from deer was significantly greater for all understory size classes of trees at GLNA than GMNF except for the tallest (>10'). There was no difference in percent mortality of understory tree size classes except for 5 – 10' tall seedlings, which was significantly lower at GLNA (0%, $p = 0.0486$).

Figure 2. Height of Shrubs & Herbaceous Plants and Tree Basal Area

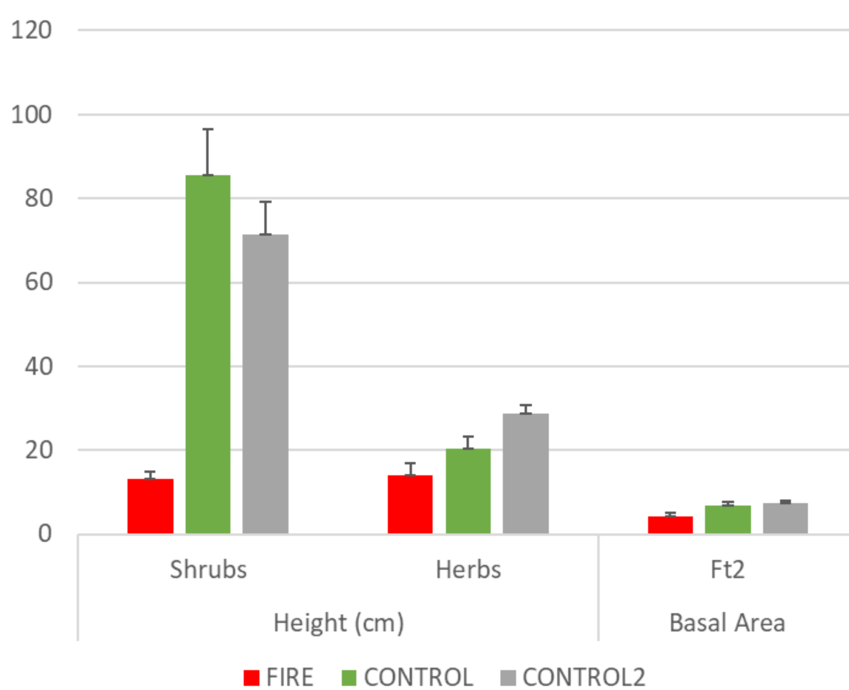
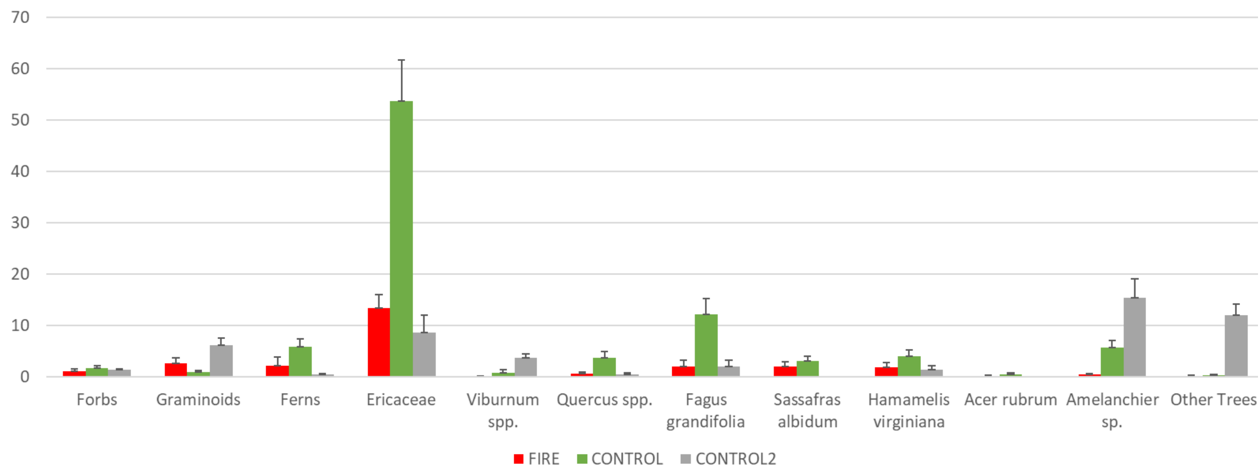


Figure 3. Cumulative % Cover of Understory Vegetation and Large Tree Seedlings (>1' Tall)



Tree Species Composition

Tree species composition was nearly identical for canopy trees (>10" dbh), with 85-95% of stems comprised of oaks (*Quercus*), and the remainder primarily consisting of red maple (*Acer rubrum*), beech (*Fagus grandifolia*) and white pine (*Pinus strobus*) (Figures 4 and 5). Small numbers of hophornbeam (*Ostrya virginiana*), white birch (*Betula papyrifera*), American chestnut (*Castanea dentata*), black cherry (*Prunus serotina*), hawthorn (*Crataegus* spp.) and white ash (*Fraxinus americana*) were also present in smaller size classes but were highly infrequent.

Average densities of understory oaks (*Quercus* spp.) were lower in each size class in burned areas compared to controls, but differences were significant only in the 1 – 3' height class (0.2 vs. 2.0, p = 0.0414). Maples (*Acer rubrum*) were significantly lower in 0 - 6" (0.7 vs. 7.1, p = 0.0004), 6 – 12" (0 vs. 0.5, p = 0.0324), 3 – 5' (0.2 vs. 0.7, p = 0.0394) and 5 – 10' height classes (2 vs. 4, p = 0.0301). Serviceberry (*Amelanchier* spp.) was significantly lower in 3 - 5' (0.6 vs. 1.0, p = 0.0498). Beeches (*Fagus grandifolia*) were significantly lower in 1 – 3' (0.1 vs. 0.4, p = 0.0382), 3 – 5' (0 vs. 0.5, p = 0.0177) and 5 – 10' (0 vs. 0.8, p = 0.0095) height classes. No difference was found for birches (*Betula* spp.) or Sassafras (*Sassafras albidum*). Witch Hazel (*Hamamelis virginiana*) was lower in all size classes, but differed significantly only in the 3 – 5' (0 vs. 0.4, p = 0.0049) class.

In terms of percent cover of large seedlings, which were measured using line intercept, significant decreases were observed in controls for red maple (0.1% vs. 0.5%, p = 0.0496), serviceberry (0.4% vs. 5.8%, p = 0.0004), and beech (2% vs. 12%, p = 0.0007). No change was observed for witch hazel, sassafras, oaks, or other infrequent species combined.

Tree mortality (Figures 6 and 7) was greater in 3 -5' classes for *Amelanchier* (67% vs. 0, p = 0.0325), *Fagus* (100% vs. 0%, p = 0.0143), and *Hamamelis* (100% vs. 11%, p = 0.0068), in 5 – 10' class for *Quercus* (100% vs. 0%, p = 0.0455) and *Fagus* (100% vs. 0%, p = 0.0082), and >10' for *Hamamelis* (100% vs. 0%, p = 0.0455). No difference existed for percent browse.

Canopy tree species composition was nearly identical at GLNA as at the GMNF controls, but with greater amounts of *Tsuga canadensis, Carya* spp., and *Acer saccharum*. Understory tree species diversity also differed slightly, with greater amounts of *Ostrya virginiana, Acer pensylvanicum, Tilia americana* amongst the larger trees, and *Populus grandidentata* in the understory. There was also less *Sassafras albidum, Fagus grandifolia*, and *Betula* spp. than at GMNF. No data on understory tree mortality was collected at GLNA as most stems were not identifiable.

