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Effects of Repeated Intensive Harvesting Practices, Prescribed Burning, and Browsing on Northern Hardwood Forest Plant Communities

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EFFECTS OF REPEATED INTENSIVE HARVESTING PRACTICES, PRESCRIBED BURNING, AND BROWSING ON NORTHERN HARDWOOD FOREST PLANT COMMUNITIES

by

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ABSTRACT

When extracting large volumes of biomass from our nation's forests, it is imperative to consider the sustainability of these intensive harvesting practices on future forests and timber products, and wildlife habitat and populations. The goal of this study was to assess if plant density and ecological integrity are affected by strip-cut harvesting silvicultural practices, prescribed burning on slash left on site and slash residue left unburned, and mammalian browse. A summer 2019 inventory of plant species throughout Compartment 33 on the Penobscot Experimental Forest, a management unit that recently was harvested for the second time in the past 55years, which utilized whole-tree harvesting, stem-only harvesting, and stem-only harvesting with prescribed burning. We evaluated the effects of strip clearcutting (stem-only removal and whole-tree removal), burning, and mammalian browse one year after the stand was harvested and burned Harvests with slash removal and slash left on site had consistently higher diversity, but lower ecological integrity based on floristic quality assessments, when compared to areas without harvest. Slash removal in conjunction with burning reduced arboreal density, particularly that of softwood species, but did not negatively impact ecological integrity. Effect of mammalian browse varied heavily by treatment, and the plant communities present on site, but did not have an overall impact on stem density. Browse was found to be particularly important for diversity indices and floristic quality assessments within stem only harvest, and harvest with burning. This investigation provided insight into successional forest composition, density, and ecological integrity (diversity and floristic quality assessment) changes in arboreal and non-arboreal plant species in response to these disturbance effects.

DEDICATION

To the advance regeneration of the Kuhn family tree: Avery, Brody, Jeffrey, and Kaleb.

I hope one day you fall in love with this wonderful planet.

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It truly took a village to raise this paper into the thesis it has become. My parents nurtured my love not only for the environment, but also for the state of Maine with my first summit of Door Mountain in 1998. Thank you to my father for his continuous plant identification lessons, catchy hiking tunes, genetic disposition to love the outdoors, and overwhelming support of my academic endeavors and life aspirations. Thank you to my mother, who has insurmountable love, has been my voice of reason over a chaotic 22 years, a love for Christmas ferns and bird watching, and for allowing me to dress in overalls to formal occasions. Thank you to my siblings, Jessica, Jenna, and Ian. For their humor, friendship, and tolerance of their eccentric younger sister who hugs way too many trees. Ultimately, my siblings deserve the biggest thank you for adding to the family not only the most amazing set of in-laws who have become a second set of siblings, but also the most incredible nieces and nephews an aunt could ask for.

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INTRODUCTION

Maine's Forests

Maine has 716,2936 hectares of forestland (Vogt and Smith, 2016). The state's disturbance regime is dominated by low severity, small-scale disturbances, such as individual tree fall from wind throw or mortality from pest damage (Fraver and White, 2009). Historically, an estimated frequency of disturbance in the State of Maine, dependent on-site quality, is a return interval of 575-1,000 years for severe windstorms and 385-1,200 years for severe fire events (Lorimer and White, 2003). Some forest managers seek to promote stand structures that are consistent with the temporal and spatial patterns of the region's natural disturbance regime, while still allowing for the sustainable extraction of timber (Arseneault et al., 2011). Application of this silvicultural theory often involves single tree selection harvests, which are low impact harvests that occur by removing small, aggregated groups of dispersed trees. However, some forest managers use and prescribe more intensive harvest methods such as, but not limited to, clearcutting. 2018 harvest activity reports state that 9,321 hectares are annually clear-cut within the state of Maine (MACF, 2018). Since timber is an economic commodity, and a necessity for societal infrastructure, it is not surprising that intensive forest management is perpetuated in practice. This is particularly the case in Maine where the majority of logging harvests occur on private and corporate land (Butler, 2016). Thus, Maine's culture is strongly rooted in its forests, and therefore forest sustainability is a pressing concern to not only citizens but also forest managers. To address this concern, Maine managers have a strong history of adopting the triad approach to forest land allocation (Seymour and Hunter, 1992). This approach focuses on three types of practices: high-yield silvicultural techniques (e.g. planted stands), ecological forestry silvicultural methods, and biological reserves. This allocation of forest management allows for ecological and societal needs to be met, while still continuing to perform intensive silvicultural harvests, with the understanding that the restoration of ecological systems post-disturbance (both human and natural) should be prioritized (Seymour and Hunter, 1992).

Intensive Forest Practices

Maine's forests are facing increased pressure to sustainably provide biomass to meet market demand (Muñoz Delgado et al., 2019), yet there is a gap in knowledge on the long-term effects of intensive harvesting practices, such as whole tree harvesting on site productivity. There are several studies that have investigated the short-term results of removing above ground biomass from forests (Berger et al., 2013; Hornbeck and Kropelin, 1982; Czapowskyj and Frank, 1976, Roxby et al., 2015), yet there are few studies that address forest recovery time frames longer than 20 years post-harvest (Thiffault et al., 2011). Findings from Roxby (2015) suggest that composition and forest soil integrity are not affected five years post-whole-tree harvesting. Findings from Thiffault et al. (2011) and Fahey et al. (2010) denotes that stand response to disturbance may be linked greater to stand characteristics and productivity, more so than silvicultural factors applied. Further long term research, on various sites with varying composition and structure will be required to fill this gap in the scientific community.

Research in northern hardwood and conifer forest stands report that harvest rotations with periods of fifty-year intervals should result in little nutrient depletion overall, although concerns over calcium depletion were raised and further research was found to be warranted (Freedman et al. 2003). Although these studies provide insight into forests after whole-tree harvests, they fail to address long-term sustainability of such practices including the cumulative effect of repeated intensive harvests impact on the regenerating community, such as species composition and densities over time. Within Whole tree harvesting, which extracts both the stem and crown of the tree, removes an increased amount of aboveground biomass from the forest relative to stem-only harvesting. It is reported that within the state of Maine, 20 percent of overall forest operations are conducted as stem-only harvests, whereas the 80 percent of production is accounted for by whole-tree harvest (Leon and Benjamin, 2012).

Stem-only harvests, in which canopy and limb biomass typically remain in forests with only the boles of trees being extracted, have greater representation in the science literature regarding effects on long-term forest integrity. The versatility of this harvest technique allows for varying levels of extraction, including both cut to length and tree length operations. This harvest technique has less impact potentially than whole-tree harvesting, since nutrient rich arboreal debris is left behind. In short-term studies, this less intensive extraction technique has similar impacts to productivity as whole-tree harvest in regard to soil productivity (Premer et al., 2019). Residue left on site post-harvest could impact stand growth, and long-term site productivity due to nutrient pulses and soil moisture (Roberts et al., 2004). Furthermore, these studies only investigate single treatment applications to forest stands, and not the reoccurrence of multiple harvest entries.

Prescribed burning is a common management tool for the prevention of large-scale fires, to conserve fire-adapted environments, for site preparation, and wildlife habitat.

Although large scale fires may still occur in fire prone ecosystems, the mimicking of low intensity surface fires can reduce biomass, and potentially decrease future intensities of stand replacing fire disturbances. Maine has moderate, infrequent forest disturbances, rarely caused by fires, that result in stand replacing disturbance (Fraver and White, 2009; Lorimer and White, 2003). Since 1903, fires have frequently consumed 20,234 hectares of forestland per year, with the occasional expansion to 40,469 hectares per year within the state (Gadzik et al., 1998). Large-scale fires in Maine are reported to occur on an interval of every 4497 years, while that may be the case, it is still estimated that 7152 hectares have still been lost to fire since 2010 (Irland, 2013). Warmer temperatures and extended summer seasons predicted for Maine could alter fire disturbance regimes (Fernandez et al., 2015). Changes in fire regimes could provide challenges to managers since there is a limited understanding of fire's role in Maine's northern forests. Cumulative effects of wind damage, increased debris, and salvage harvest efforts were reported to cause severe fire disturbance in Baxter State Park, in Maine in 1977. When residue on forest floors ignited, 2000 hectares of land burned around the park (Scee, 1999). This was an example of forest management interacting natural disturbance, resulting in severe fire damage in the state (Small et al., 2003). The disturbance conditions, which resulted in the fire, can easily be simulated unknowingly by timber activities through the intensive removal of trees, and increased slash residue left on site. Altogether, the interacting effects of wind disturbance, followed by fire and harvesting, can have implications for understory plant communities (Small et al., 2004). This 2019 study will discuss the effects of repeated intensive harvests and prescribed burning on understory plant communities and tree regeneration in light of an uncertain climate future for Maine.

Mammalian Browse

The effects of intensive harvesting practices, such as whole-tree harvesting, and prescribed burning have the potential to also interact with the effects of mammalian browsing on plant communities following treatment application (Harris et al., 2012; Leak et al., 2014; McWilliams et al., 2018). As early as the 1950s, it was found that deer browse damage influenced tree reproduction and development within clearcut forests (Curtis et. al 1958). In Maine, both snowshoe hare (*Lepus americanus*) and white-tailed deer (*Odocoileus virginianus*) are reported tree herbivores, which can hinder regeneration (Homyack et al., 2006; Russell et al., 2001; Table A.1). Since the early 1980s, Maine has averaged 200,000 wintering deer (MDIFW, 2020). In the 2000s, snowshoe hare densities were estimated to be 0.56-3.04 hares/ha based on pellet density studies (Homyack et al., 2006). Waller and Alverson (1997) reported a high probability of deer removing both arboreal and non-arboreal species from forest ecosystems. Mammalian browsing can not only result in the absence of some species across the landscape, but more often resulted in growth defects in regenerating trees such as fork, broom and crook abnormalities (Andreozzi et al., 2014; Bergeron et al., 2011). Mammalian browse has species-specific effects on plants at the population level (Bergeron et al., 2014). Clearcutting also creates an environment in which preferred non-arboreal species were aggregated in patches, increasing the level of browse observed overall, especially in hardwood-dominated areas (Bailey, 1977). Biomass harvesting, prescribed burning, and mammalian browse potentially influence the success of tree regeneration and species composition of early-successional plant communities (Harris et al. 2012; McWilliams et al. 2018).

Long-term Research of Biomass Harvesting in Maine

Arboreal biomass, often extracted by intensive harvesting practices, can be used as a renewable energy source to mitigate the effects of climate change, as an alternative to fossil fuel. Long-term effects of arboreal biomass harvesting practices, coupled with mammalian browsing on arboreal and non-arboreal plants following treatment, are not well understood in northern mixedwood stands. Effects of prescribed burning, which also reduce on-site arboreal biomass, also need investigation in these stand types. In 1964-65, three slash disposal techniques were implemented within the clear-cut strips of a forest stand. Strip cutting with arboreal slash left (i.e., stem only harvests), arboreal slash left and burned (i.e., stem only harvests and prescribed burning), and arboreal slash removed (i.e., whole tree above-ground biomass harvests) were applied on the Penobscot Experimental Forest (PEF) in Bradley, Maine as three treatment types (Bjorkbom and Frank 1968; Czapowskyj, 1979; Patterson, 1967).Initial research conducted within C33 resulted in baseline findings on silvicultural effects on spruce-fir regeneration, foliar and soil concenctrations, and site productivity. Four-years later, it was found that slash should be burned to increase available hardwood regeneration for browsing; whereas to establish softwood regeneration, slash should be left in place without burning (Rinaldi, 1970). In 2018, when this study area was harvested again it posed a unique opportunity to investigate long-term changes in understory plant communities and tree regeneration 55 years following initial application of these treatments. Research ecologists investigating this management unit in 2014-2015 found that although differences in species composition were found across treatments, differences in long-term northern mixedwood productivity was more closely related to site quality rather than treatment (Muñoz Delgado et al., 2019).

This response was consistent with other long-term productivity following a biomass removal experiment, which concluded responses varied by site (e.g., Jang et al., 2015, Johnson et al., 2016).

Research Objectives

The goal of this study aims to evaluate the effects of intensive arboreal biomass removal (harvesting and burning) and mammalian (deer and hare) browsing on understory plant communities (arboreal and non-arboreal). This study will assess how whole-tree harvests, stem-only harvests, and burning in conjunction with stem-only harvesting affects plant species composition, species prevalence throughout the compartment, and community integrity. The objectives of this study are: 1) to compare strip clearcut harvesting silvicultural practices with and without slash removal on regenerating arboreal and non-arboreal plant species density (stems per ha and stems per m^2) and ecological integrity, 2) to discern if prescribed burning, performed after stem-only harvests, alters plant density and ecological integrity, and 3) to determine if mammalian browse effects plant species stem density and ecological integrity within northern hardwood forests.

Ecological integrity can be defined as the ability of an ecological system, to support and maintain a community of organisms, that has species composition, diversity and functional characteristics comparable to those of the region's natural habitats (Wutzebach et al., 2016). Similarly, ecosystem health refers to the comprehensive, multiscale, dynamic and hierarchical measure of system's resilience, organization, and vigor (Costanza, 1992).

The effect of treatments on arboreal and non-arboreal species plant density and ecological integrity across the compartment will be assessed by comparing species-specific mean arboreal and non-arboreal stem density across four treatment types (SOH, WTH, SOHB, UNH). Shannon's diversity, and evenness as well as Simpson's Index will be computed and summarized at the 1-m^2 plot level to provide insight into arboreal and non-arboreal plant community diversity. A measurement of stem densities within and outside deer and hare exclosures will be measured to assess how browse impacts on vegetation diversity among treatments. Floristic quality assessments (FQA) will be calculated per plot, and then summarized, to determine each treatment's effect on the compartment's ecological stability (Wilhelm et al., 1995).

METHODOLOGY

Study Area

The study area, compartment 33 (hereafter referred to as "C33"), is a 26-ha stand located within the PEF in Bradley, Maine (44° 51' 56.754" N, 68° 38' 12.1812" W). The PEF is managed by the U.S. Forest Service as a site for long-term research. It is the located between the boreal and broadleaf forest types in the Acadian Forest region, giving rise to the presence of northern mixedwood stand types throughout the PEF (PEF, 2019). Historic species composition includes spruce-fir dominated stands prior to 1964-65 harvest entry (Czapowskyj and Frank, 1976). In 1970, four-years post harvest composition showed an increase in hardwood composition, and a decrease in softwood composition (Rinaldi, 1970). 2014-15 inventories concluded that the regenerated stand type was a northern mixedwood forest (Muñoz-Delgado et al., 2019). In 2019, tree species present in the regenerative communities of C33 were predominately red maple (38%), gray birch (30%), quaking aspen (11%), white birch (5%), and big tooth aspen (2%). Coniferous species were observed but were a minority (<4.5%) of species. Spruce species were absent within the management unit, and balsam fir was observed occasionally (3%). Species observed in the unharvested, reference site (hereafter referred to as UNH) were dominated by red maple, quaking aspen, balsam fir and white pine. A full plant list of both arboreal and non-arboreal species observed in Compartment 33 during Summer 2019 inventories can be found in Table's A1 and A2 within the Appendix. Parent material within the PEF is predominately composed of Wisconsin glacial till and marine sediment, with major soil characteristics across the forest consistent with either well drained or moderately well drained loams and stony loams soil types with overall soil drainage characteristics varied across site (Safford et al., 1969; Munoz Delgado et al., 2019). Within C33 specifically, soils derived from parent materials, are consistent with Typic and Aquic Haplorthods and Typic and Aeric Epiaquepts (Muñoz Delgado et al., 2019).