Figure 4. Stem Density and Species Composition of Tree Species by Size Class

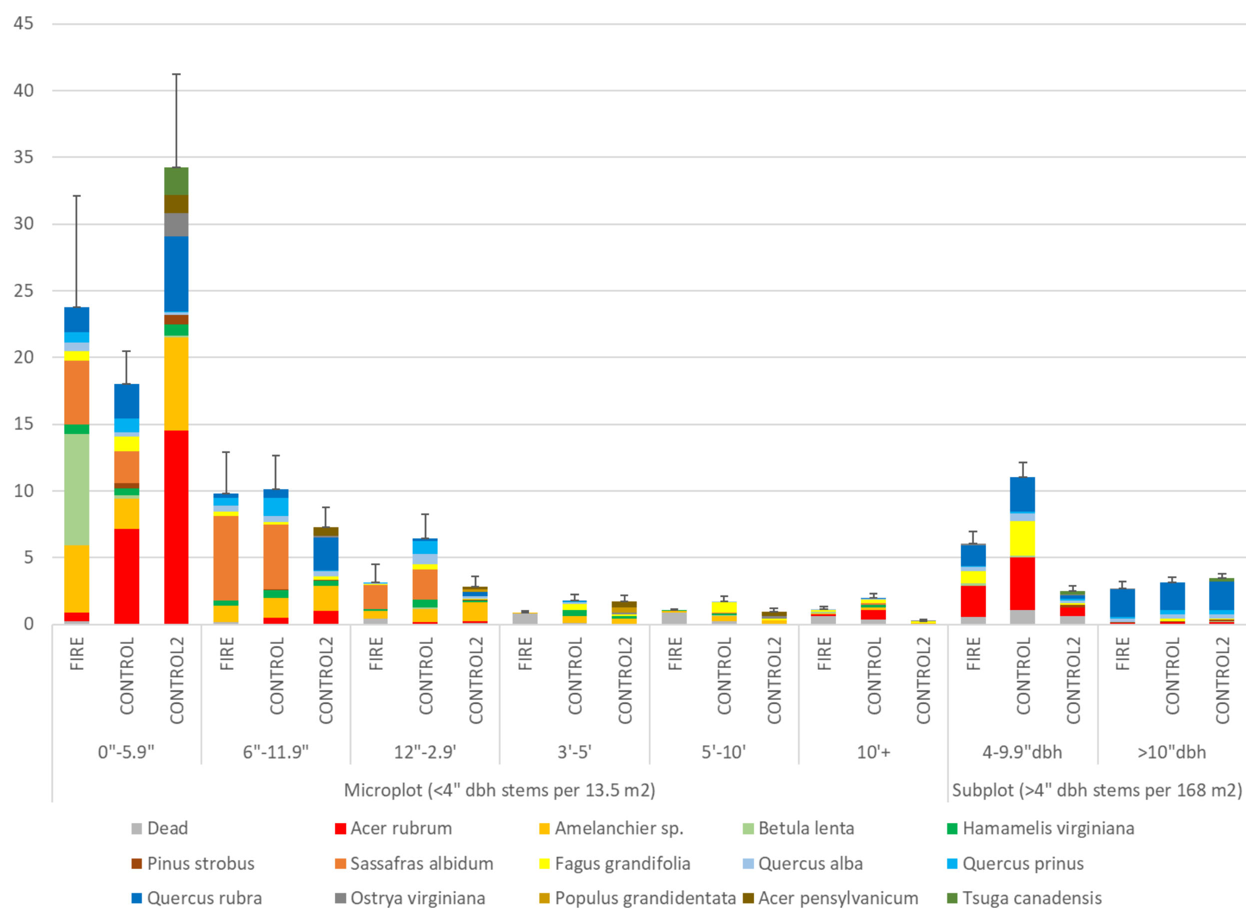


Figure 5. % Composition of Tree Species by Size Class

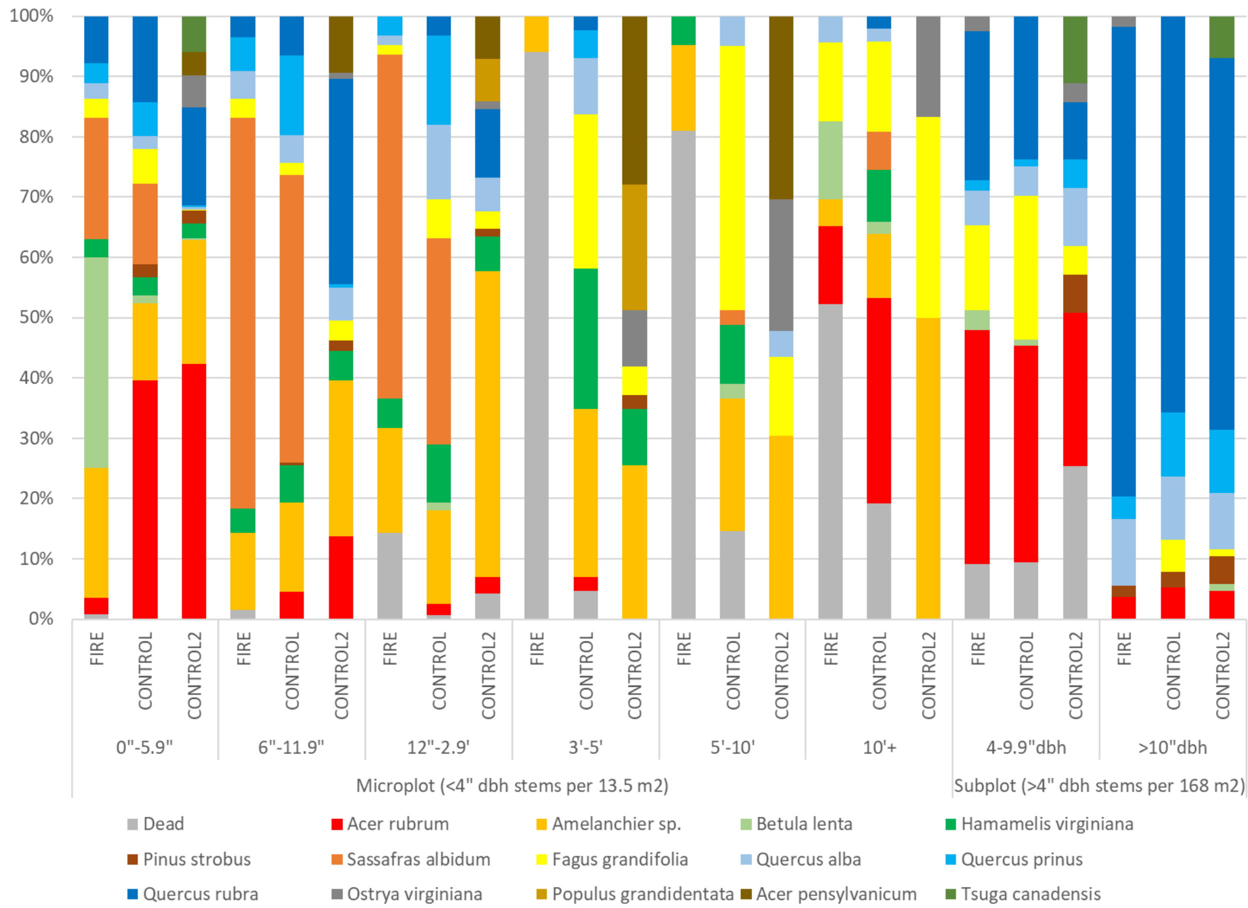


Figure 6. Density and Species Composition of Dead Tree Stems by Size Class

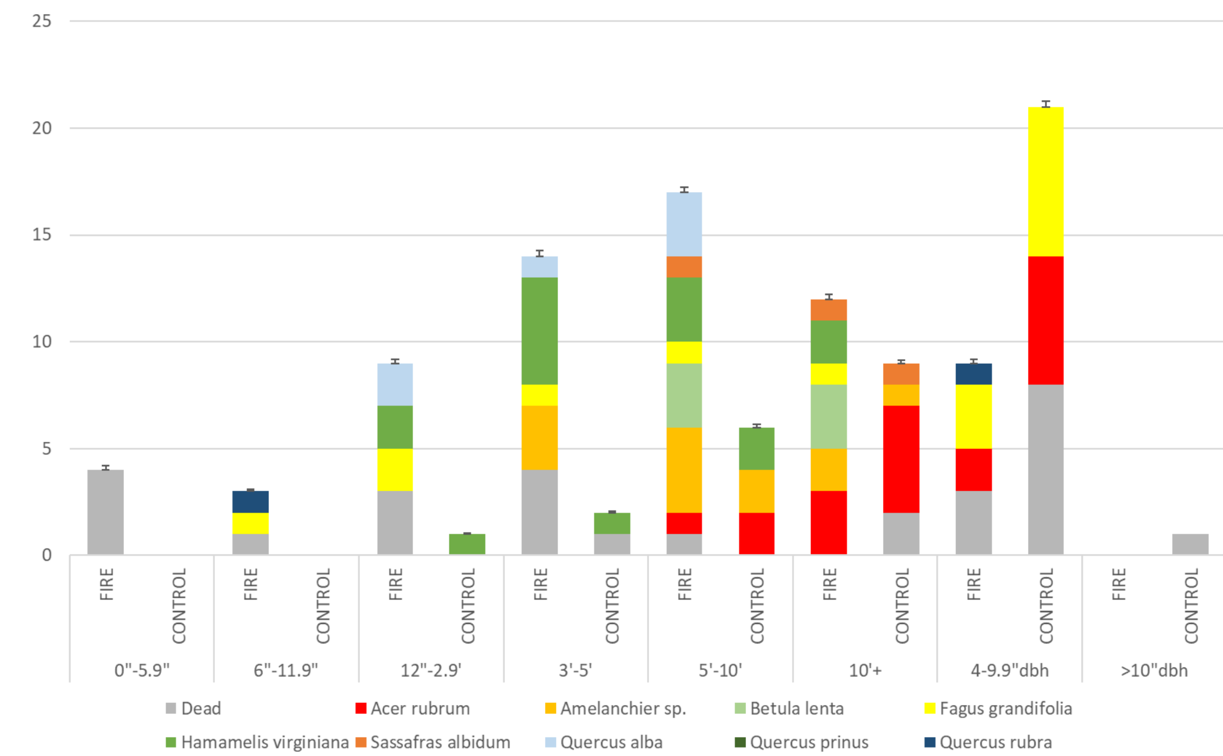
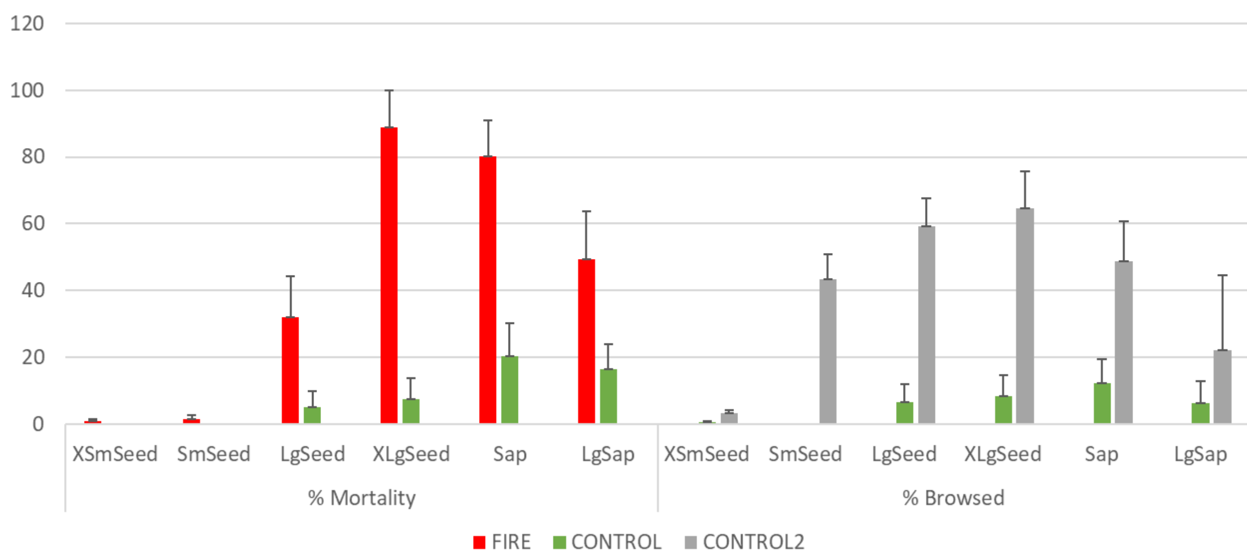


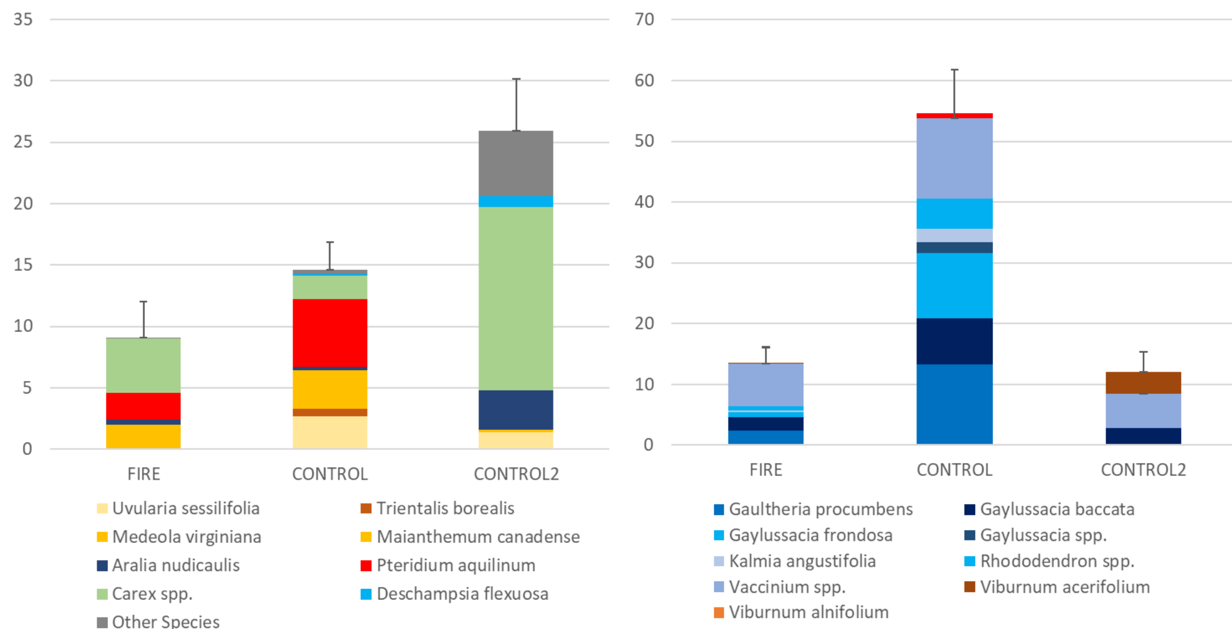
Figure 7. % Mortality and Browse of Tree Stems by Size Class



Shrub and Herb Composition

In terms of individual species changes (Figures 8 – 10), major decreases in percent cover were observed at the burn sites for Sessile bellwort (*Uvularia sessilifolia*; 0% vs. 3%, p < 0.0001), starflower (*Lysimachia borealis*; 0% vs. 1%, p = 0.0013), bracken fern (*Pteridium aquilinum*; 2% vs. 6%, p = 0.0208), wintergreen (*Gaultheria procumbens;* 2% vs. 13%, p = 0.0054), azalea (*Rhododendron* spp.; 1% vs. 5%, p = 0.0101), and blueberry (*Vaccinium* spp.; 7% vs. 13%, p = 0.0069). Although average amounts were lower for many other species as well, these were not statistically significant. No significant increases were observed for any species. Noteworthy infrequent species included *Clintonia borealis, Isotria verticillata* and *Monotropa hypopythis*.

Figure 8. Average % Cover of Dominant Herbaceous (Left) and Woody Shrub (Right) Species



As with understory structure and tree composition, shrub and herb species composition was significantly different at GLNA than GMNF, with lesser amounts of *Pteridium aquilinum* and *Medeola virginiana*, greater amounts of *Maianthemum canadense*, *Carex* spp., *Aralia nudicaulis*, *Melampyrum lineare, Mitchella repens*, and other species among those that were dominant. There were also many other infrequent species that did not appear at the other sites, including *Botrychium virginianum, Dryopteris marginalis, Prenanthes* spp., *Oryzopsis asperifolia, Waldsteinia fragarioides, Thalictrum dioicum, Polygonatum biflorum, Polgala pauciflora, Lysimachia quadrifolia, Viola* spp., *Hypericum* spp., *Hepatica americana, Geranium robertianum, Helianthus divaricatus, Fragaria virginiana, Dichanthelium* spp., and others.

Figure 9. Average % Cover of Dominant Woody Shrub Species. NOTE: Data on *Gaultheria procumbens* was not collected in the same way at GLNA and was excluded from the data below.