For the purpose of community regeneration investigations, C33 was established as a site to investigate silvicultural techniques affect on spruce-fir regeneration in 1964 (Bjorkbom and Frank, 1968). C33 is divided into three replicated sites (Figure 1). These replicates are the location of repeated, intensive harvesting practices consisting of strip-cutting with:1) whole-tree harvesting (WTH); 2) stem-only harvesting (SOH); and 3) stem-only harvesting with prescribed burning (SOHB). Overall size of harvested strips equates to 21.6 ha, with the last 4.9 ha encompassing the unharvested control sites.

Within each replicate, there are three harvested strips each with a different randomly assigned width (20.1 m, 40.2 m, 60.4 m) and separated by a buffer of mature forest (20.1-40.2 m in size). Each of these harvested strips were divided into experimental units that were randomly assigned a harvest silvicultural technique (SOH, SOHB, WTH). The complete randomized block design allows for a more robust sample to quantify intensive harvesting and prescribed burning effects within a single forest landscape. These experimental units were treated initially in 1964-65 and repeated in 2018. Differences in establishment of this study area include varying harvesting equipment and burning techniques. In 2018 timber harvest was conducted using a feller buncher, in-woods stroke delimber and grapple skidder. The mechanized equipment used for initial establishment was a John Deere Model 420 crawler-type tractor for skidding, in combination with chainsaw felling (Bjorkbom and Frank 1968). A boom delimber was applied in stem only harvest treatment units, ensuring arboreal debris from canopy and limbs was left in treatment strips before the bole of the tree was extracted to the landing (Soman et al., 2020). It was reported that the burn treatment in 1964-65 was produced by using pile and burn methods, in which during harvest slash was accumulated in piles and then allowed to ignite (Patterson, 1967). There is specific denotation that not all arboreal debris was ignited in 1964-65 by these sprawling fires, as well as strip edges which were exempt from fire application (Bjorkbom and Frank 1968; Czapowskyj et al., 1976). In the process of replicating this experiment in Fall 2018, broadcast prescribed burning was used.

In 2018, there were ten deer-hare exclosures installed, roughly measuring 1.8 meters by 1.8 meters and sealed flush to the ground. Nine of these exclosures were in the center three experimental units of only the 60.4-m strip widths, and one within the unharvested reference area for analytical comparison (Appendix Figure 2). These deer-hare exclosures create an environment that discourage both deer and hare from gaining access to plants within the exclosure, therefore reducing the effects of browse. Within each deer-hare exclosure is a single 1 m^2 sample plot. These sample plots are also paired to another 1 m^2 sample plot (hereafter referred to as 'paired plot'), located 30 m to the east outside of each exclosure. This equates to ten deer-hare exclosure and ten paired 1 m^2 sample plots, or 20 in total.

In 2019, 1 m^2 sample plots were installed through stratified random assignment in each experimental unit. To minimize edge effect, a minimum buffer of ten feet was first applied between each of the central three experimental units of each strip. Stratified random assignment within the experimental unit was done by proportionately dividing each experimental unit into three parts running north south. A single 1 m^2 sample plot was then randomly located within each of the three parts, except in cases where one of the three parts contained paired deer-hare sample plots. These 1 m^2 sample plots were nested within 202-m^2 plots, denoted by a letter variable pertaining to the silvicultural system used to harvest those respective strips (i.e. "R" is equal to WTH, "L is equal to SOH", "B" is equal to SOHB). Mean data collected from these 1- m^2 were summarized and reported on the overall 202-m^2 plot level they were nested within. Plot assignment was done with ArcMap software. In total, these 76 1 m^2 sample plots serve as the location for understory plant data collection. In addition to the 1 m^2 sample plots within the experimental units, four additional 1 m^2 sample plots were also randomly located in an un-harvested reference area within C33. Plot installation involved monumenting 1 m^2 sample plot locations with rebar posts. Overall, 96- 1 m^2 sample plots were installed to measure the effects of treatment and mammalian browse on arboreal and non-arboreal species composition.

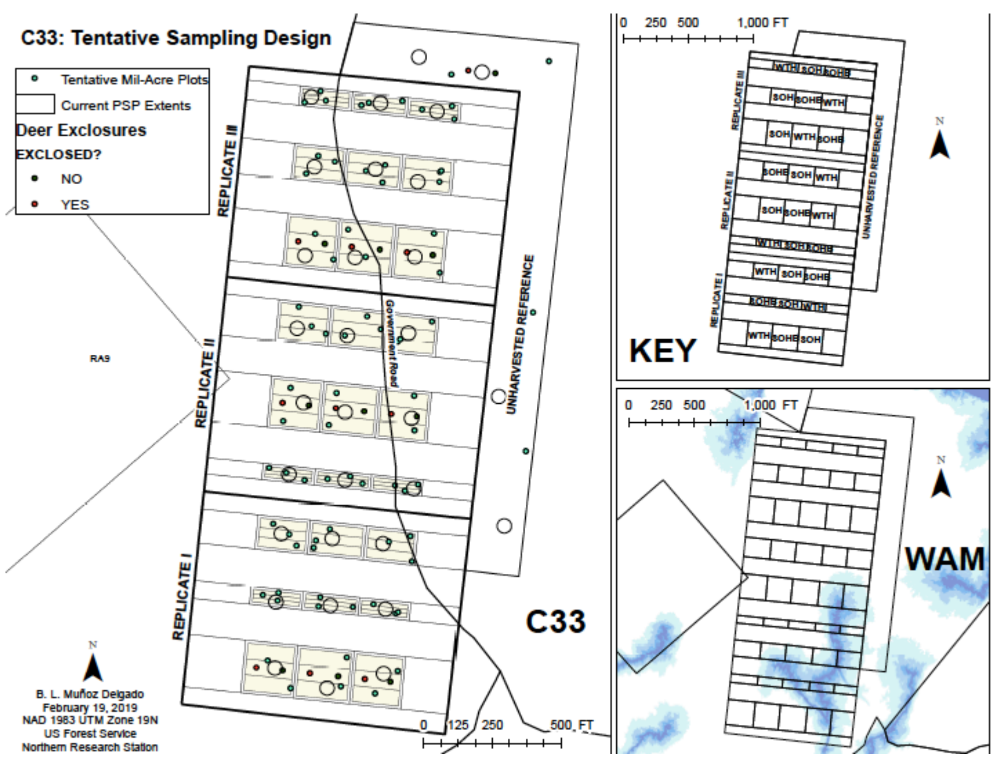

Figure 1. Overview of Compartment 33 sample plot layout, displaying all 96 sample plots inventoried in 2019 summer inventories. Further detail of sample plots can be found in Figure A.2 located in appendix.

Field Methods

Vegetation Survey

I conducted the vegetation survey twice in 2019, in which I visited each 1-m^2 sample plot over the course of the field season to account for varying blooming seasons of non-arboreal plants. The first inventory was conducted June 19-July 11, and the second inventory occurred July 15-30. This not only allowed for a more accurate representation of the non-arboreal species present, but also allowed for a more accurate recording of unknown species observed, as they were identified and collected twice during their growing cycles. A full list of species observed, and their scientific names are reported in Table A2-3.

At each 1 m^2 sample plot I inventoried the arboreal and non-arboreal species present within a 0.6 m radius around plot center. Precautions were taken upon approaching the 1 m^2 plot to ensure that no vegetation was accidentally trampled, confirming that an accurate counting of individuals was conducted. Each arboreal species present was recorded as an individual stem. Categorical height classes were recorded using the convention of Waskiewicz (2015) to be consistent with regeneration surveys throughout the PEF land base. All arboreal species with heights between > 15.2 cm to ≥ 137.16 cm, but with a diameter at breast height (dbh) < 1.3 cm, were measured. For each non-arboreal species, the number of individuals were recorded up to a height of 2 m. If the species was unknown at the time of visitation it was denoted in the comments of the inventory and a photo and sample of the specimen were collected.

For each non-arboreal species, the number of individuals and percent cover were recorded up to a height of 2 m. Percent cover was determined using the releve method

(MNDR, 2013; Dibble, 2010). This entailed the investigator to count the number of individuals of a species present in the plot, and then envision that the above ground plant biomass is pressed down from 2 meters high to ground coverage. It is then subjective to the investigator what percent of the plot would be covered by the plant biomass, by percent. For example, this indicated that five individuals of Canada mayflower (*Maianthemum canadense*) may represent five percent of the plot's cover, whereas five individuals of an awl-fruited sedge (*Carex stipata)* may represent take up to 15 percent cover.

In the 20.1 m, and 40.2 m width strip cuts, all three 1-m^2 sample plots within an individual 202-m^2 treatment type (WTH, SOH, SOHB) were inventoried as vegetation plot data. In the 60.4 m width strip cuts of 202-m^2 plot treatments, two 1 m^2 sample plots were inventoried as a randmom management plot data, one 1 m^2 sample plot was inventoried within deer-hare exclosure and recorded as within exclosure data, and 1 m^2 was inventoried as a paired exclosure plot, and recorded as outside exclosure data.. Random management plots will be used in the analysis of treatment effect, and ecological integrity. Exclosure plot data inside and outside exclosures will be used in the analysis of mammalian browse effect on plant density and plant community integrity.

Mammalian Browse Survey

For each arboreal and non-arboreal species observed, a measure of browse damage was recorded. For each individual arboreal stem, a percent browsed value was assigned based on the number of branches browsed and was further classified as either being clipped or ripped. Browse data was collected on all 1 m^2 sample plots, including vegetative plots associated with treatment effect, and paired plots associated with exclosures effect. No browse was recorded within 1 m^2 exclosure plots. For analysis portions of this project, to determine browse effect, paired and exclosure datasets were used to estimate overall stem density present within and without exclosures.

Data Analysis

Computations included species-specific mean stem count of non-arboreal and arboreal plants, diversity index (both Shannon's and Simpson's), Shannon's evenness, richness, as well as the floristic quality assessment (FQA) of the four treatments types (WTH, SOH, SOHB, UNH), within and outside of deer-hare exclosures. All metrics were calculated at the 1-m2 plot level, and then their respective mean values were extrapolated to the 202-m^2 plot level and reported.

It is important to note that for arboreal plant densities, stems were extrapolated to the hectare level, whereas non-arboreal plant densities were analyzed as stems/m^2. For both arboreal and non-arboreal species, stems per unit of measurement were calculated at the 202-m^2 treatment plot level. This measurement of density provided context to treatment effect, mammalian browse effect, and burn effect on quantity of lifeform present after disturbance.

Diversity indices calculated included Shannon's diversity and evenness, and Simpson's diversity, and richness. Shannon's diversity index is calculated by the summation of the calculated natural log of species richness within 202-m^2 plots, multiplied by the relative abundance in terms of total individuals of species within plot. Shannon's evenness can then be extrapolated by the division of Shannon's diversity by the natural log of the plot's richness. Simpson's diversity is calculated by the number of individuals of a species within a 202-m^2 plot, multiplied by the number of individuals subtracted by one. The sum of this species level calculation, divided by the overall total sum of all individuals within the plot multiplied by that value minus one, results in the Simpson's diversity. Richness refers to the metric of the number of different species represented in each plot level.

Calculating both Shannon's and Simpson's diversity indexes provide context as to which species is prevalence, while taking into effect both richness and evenness across a given unit within a landscape. In regard to the way that these two diversity indexes differ, it is reported that Shannon's formulas result in an emphasis on richness in calculations, whereas Simpson's results in an emphasis on evenness (Nagendra, 2002).

To assess floristic quality, I used the floristic quality assessment (FQA) framework to allow for plant species to be ranked by coefficient of conservatism values, and therefore the plant communities overall regenerative integrity in this new manipulated environment. This will allow for a uniform method of comparing ecological integrity of regenerative vegetation among the treatments. The Coefficient of Conservatism (COC) scores for each plant species were obtained from the Maine Department of Agriculture, Conservation and Forestry Database (Floristic Quality, 2013). COC scores rank between 0-10, in which species with lower values generally possess higher levels of success in disrupted environment (Wilhelm and Masters 1995). To compute FQA, the average coefficient of conservatism of all species present on a plot is averaged, and then divided by the square root of the population of the plot. Using the coefficient of conservatism, stem count, and species present it is possible to provide a metric of how well individual plots are adapting to new vegetative communities. Therefore, both density of species present and their ability to adapt to degraded ecological systems are taken into consideration with this metric. FQA was analyzed by average of computed values at the 202-m^2 plot treatment level.

To discern if there was significant treatment effect, burning effect, and browse effect on stem density and ecological integrity, statistical analysis was computed using SPSS Software Program (Version 26). To compare the three harvest treatments (SOH, WTH, and UNH), a one-way analysis of variance (ANOVA) was used for all metrics. Separate ANOVAs were conducted for arboreal and non-arboreal communities using only vegetation datasets of average 202-m^2 treatment values. Multiple comparisons, or post-hoc tests, were generated using Tukey's method and were reported where treatment groups were found to be significantly differed. The effect of burning on treatments was determined through an unpaired t-test of SOH and SOHB vegetation metrics (stem density, diversity, and FQA) at the 202-m^2 treatment plot level. Mammalian browse impact on arboreal and non-arboreal regeneration densities and ecological integrity were compared using a paired t-test of paired plots inside and outside of exclosures. Statistical significance for ANOVAs and t-tests was determined at α=0.05.

RESULTS

Strip clear-cutting with and without slash removal effects

Arboreal Plant Density

To compare strip-cut harvesting silvicultural practices with, and without slash removal on regenerating arboreal species effect on aboreal plant density, a comparison of mean specieis specific stems per treatment was analyzed. Eleven arboreal species were recorded throughout the inventory (Table A2.). Based on stem densities, the most frequent arboreal plants observed included gray birch, red maple, quaking aspen, white birch, eastern white pine, and bigtooth aspen, respectively. Balsam fir, red oak, glossy buckthorn, eastern hemlock and northern white cedar present were observed infrequently (<4.5% of plots).

To note, gray birch was only observed in harvest types, whereas red maple was observed on all plots sampled including that of the unharvested reference treatment. Big-toothed aspen was present in SOH and WTH plots and absent in UNH (Figure 2). Coniferous species present included balsam fir, eastern hemlock, white pine, and northern white cedar. Balsam fir was found throughout both harvest treatments with slash with and without removed. Both eastern hemlock and northern white cedar were only observed in WTH. White pine was found throughout treatments, but was most prevalent in stem density within UNH and followed closely by WTH and SOH. Density for all arboreal plants combined did not differ among strip clearcut harvest treatments.