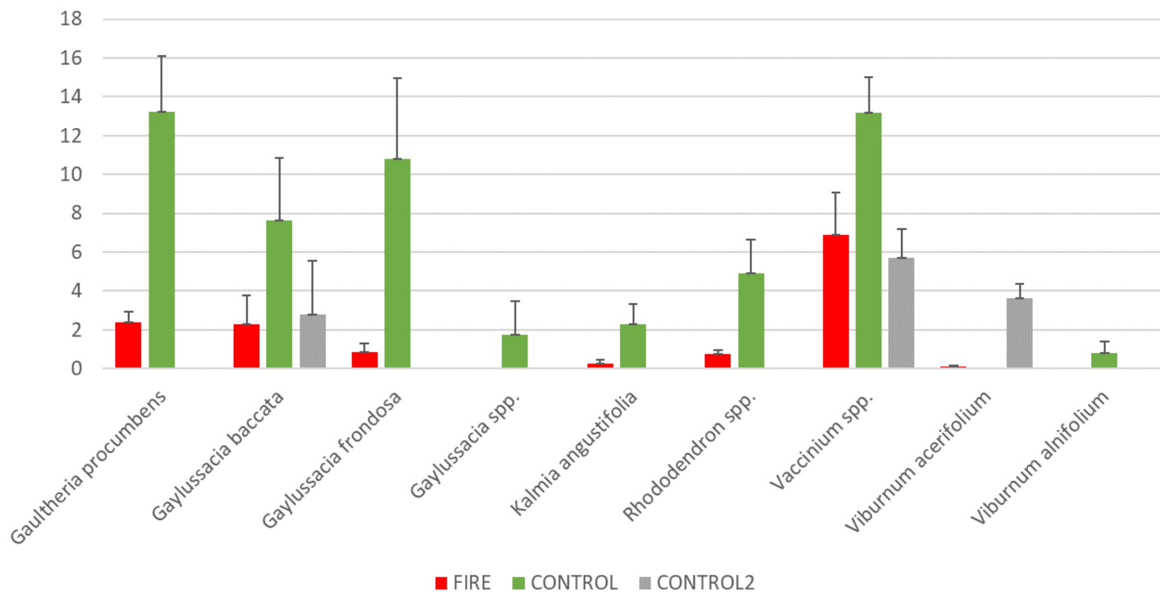
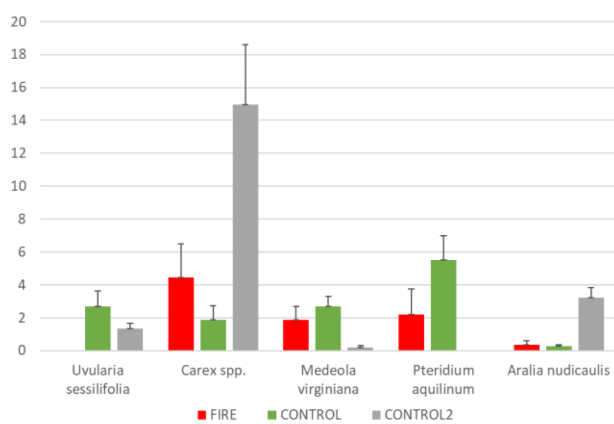
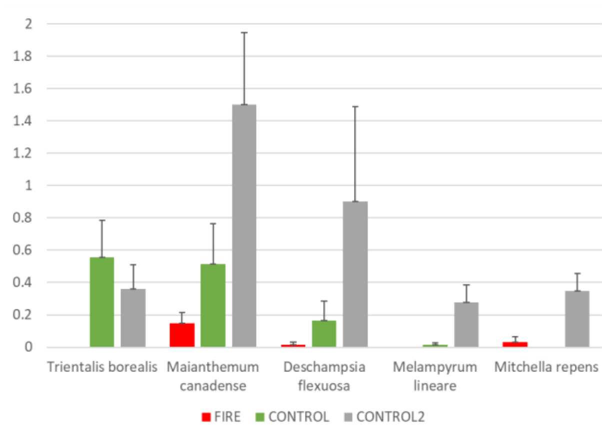
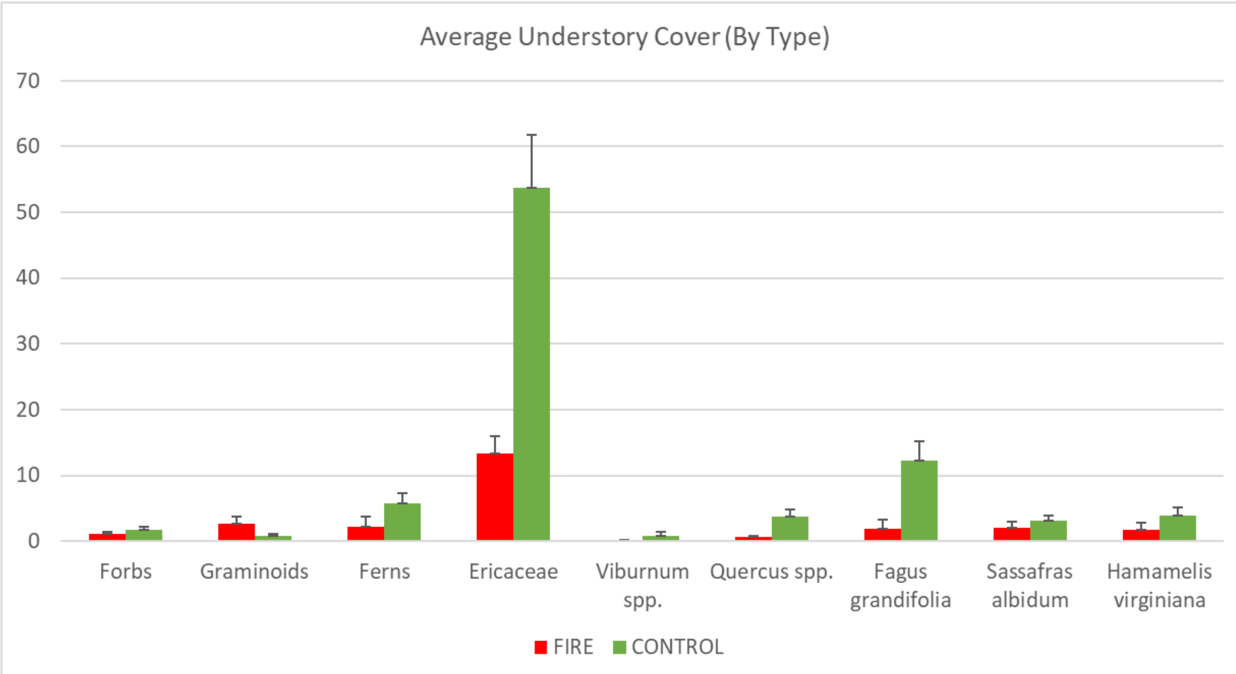


Figure 10. Average % Cover of Dominant Herbaceous Species







Deer Density Results

An overall density of 10 deer/mi^2 was observed at The Dome, where a total of 19 deer were observed in the 1.97 mi^2 survey area. Localized densities reached above 20 deer/mi^2 within the survey area (Figure 11). Local deer densities increased to 10-20 in some areas of Dry Oak habitat (S3) within the survey area, however, most areas of Dry Oak habitat had <10 deer/mi^2 based on the 1 mi^2 home range size.

Similarly, a total of 13 deer were observed in the 1.05 mi^2 Great Ledge Natural Area survey area, resulting in a density of 12 deer/mi^2 (Table 1). Localized densities in the survey area increased above 20 deer/mi^2, encompassing a large section of the dry oak habitat within the survey area (Figure 12).

Table 1. Deer densities observed during sUAS thermal imaging surveys at each study location.

Date	Location	Area (mi)	# of Deer Observed	Density (deer/mi)
3/25/2023	The Great Ledge Natural Area -TNC	1.05	13	12
3/26/2023	The Dome – GMNF	1.97	19	10