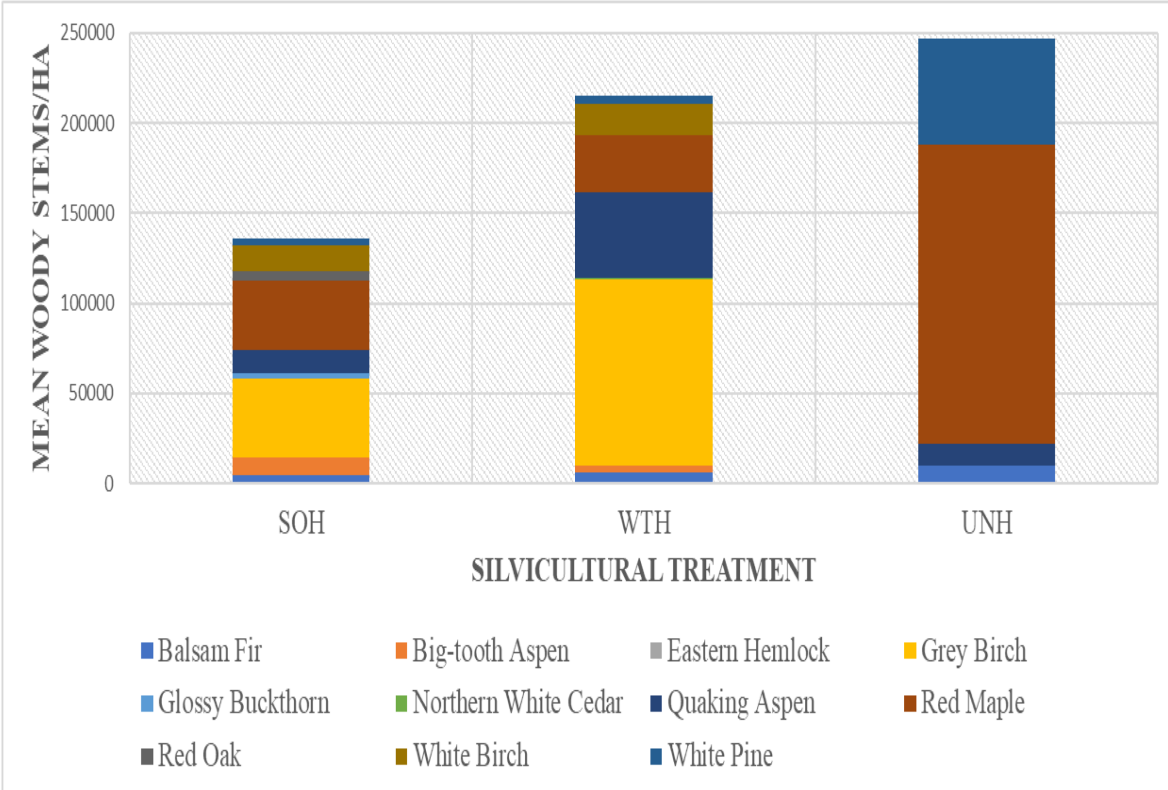

Figure 2. Mean arboreal stems per hectare throughout treatment types in Compartment 33, Penobscot Experimental Forest, from June-July 2019 arboreal inventories. These estimations are based off of only vegetation plot data. Arboreal stems between the height of >15.2 cm to ≥ 137.16 cm, with a dbh of <1.3 cm was measured in this inventory. Treatment types are equivalent to: stem only harvest (SOH),whole tree harvest (WTH), and unharvested reference (UNH).

<u>Arboreal Plant Ecological Integrity</u>

To compare strip-cut harvesting silvicultural practices with, and without slash removal on regenerating arboreal species effect on arboreal ecological integrity, a comparison of six integrity metrics were reviewed between SOH, WTH, and UNH harvest types. All ecological intergrity metrics differed among treatments (Table 1). From post-hoc tests, there is confidence that richness, Shannon's diversity and evenness, and FQA were similar in SOH and WTH, but differed from the UNH treatment. Both Shannon's diversity and Simpson's diversity differed by treatment (P=<0.001, P=0.014, respectively;

Table A7 and A8). For Simpson's index, UNH and SOH were similar, as well as SOH and WTH, but WTH was determined to be different than UNH. The mean coefficient of conservatism for all treatments combined of arboreal species was a value of 2. A full list of coefficients of conservatism, reported by species is reported within the Appendix (Table A4-5). Arboreal species had highest FQA values in UNH (P=0.047; Table A6).

Table 1. One-way ANOVA analysis of stem only harvest (SOH), whole tree harvest (WTH), and unharvested (UNH) vegetation plot data within Compartment 33, Penobscot Experimental Forest. Analysis of treatment effect (respective silvicultural technique) on floristic quality assessment (FQA), Shannon's diversity, Simpsons index, richness, abundance, evenness, and overall stem count per hectare of arboreal species. Reported are treatment means and standard error (SE), degrees of freedom ($F_{2,19)}$ and P-values. Total sample size (N) for SOH and WTH were 9 individual 202-m^2 treatment plots, and 4 individuals 202-m^2 treatment plots, for UNH. Harmonic mean sample size was used for statistical analysis (6.35).

METRIC	SOH $\bar{x}$ (se)	WTH $\bar{x}$ (se)	UNH $\bar{x}$ (se)	$F_{2,19}$	P-value
RICHNESS	8.0 (1.0)	10.0 (1.0)	3.0 (0.4)	7.070	0.005
DENSITY (STEMS/HA)	11478 (3515)	17006 (4059)	25459 (7039)	1.152	0.337
SHANNONS INDEX	1.63 (0.20)	1.71 (0.13)	0.62 (0.14)	7.622	0.004
SIMPSONS INDEX	4.99 (0.66)	5.64 (0.98)	1.75 (0.27)	4.062	0.034
SHANNONS EVENNESS	0.82 (0.03)	0.78 (0.04)	0.47 (0.13)	5.372	0.014
FQA	0.26 (0.05)	0.27 (0.04)	0.51(0.09)	3.962	0.036

Non-Arboreal Plant Density

To compare strip-cut harvesting silvicultural practices with, and without slash removal on regenerating non-arboreal species effect on arboreal plant density, a comparison of mean specieis specific stems per treatment was analyzed.A total of 57 non-aboreal species were recorded throughout the inventory (Table A3.) The most frequent non-arboreal species, with the highest stem density across the study area, were American burnweed (*Erechtites hieraciifolius)*, Bicknell's cranesbill *(Geranium bicknelliii),* red raspberry (*Rubus idaeus)*, *Viola* spp., brownish sedge (*Carex brunnescens)*, bush honeysuckle (*Diervilla lonicera)*, and bristly sarsaparilla (*Aralia hipsida)*
(Figure 3). Based on mean stem density, American burnweed was the most prolific non-arboreal species, in this case dominating the study area with 30 percent of plant cover. It was only closely rivaled by Bicknell's cranesbill, which was 15 percent of the total non-arboreal stem's densities found within the vegetative plots. The most common species, American burnweed, was not found on any sample plots that did not undergo an intensive harvesting technique. Similarly, red raspberry was found to be more prolific in density on areas that experienced a form of disturbance. *Viola* species were completely absent from UNH, but prolific throughout all other harvest types. There were no species observed only in UNH.

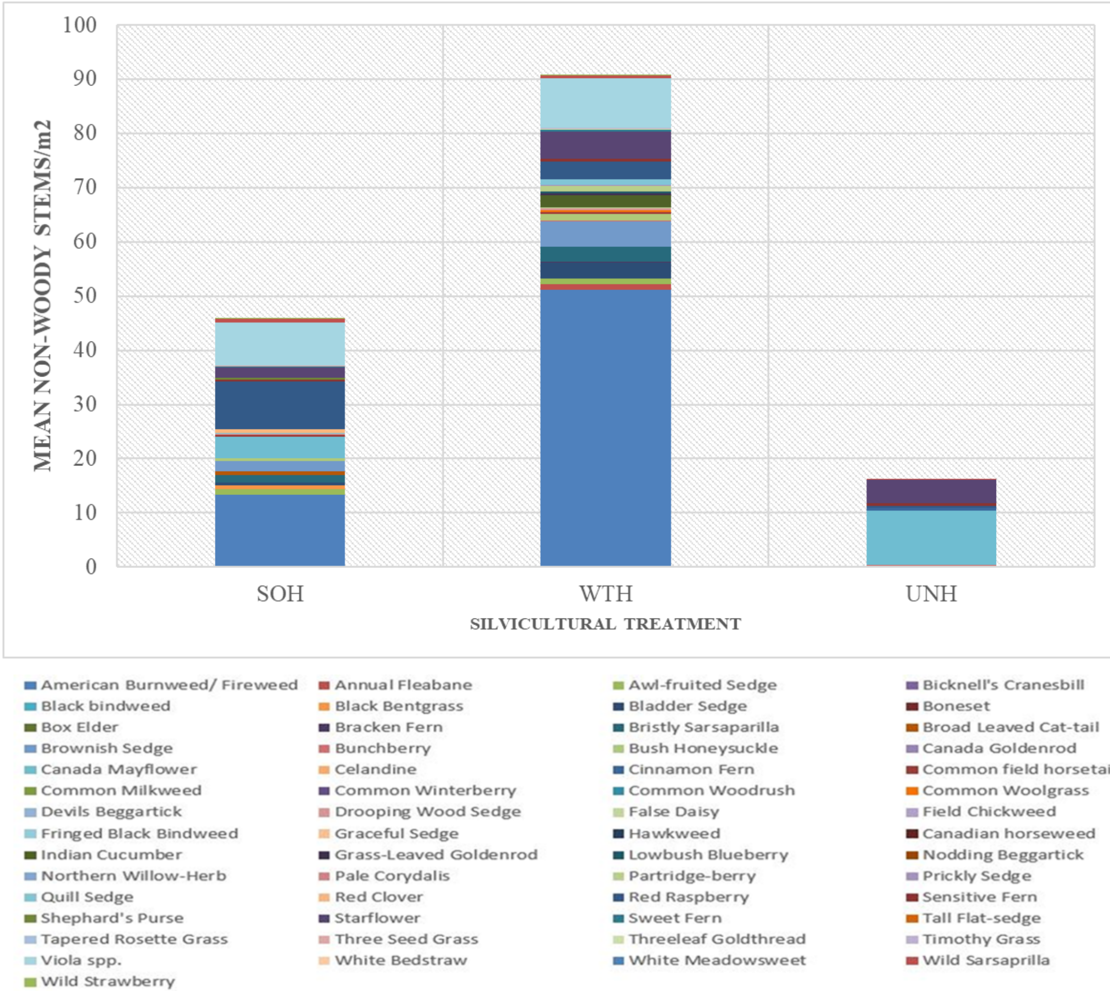

Figure 3. Mean non-arboreal stems per m^2 throughout treatment types in Compartment 33, Penobscot Experimental Forest, based off of June-July 2019 non-arboreal inventories. All non-arboreal stems below 2 m were inventoried and included in stem count summaries. These estimations are based off of only vegetation plot data. Treatment types are equaivalent to: stem only harvest (SOH), whole tree harvest (WTH), and unharvested reference (UNH).

Non-Arboreal Plant Ecological Integrity

All metrics differed among harvest treatments (Table 2). For abundance, SOH was similar to WTH and UNH, but WTH and UNH treatment plots differed. For richness, Shannon’s evenness, FQA, and Shannon’s index, SOH and WTH treatment group were similar, and both differed from UNH in the regards that they were consistently higher in value. The mean COC for non-arboreal species across all treatments within C33 was a value of 3. Similarly to arboreal results, Simpson’s index for SOH was similar to WTH and

UNH, but WTH and UNH differed. Among the three harvest types, WTH was most diverse, followed by SOH, with UNH being the least diverse treatment.

Table 2. One-way ANOVA analysis of stem only harvest (SOH), whole tree harvest (WTH), and unharvested (UNH) vegetation plot data. Analysis of treatment effect (respective silvicultural technique) on floristic quality assessment (FQA), Shannon's diversity, Simpsons index, richness, abundance, evenness, and overall stem count per meters squared of non-arboreal species. Reported are treatment means and standard error (SE), degrees of freedom ($F_{2,19}$) and P-values Total sample size (N) for SOH and WTH were 9 individual 202-m^2 treatment plots, and 4 individuals 202-m^2 treatment plots, for UNH. Harmonic mean sample size was used for statistical analysis (6.35)

METRIC	SOH $\bar{x}$ (se)	WTH $\bar{x}$ (se)	UNH $\bar{x}$ (se)	$F_{2,19}$	P-value
RICHNESS	12.0 (2.0)	18 (2.0)	3.0 (2.0)	11.166	<0.001
DENSITY (STEMS/m^2)	0.84 (1.74)	1.74 (0.42)	0.29 (0.02)	4.028	0.035
SHANNONS INDEX	1.86 (0.16)	2.12 (0.16)	0.63 (0.80)	11.829	<0.001
SIMPSONS INDEX	6.27 (1.05)	6.78 (1.23)	2.16 (0.80)	3.092	0.002
SHANNONS EVENNESS	0.78 (0.04)	0.75 (0.03)	0.41 (0.23)	4.625	0.023
FQA	0.20 (0.04)	0.13 (0.02)	0.454(0.16)	6.431	0.007

Prescribed Burning Effects

Arboreal Plant Density

Significant differences were observed between SOH and SOHB for the six metrics investigated (Table 3). SOH resulted in higher stem density of arboreal plant regeneration, as well as increased species richness, relative to SOHB.-Burning increased the proportion of hardwood components within the treatment plot, and decreased softwood presence (Figure 4). To note, white pine, eastern hemlock and northern white cedar mean densities were lowest within treatment areas that underwent burning (Figure 4).