Figure 11: Total survey area and locations of deer observations on the Dome

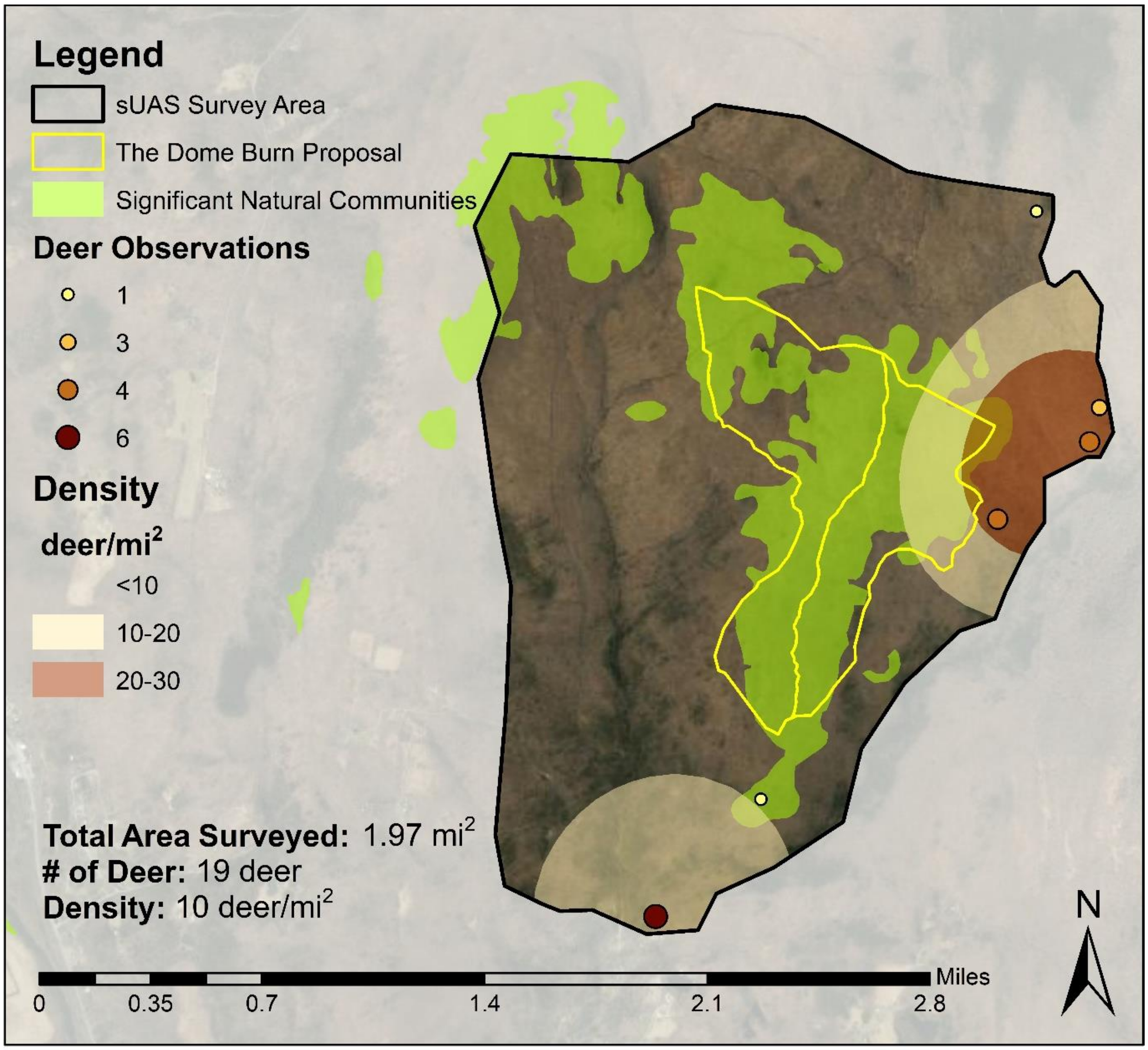
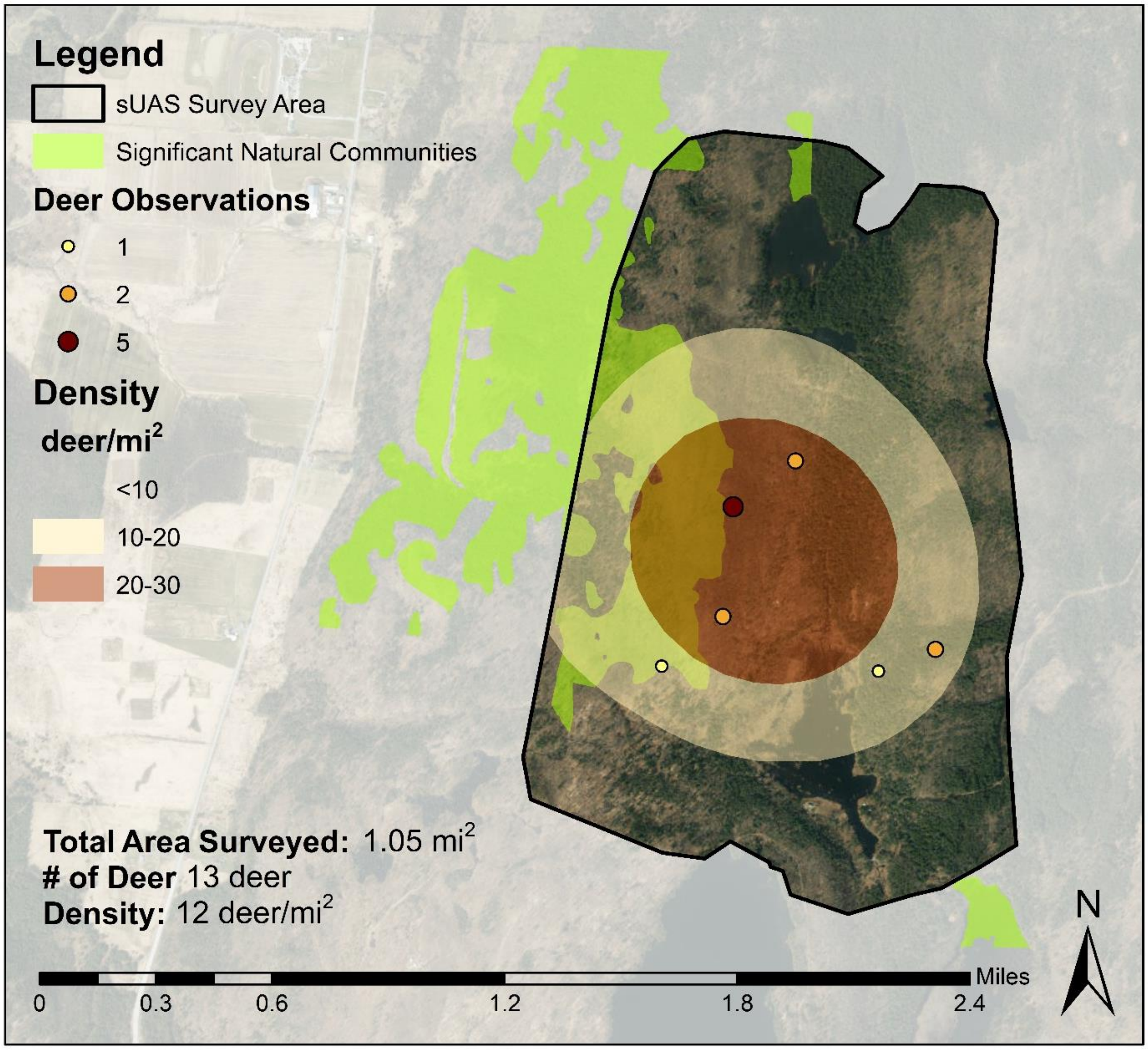


Figure 12: Total survey area and locations of deer observations on the Great Ledge Natural Area



Discussion

This project represented an opportunistic study to develop baseline monitoring data for Two Dry Oak habitats as well as compare post-fire forest response between adjacent and satellite control sites. Given the variability in fuels, conditions, and fire dynamics on any given site, within fire forest responses can vary significantly, and we believe the spatial arrangement of monitoring sites adequately covered the managed area. This monitoring project allowed us to observe responses during the first growing season after a burn and as a result, does not fully capture the forest's response to disturbance that would be best described with several years of follow-up monitoring.

While fire intensity was not directly measured during the burn, burn severity at the Dome was high enough to consume more leaf litter and expose more mineral soil, but did not produce significant reductions in the duff layer when compared to the adjacent control site. Partial consumption of the duff layer was a stated goal of this burn as it would have addressed concerns regarding potential mesophication at this site. Reductions in the duff layer is expected to promote greater oak germination and localized changes to the shrub and herbaceous species composition. Retained moisture and compaction of the duff layer from snowpack likely reduced the ability of this low-intensity prescribed burn to consume duff upon first entry and the availability of fuel load may limit the frequency of prescribed fire return intervals. Future attempts to introduce fire intense enough to consume significant amounts of duff may require changes in the timing and prescription of the burn, though these changes may exceed current safety parameters considered when planning prescribed burns.

Burn intensity left canopy trees and canopy cover largely unaffected but was successful in creating measurable changes in the sapling community, a second stated goal of this burn. The differences in shrub height between burned and controlled plots are the result of the timing of this monitoring. While the shrub community did not experience significant mortality, above-ground growth consumed during the May fire had not fully regrown when surveying took place in August. Whereas canopy trees can sustain low-intensity fires, and many observed seedlings may have germinated after the fire, the sapling size class is particularly susceptible to fire and that was reflected in this site with a lower density and higher mortality in saplings on the burned portion. This burn was able to reach or exceed its sapling mortality goals in the 3’-5’ and 5’-10’ size classes and still achieved approximately 50% mortality in the 10’+ size class. While the canopy remains dominated by *Quercus rubra*, saplings were targeted in this burn because their composition is comprised of a greater percentage of *Fagus grandifolia and Acer rubrum*, both expected to perform better under mesophitic conditions. This burn resulted in the reduction of all three of these species specifically and the sapling size class in general. Many of the seedlings under 12” in height may have germinated after the fire and were thus unaffected. The seedling size class is comprised of a greater richness of tree species not all of which will become canopy trees. With few remaining saplings the survival and ultimate recruitment of the seedling cohort to reproductive individuals would have to be followed with additional monitoring in order to assess whether the burn was successful in promoting oaks over maple and beech.

At the time of monitoring significant reductions in the cover of some shrub and herbaceous species were recorded without a corresponding significant increase in cover by the remaining vegetative community. This response is also likely the result of monitoring during the first growing season after a burn. While not statistically significant, percent cover of *Carex* species did increase. *Carex* species constituted a much greater percentage of ground cover at the Great Ledge Natural Area site and the ongoing change to this genus and the greater shrub and herbaceous plant composition following the burn is best measured with additional follow-up visits after the burn.

The composition of canopy tree species did not differ much between the two control sites but it is interesting to note the significant differences in the shrub and herbaceous plant cover. The differences in ericaceous shrub cover and herbaceous plant cover between the two control sites may be explained in part by the depth of the duff layer. Sites at the Dome averaged over 50% deeper duff layers than at the Great Ledge site and many ericaceous shrubs including those found on the Dome site such as *Kalmia angustifolia, Vaccinium angustifolium, Gaylussacia baccata,* and *Gaultheria procumbens* are known to develop their rhizomes in the O horizon (Laycock 1967). The depth of the duff layer alone may not explain the understory differences between the two sites and past land use and disturbance may also play a role. Incorporating existing records of past disturbance, fire, and otherwise, will be important in not only explaining current observed differences but tracking changes in these sites over time.

The plant community at these sites was largely intact and native, though non-native species were regularly identified outside of subplots at trailheads, access roads, and along trails. Particular consideration should be given to the potential for invasion and spread of these nearby sources of non-native species when considering disturbance on site. While prescribed burns have been effective at reducing certain species of thin-barked non-natives, it has also been shown to create conditions conducive to the spread of some other woody and herbaceous non-native species. The establishment of non-native species in the understory of these forests has the potential to significantly impact the regeneration of native trees on site. A survey and assessment of the nearby non-native plant species prior to disturbance can help inform the management of the site and any needed mitigation measures to address potential spread.

Beyond failing to reduce the duff layer, the burn did not stimulate the regeneration of oaks or ericaceous shrubs as both were described in the management plans as goals for this site. Instead shrub cover was significantly reduced and density of oak seedlings declined when compared to both the adjacent and satellite control sites. While it may be too early to determine if the oak species on site will respond positively to the fire, the goal of stimulating oak regeneration through fire may not be achieved if deer herbivory and ambient deer densities are not considered given that oaks are a preferred browse species. Current deer densities on-site may already be impacting the regeneration of oaks beyond the lack of light reaching the understory mentioned in the management plan for this site. Signs of spongy moth herbivory in the oak canopy and signs of beech bark and leaf disease throughout the site suggest that much more light may be reaching the understory than densiometer-based measures of cover would suggest. Deer herbivory may then help explain the limited number of oaks represented in the sapling size classes of both control sites.

In order to interpret the results of the deer surveys, it is important to understand the environmental impacts of different deer densities. Biologists estimate precolonial deer densities to be approximately 8-11 deer/mi^2 (McCabe and McCabe 1997). This is supported by the negative impacts from deer browse that tend to occur at densities above these levels for preferred browse species and forest structure (Almendinger et al. 2020, deCalesta and Stout 1997; Alverson et al. 1988; Frelich and Lorimer 1985; Behrend et al. 1970). Additional indirect or “cascade” effects on food webs and other ecosystem properties tend to occur at densities above 15-20/mi^2 (McWilliams et al. 2018, Russell et al. 2017, Chips et al. 2015, Nuttle et al. 2011, Horsley et al. 2003, Drake et al. 2002, de Calesta 1994). These densities, therefore, provide useful benchmarks for deer management to achieve ecological goals, with ~10 deer/mi^2 being the optimal target for supporting the greatest biodiversity and ecosystem structure and function.

The low densities observed at each of the sites fit within, or close to the goal of 10 deer/mi^2. However, localized deer populations increased between 10-20 and 20-30 deer/mi^2 in Dry Oak forest communities at the Dome and Great Ledge, respectively. Additionally, the densities are likely to be higher during the growing season after the birthing of fawns. To estimate deer populations at those times, the reproductive and mortality rates must be considered. Reproductive rates are generally 1.6 fawns/doe per year in Vermont (Vermont Fish and Wildlife Department 2021). Thus, the effective deer densities from late May through September are therefore likely to be up to 60% higher than the densities observed during this survey period. Resultingly, the overall densities could increase to 16 and 19 deer/mi^2 at the Dome and the Great Ledge Natural Area, respectively. Similarly, this would increase areas of localized deer populations and would suggest that negative ecological impacts are occurring at these densities.

In total 80 bird species were recorded with ARUs throughout the Dome and 52 species of plants were positively identified in sampling plots. Of the recorded species, four are considered rare in the state of Vermont, *Castanea dentata* (S3), *Isotria verticilata* (S2), *Sassafras albidum* (S3), and *Uvularia perfoliata* (S2). Differences in life history traits and phenology of these four species may influence individual responses to fire management and changes to demography as a result of prescribed fire can only be determined with follow up monitoring.

Plant species in the genera *Castanea, Lysimachia, Rhododendron*, *Vaccinium,* and *Viola* have already been documented on-site and are known to support species of rare or specialist bees and lepidoptera, and should be priorities for observation during their flowering period in order to better document the bee diversity supported by this site. Future pollinator surveys for this site are justified given the site's potential to support a diverse pollinator community as pollinator species richness and floral abundance have been found to be highest in the first two years after the fire then slowly begin to decline (Potts et al. 2003). Species or genera of plants known to exist on site and support priority bee species are listed below (Associations below were developed from data described in Hardy et al. 2022).

Sheep Laurel (*Kalmia angustifolia*) - Host to the S2 Sheep-laurel Miner (*Andrena kalmiae*) and possibly associated with the SH Kindred Cellophane Bee (*Colletes consors*).

Blueberries (genus *Vaccinium*) - Host to multiple Miner and Mason bees, including several rare species. A few blueberry specialists also need sandy soils for nesting, further limiting their distribution.

Early Azalea (*Rhododendron prinophyllum*) - Host of the S1 Azalea Miner (*Andrena cornelli*), which is only known from one site in VT though may occur more widely. Early Azaleas are likely vulnerable to overbrowsing by White-tailed deer.

American Chestnut (*Castanea dentata*) - Historically American Chestnut was probably a keystone pollinator species, providing abundant pollen in mid-summer. Rehn's Miner (*Andrena rehni*) is thought to be a *Castanea* specialist and is known from several locations in Massachusetts and likely occurred in VT prior to the arrival of Chestnut blight. Targeted efforts to locate this species here have so far been unsuccessful.

Yellow Loosestrifes (genus *Lysimachia*) – Based on historical collections, plants in the genus *Lysimachia* are believed to be declining in Vermont. *Lysimachia's* are important in supporting *Macropis* bees that collect oil from their non-nectar producing flowers. *Lysimachia cilliata, L. terrestris*, and *L. quadrifolia* being the primary host species in the northeast. *Macropis* are ground nesting bees that often aggregate nests on sloping banks. River banks, particularly south facing, have also been identified as nesting sites. The presence of Dogbane (*Apocynum canabinum*) in addition to Loosestrife has been strongly correlated with the presence of Yellow Loosestrife Bees. Species associated with *Lysimachia* are the S3 Dark-legged Yellow Loosestrife Bee (*Macropis nuda*), the S1 Patellate Yellow Loosestrife Bee (*Macropis patellata*), and two species likely to occur in Vermont but have not yet been documented the Ciliate Yellow Loosestrife Bee (*Macropis ciliata*), and the Pilose Yellow Loosestrife-Cuckoo (*Epeoloides pilosula*) a kleptoparasite of Macropis bees.

Violets (genus *Viola*) - The S1 Violet Miner (*Andrena violae*) is poorly known in VT, though fairly common further south. The specific violets targeted by this bee aren't well documented, but many forest violets are visited by a range of native bees.

Loose, well-drained soils, like those found at the Dome, are important for most ground-nesting bees (Hardy et al. 2022). Many species are only found where the soil is sparsely vegetated and/or intermittently disturbed suggesting that moderate human activity is compatible with many of these rare bees, including prescribed burns which can expose more mineral soil. At some locations, the most active nesting locations may only be a few square meters and easily located by the presence of kleptoparasitic species. Bee species associated with sandy soils are listed below.

Viereck's Metallic-Sweat bee (*Lasioglossum vierecki*) - This tiny but distinctive species is only found at sandy sites, where it can be abundant. Active from May through September with a broad diet. S3.