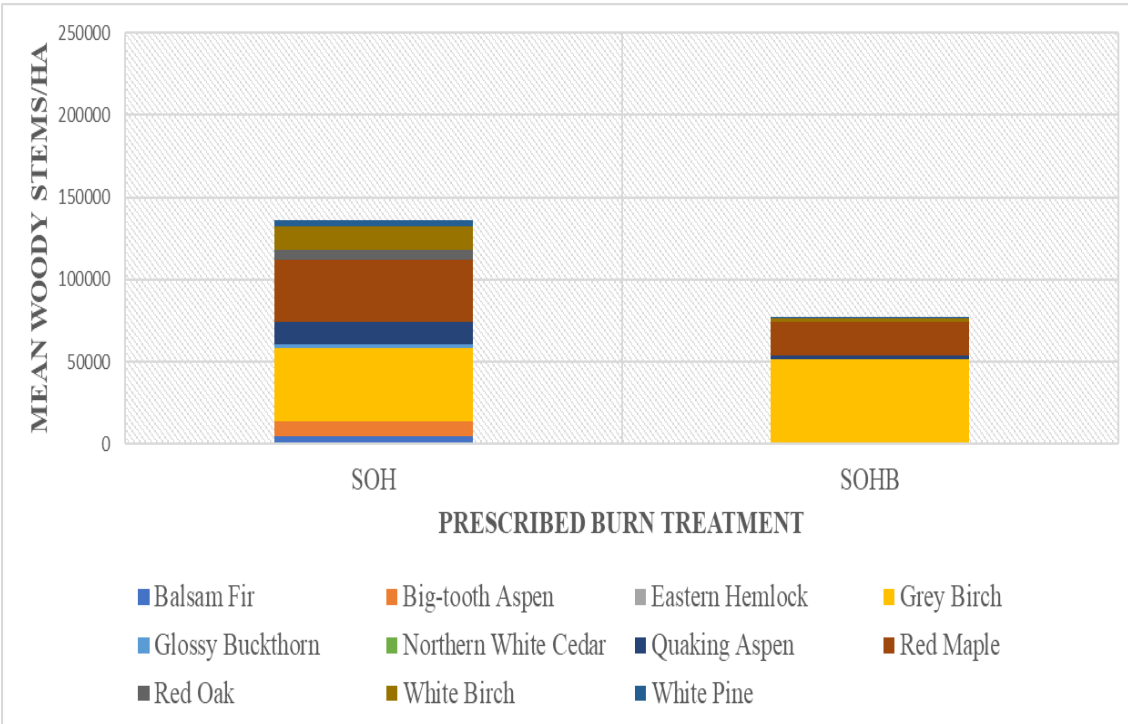

Figure 4. Mean arboreal stems per hectare throughout treatment types in Compartment 33, Penobscot Experimental Forest, from June-July 2019 arboreal inventories. These estimations are based off of only vegetation plot data. Arboreal stems between the height of >15.2 cm to ≥ 137.16 cm, with a dbh of <1.3 cm was measured in this inventory. Treatment types are equivalent to: stem only harvest (SOH), and stem only harvests with prescribed burning (SOHB).

<u>Arboreal Plant Ecological Integrity</u>

Mean values for SOHB treatment plots for metrics including abundance, richness, stem density, and diversity ecological metrics, where all higher averages when compared directly to SOH mean values. Shannon’s index was the only diversity metric found to not be significant (P=0.080), whereas Simpson’s index, richness, and evenness differed between the two treatments (P=<0.001)SOHB resulted in the highest FQA among disturbed treatments, with SOH resulting in the lowest calculated FQA value(P=<0.001).

Table 3. Statistical significance of the effect of prescribed burn on arboreal plant communities within Compartment 33, Penobscot Experimental Forest. Determined through a paired t-test analysis of burning treatment effect (stem only harvest (SOH) vegetation plot data, and stem only harvest burn SOHB) vegetation plot data) on floristic quality assessment (FQA), Shannon's diversity, Simpsons index, richness, abundance, evenness, and overall stem count per meters squared of non-arboreal species. Total sample size (N) for each treatment included 9 individual 202-m^2 plots.

METRIC	SOH $\bar{x}$ (se)	SOHB $\bar{x}$ (se)	T_9	P-value
RICHNESS	8.0 (1.0)	18.0 (2.0)	6.210	<0.001
DENSITY (STEMS/HA)	11478 (3515)	7711 (2040)	4.741	<0.001
SHANNONS INDEX	1.63 (0.20)	2.06 (0.17)	1.863	0.080
SIMPSONS INDEX	4.99 (0.66)	5.94 (1.01)	6.854	<0.001
SHANNONS EVENNESS	0.82 (0.03)	0.72 (0.04)	4.091	<0.001
FQA	0.26 (0.05)	0.20 (0.35)	8.177	<0.001

<u>Non-Arboreal Plant Density</u>

As with arboreal species, all metrics were similar between SOH and SOHB (Table 4). However, it is important to note some fire prone species, such as Bicknell's cranesbill, were only present on burned plots (Figure 5). Bristly sasparilla, a sedge species, and American burnweed were also more prolific on burned treatment plots (Figure 5).

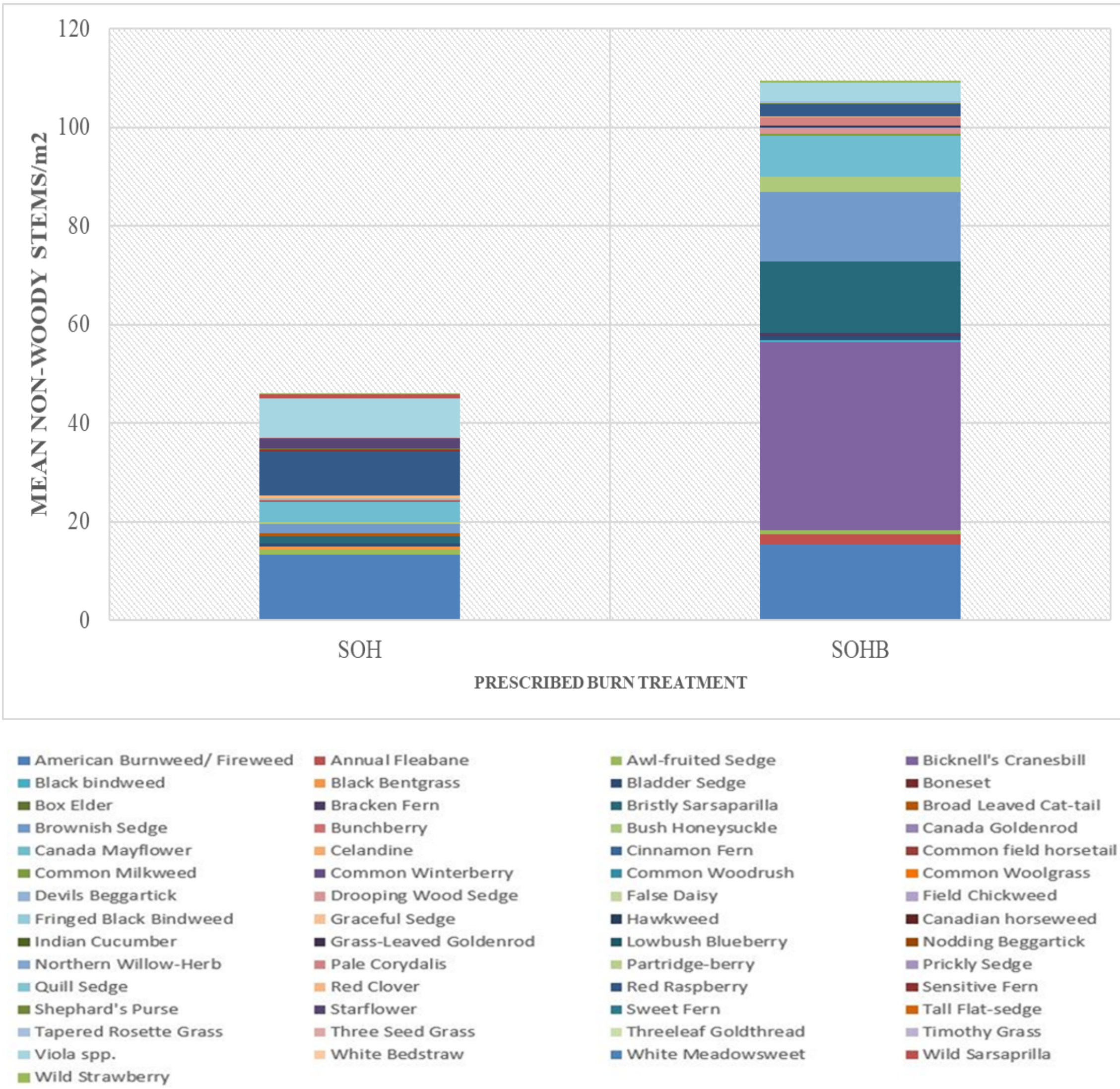

Figure 5. Mean non-arboreal stems per m^2 throughout treatment types in Compartment 33, Penobscot Experimental Forest, from June-July 2019 vegetation inventories. All non-arboreal stems below 2 m were inventoried and included in stem count summaries.Treatment types are equivalent to: stem only harvest (SOH), and stem only harvests with prescribed burning (SOHB).