Fairy Bees (*Perdita*) - All three species in VT are tiny specialists only found near sand, active from July through September.

Blood Bees (*Sphecodes*) - More than 20 species occur in Vermont, most of which are kleptoparasites of Sweat Bees (family *Halictidae*). Most abundant and diverse near sandy soils, they can be a quick way to locate important nesting locations.

The plant species list reported here reflects only those species identified within sampling locations and is not a complete species list for the site. Intentional plant surveys would be needed to develop a more rigorous species list. A list of rare plant species known from Dry Oak habitats in Vermont but not yet encountered on the Dome is included in Appendix 7.

A list of butterfly species expected to occur at the Dome site has been included as Appendix 8 in this document. This list was generated from crowd sources species identified within the same 5x5km Vermont Butterfly Atlas survey block as the Dome. This list includes three rare species and species with flight times throughout the growing season and should be the focus of butterfly surveys on site.

Conclusions

The monitoring outlined in this report identified some significant post-burn changes that will influence the trajectory of this forest into the future. Additionally, it helped develop a robust baseline for which future monitoring can reference. Ultimately, the effectiveness of this burn at promoting oaks species over the maple and beech will require additional monitoring and we recommend that this site be revisited in 2024 in order to assess early seedling and sapling regeneration as well as responses of other understory plant species occurring on site two years post-burn. Revisiting the burn sites two-years after the burn can help identify if oak seedling densities have increased to match or exceed those found on the control sites. Additional monitoring should then occur at 5-year intervals. Future monitoring should focus on rare plant species found to occur on-site and their response to fire as well as commit efforts to identifying other rare species that are likely to occur on-site. Several species of plants known to support rare pollinator species were documented at both sites and future surveys should focus on identifying the presence of any priority insect species on site prior to burning. These species-specific surveys can then help plan future management of this habitat. Similarly, nearby non-native species and their eradication or prevention of spread should be accounted for in future management. Regular assessment of local deer density will be an important component of the management of this forest moving forward as increases beyond the levels recorded currently can have a negative impact to the regeneration of target species and reductions of elevated deer densities can be a difficult and costly process. We believe that periodic monitoring and assessment of this uncommon habitat type can lead to informing a more dynamic management strategy that can ensure the greatest likelihood of meeting the anticipated ecological outcomes.

Acknowledgments

This work was supported by a grant through the Forest Ecosystem Monitoring Cooperative. We would like to that the Green Mountain National Forest and the Nature Conservancy for access to sites and to support this work. Thanks to VCE biologist Spencer Hardy for language and resources on bee species likely to be present on site. We would also like to thank our team of RVCC and VCE seasonals and interns who helped collect these data.

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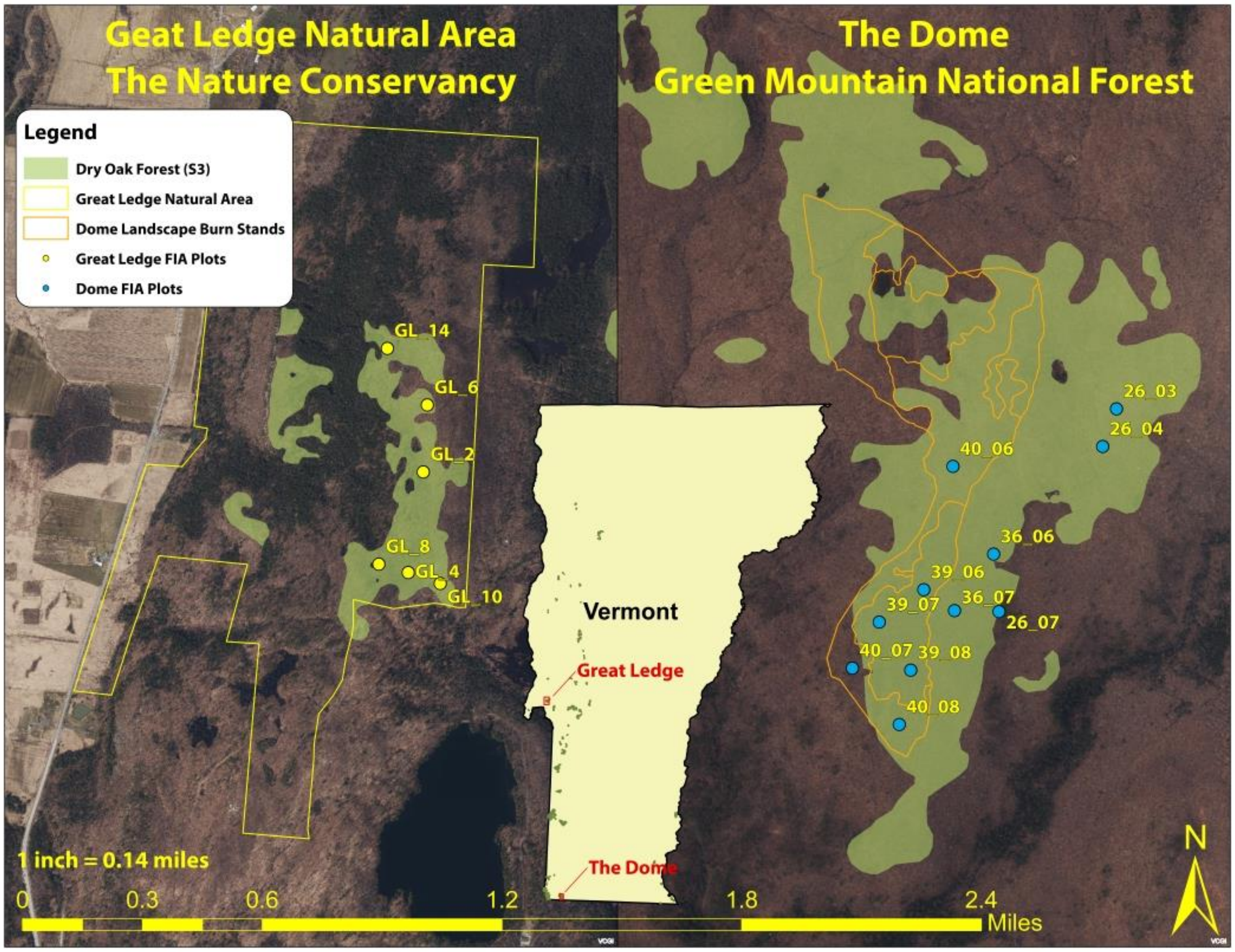
Appendix 1: Extent of dry oak forest and locations of sampling plot at the Great Ledge Natural Area and the Dome.


Geat Ledge Natural Area
The Nature Conservancy
The Dome
Green Mountain National Forest
Legend
Dry Oak Forest (S3)
Great Ledge Natural Area
Dome Landscape Burn Stands
Great Ledge FIA Plots
Dome FIA Plots
GL_14
GL_6
GL_2
GL_8
GL_4
GL_10
Vermont
Great Ledge
The Dome
26_03
26_04
40_06
36_06
39_06
39_07
36_07
26_07
40_07
39_08
40_08
1 inch = 0.14 miles
0
0.3
0.6
1.2
1.8
2.4
Miles
N

Appendix 2: Locations of sampling plots on the Dome and Great Ledge Natural Area

Location	Plot Number	LAT	LONG
Dome	40_6	42.7594	-73.1788
Dome	40_7	42.7541	-73.1824
Dome	40_8	42.7526	-73.1808
Dome	39_6	42.7562	-73.1799
Dome	39_7	42.7555	-73.1813
Dome	39_8	42.7540	-73.1803
Dome	26_3	42.7610	-73.1729
Dome	26_4	42.7600	-73.1734
Dome	26_7	42.7556	-73.1771
Dome	36_6	42.7571	-73.1773
Dome	36_7	42.7556	-73.1788
Great Ledge	2	43.6561	-73.2788
Great Ledge	4	43.6525	-73.2795
Great Ledge	6	43.6586	-73.2786
Great Ledge	8	43.6528	-73.2810
Great Ledge	10	43.6521	-73.2779
Great Ledge	14	43.6606	-73.2807

Appendix 3: Locations of ARU placements on the Dome

ARU	
Lat	**Long**
42.75918	-73.1804
42.75637	-73.1771
42.75377	-73.1773
42.75808	-73.1768
42.75644	-73.1806
42.75352	-73.1809

Appendix 4: List of vascular plant species on the Dome and Great Ledge Natural Area with state ranks for S1-S3 species

Dome Species List	**Great Ledge Species List****
Acer rubrum	*Acer pensylvanicum*
Amelanchier laevis	*Acer rubrum*
Amelanchier sp.	*Acer saccharum*
Aralia nudicaulis	*Amelanchier arborea*
Betula lenta	*Amelanchier sp.*
Betula papyrifera	*Amphicarpaea bracteate*
Carex sp.	*Anemone Americana*
*Castanea dentata (S3)**	*Antennaria neglecta*
Clintonia borealis	*Aralia nudicalis*
Crataegus sp.	*Asclepias quadrifolia*
Deschampsia flexuosa	*Aster sp.*
Deschampsia sp.	*Betula lenta*
Fagus grandifolia	*Betula populifolia*
Fraxinus Americana	*Botrychium virginianum*
Gaultheria procumbens	*Carex laxiflora*
Gaylussacia baccata	*Carex lucorum*
Gaylussacia frondosa	*Carex rosea*
Hamamelis virginiana	*Carex sp.*
Isotria verticilata (S2)	*Carya ovata*
Kalmia angustifolia	*Deschampsia flexucosa*
Lysimachia borealis	*Dichanthelium latifolium*
Maianthemum canadense	*Dichanthelium sp.*
Maianthemum sp.	*Dryopteris marginalis*
Medeola virginiana	*Fagus grandifolia*
Melampyrum lineare	*Fragaria virgiana*
Mitchella repens	*Fraxinus Americana*
Monotropa hypopitys	*Gallium circaezans*

Nabalus sp.	*Galium sp.*
Ostrya virginiana	*Gaultheria procumbens*
Pinus strobus	*Gaylussacia baccata*
Poaceae sp.	*Geranium robertianum*
Prunus serotina	*Geranium sp.*
Pteridium aquilinum	*Hamamelis virginiana*
Pyrus communis	*Helianthus divaricatus*
Quercus alba	*Hepaticum Americana*
Quercus montana	*Hypericum sp.*
Quercus rubra	*Lysimachia borealis*
Quercus velutina	*Lysimachia quadrifolia*
Rhododendron prinophyllum	*Maianthemum canadense*
Rhododendron sp.	*Medeola virginiana*
Sassafras albidum (S3)	*Melampyrum lineare*
Trillium sp.	*Mitchella repens*
Uvularia perfoliata (S2)	*Oryzopsis asperifolia*
Uvularia sessilifolia	*Ostrya virginiana*
Uvularia sp.	*Parthenocissus quinquefolia*
Vaccinium angustifolium	*Pinus strobus*
Vaccinium corymbosum	*Poaceae sp.*
Vaccinium sp.	*Polygaloides paucifolia*
Viburnum acerifolium	*Polygonatum biflorum*
Viburnum alnifolium	*Populus grandidentata*
Viburnum sp.	*Prunus sp.*
Viola sp.	*Quercus alba*
	Quercus montana
	Quercus rubra
	Rubus flagellaris
	Solidago caesia
	Solidago sp.
	Taraxacum officinale
	Thalictrum dioicum
	Tilia americana
	Tsuga canadensis
	Uvularia perfoliata (S2)
	Uvularia sessifolia
	Uvularia sp.
	Vaccinium angustifolium
	Vaccinium pallidum
	Viburnum acerifolium
	Viola sp.
	Waldsteinia fragarioides

* Only saplings were observed, state monitors only flowering individuals of this species

** Two species of note encountered at the Great Ledge Natural Area outside of study sites were- *Houstonia longifolia* (S2) and *Crotalus horridus* (E)

Appendix 5: List of priority plant species identified within plots by site

Dome Species List	**Great Ledge Species List**
Castanea dentata	*Fragaria virgiana*
Lysimachia borealis	*Helianthus divaricatus*
Rhododendron prinophyllum	*Lysimachia borealis*
Vaccinium angustifolium	*Lysimachia quadrifolia*
Vaccinium corymbosum	*Vaccinium angustifolium*
	Vaccinium arborea
	Vaccinium palidum

Appendix 6: List of bird species recorded on the Dome
Bird Species List for the Dome
Acadian Flycatcher
American Goldfinch
American Redstart
American Robin
Bald Eagle
Baltimore Oriole
Belted Kingfisher
Black-and-white Warbler
Blackburnian Warbler
Black-capped Chickadee
Blackpoll Warbler
Black-throated Blue Warbler
Black-throated Green Warbler
Blue Jay
Blue-headed Vireo
Broad-winged Hawk
Brown Creeper
Brown Thrasher
Canada Goose
Cedar Waxwing
Chestnut-sided Warbler
Chimney Swift
Chipping Sparrow
Common Grackle
Common Loon
Common Raven
Cooper's Hawk
Dark-eyed Junco
Downy Woodpecker
Eastern Bluebird
Eastern Phoebe
Eastern Towhee
Eastern Wood-Pewee
Field Sparrow
Golden-crowned Kinglet
Gray Catbird
Great Crested Flycatcher
Green Heron
Hairy Woodpecker
Hermit Thrush
Herring Gull

Indigo Bunting
Least Flycatcher
Least Flycatcher
Louisiana Waterthrush
Magnolia Warbler
Mallard
Mourning Dove
Nashville Warbler
Northern Cardinal
Northern Flicker
Northern Parula
Northern Rough-winged Swallow
Northern Waterthrush
Osprey
Ovenbird
Palm Warbler
Pileated Woodpecker
Pine Warbler
Purple Finch
Red-bellied Woodpecker
Red-breasted Nuthatch
Red-eyed Vireo
Rose-breasted Grosbeak
Ruby-throated Hummingbird
Savannah Sparrow
Scarlet Tanager
Swainson's Thrush
Swamp Sparrow
Veery
White-throated Sparrow
Wild Turkey
Wood Duck
Wood Thrush
Worm-eating Warbler
Yellow-bellied Sapsucker
Yellow-rumped Warbler
Yellow-throated Vireo
Yellow-throated Warbler

Appendix 7: Rare Plant Species Known to Occur in Dry Oak Habitats

Slender Wheatgrass	*Elymus trachycaulus*
Downy Arrowwood	*Viburnum rafinesquianum*
Panicled tick-trefoil	*Desmodium paniculatum*
Squawroot	*Conopholis americana*
Flowering dogwood	*Cornus florida*
Lopsided rush	*Juncus secundus*
Spotted wintergreen	*Chimaphila maculata*
Violet bush-clover	*Lespedeza violacea*
Scarlet oak	*Quercus coccinea*
Wood lily	*Lilium philadelphicum*
Smooth false-foxglove	*Aureolaria flava*
Rattlesnake weed	*Hieracium venosum*
Fragrant Sumac	*Rhus aromatica*

Appendix 8: List of Butterfly Species Recorded Near the Dome Site

American Lady	*Vanessa virginiensis*
Arctic Skipperling	*Carterocephalus mandan*
Baltimore Checkerspot	*Euphydryas phaeton*
Black Swallowtail	*Papilio polyxenes*
Cabbage White	*Pieris rapae*
California Ringlet	*Coenonympha california*
Canada Swallowtail	*Papilio canadensis*
Cherry Gall Auzure	*Celastrina serotina*
Clouded Sulphur	*Colias philodice*
Common Wood-nymph	*Cercyonis pegala*
Dreamy Duskywing	*Erynnis icelus*
Dun Skipper	*Euphyes vestris*
Early Hairstreak	*Erora laeta*S2S3*
European Skipper	*Thymelicus lineola*
Harris's Checkerspot	*Chlosyne harrisii*
Lucia Azure	*Celastrina lucia*
Milbert's Tortoisshell	*Aglais milberti*
Monarch	*Danaus pleippus*
Mourning Cloak	*Nymphalis antiopa*
Northern Pearly-eye	*Lethe anthedon*
Orange Sulphur	*Colias eurytheme*
Pearl Crescent	*Phyciodes tharos*
Question Mark	*Polygonia interrogationis*
Red Admiral	*Vanessa atalanta*

Red-spotted Admiral	*Limenitis arthemis*
Silvery Blue	*Glaucopsyche lygdamus*
Tawny-edged Skipper	*Polites themistocles*
Viceroy	*Limenitis archippus*
West Virginia White	*Pieris virginiensis**S3S4*
	Speyeria cybele
	Speyeria atlantis
	Coenonympha tullia
	Lycaena phlaeas
	Papilio tydeus
	*Papilio troilus**S1*
	Polities mystic
	Lon hobomok
	Carterocephalus palaemon
	Wallengrenia egermet
	Euptychia cymela
	Cyanirirs neglecta
	Incisalia niphon
	Incisalia irioides
	Atryton delaware
	Mastor hegon
	Enodia anthedon
	Limentis astyanax fabricius
	Polygonia vaualbum
	Elkalyce conyntas
	Erynnis juvenalis