Non-Arboreal Plant Ecological Integrity

Diversity and FQA metrics differed between SOH and SOHB (Table 4). Diversity indices, richness, and Shannon’s evenness were all found statistically significant

(P=<0.001). Floristic quality assessment was as well significant, and greater in value in areas slash had been burned (P=<0.001). Mean richness was over double in value in value within SOH plots compared to SOHB, as well as diversity indices were consistently higher within SOH. Diversity increased in treatment units with slash left on site, but ecological integrity, through FQA metrics, was best preserved within treatment units that's slash was burned.

Table 4. Statistical significance of the effect of prescribed burn on non-arboreal plant communities within Compartment 33, Penobscot Experimental Forest. Determined through a paired t-test analysis of burning treatment effect (stem only harvest (SOH) vegetation plot data, and stem only harvest burn SOHB) vegetation plot data) on floristic quality assessment (FQA), Shannon's diversity, Simpsons index, richness, abundance, evenness, and overall stem count per meters squared of non-arboreal species. Total sample size (N) for each treatment included 9 individual 202-m^2 plots

METRIC	SOH $\bar{x}$ (se)	SOHB $\bar{x}$ (se)	T_9	P-value
RICHNESS	12.0 (2.0)	5.0 (1.0)	8.959	<0.001
DENSITY (STEMS/m^2)	0.8 (1.7)	1.8 (0.3)	0.626	0.540
SHANNONS INDEX	1.86 (0.16)	1.06 (0.06)	2.517	0.022
SIMPSONS INDEX	6.27 (1.05)	3.35 (0.44)	6.501	<0.001
SHANNONS EVENNESS	0.78 (0.04)	0.97 (0.10)	6.385	<0.001
FQA	0.20 (0.03)	0.40 (0.06)	10.489	<0.001

Mammalian Browse Effect

Arboreal Plant Density

Exclosures had higher mean abundance but lower mean arboreal stem densities (Table 5, Figure 6). Balsam fir, and white pine were notably more prevalent in these plots than their paired vegetation plot counterparts. No browse was observed in deer-hare exclosures. From this, we can infer that these exclosures succeeded in preventing deer and hare, and other possible herbivores, browsing these areas. Outside exclosures, gray birch and quaking aspen were browsed by hare, with gray birch being more prefered. Overall, gray birch was on average browsed 20 percent by clipping, whereas quaking aspen was only clipped by five percent (data not shown). Plots outside exclosures featured lower arboreal species diversity, when in direct comparison to plots located within exclosures.

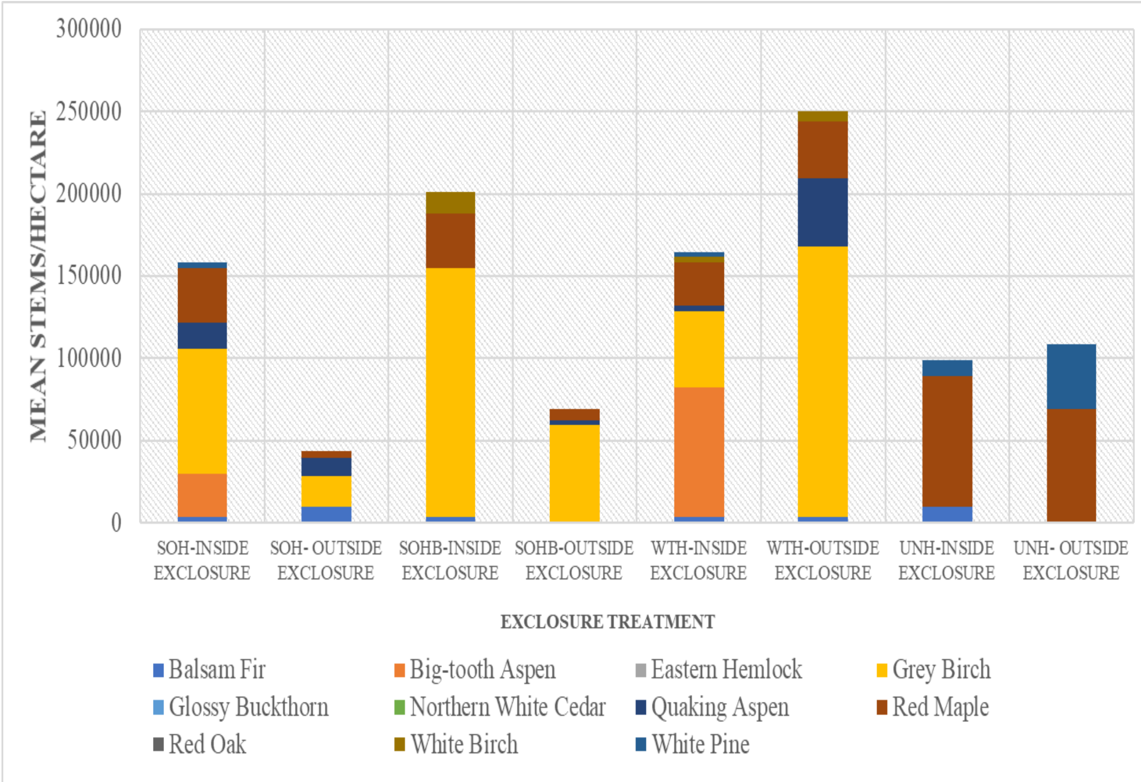

Figure 6. Mean arboreal stems per hectare throughout treatment types in Compartment 33, Penobscot Experimental Forest, from June-July 2019 arboreal inventories. These estimations are based off of both excolusre (within exclosure) and paired plot (outside exclosure) data. Arboreal stems between the height of >15.2 cm to ≥ 137.16 cm, with a dbh of <1.3 cm was measured in this inventory. Treatment types are equivalent to: stem only harvest (SOH),whole tree harvest (WTH), stem only harvest with bruning (SOHB) and unharvested reference (UNH).

Arboreal Plant Ecological Integrity

Most metrics for ecologicial integrity differed inside exclosures relative to pair plots outside exclosures (Table 5). Simpson's index was the only metric that didn't differ (P=0.492). Shannon's and Simpson's diversity indices were higher within exclosure plots, but evenness was higher outside exclosures.

Table 5. Statistical significance of the effect of mammalian browse on arboreal plant communities, within Compartment 33, Penobscot Experimental Forest. Determined through a paired T-Test analysis of paired (outside exclosure) and exclosure (inside exclosure) plot data, for arboreal plant species inventoried in June-July of 2019.

METRIC	INSIDE EXCLOSURE $\bar{x}$ (se)	OUTSIDE EXCLOSURE $\bar{x}$ (se)	T_9	P-value
RICHNESS	17.0 (5.0)	16.0 (7.0)	3.123	0.002
DENSITY (STEMS/HA)	15186 (4801)	29114 (1201)	3.411	0.003
SHANNONS INDEX	0.60 (0.12)	0.50 (0.13)	7.222	<0.001
SIMPSONS INDEX	2.43 (0.99)	1.29 (0.36)	0.700	0.492
SHANNONS EVENNESS	0.48 (0.10)	0.51 (0.13)	7.185	<0.001
FQA	0.61 (0.17)	0.85 (0.21)	3.934	<0.001

Non-Arboreal Plant Density

Outside of deer-hare exclosure, species obsered browsed included: bristly sarsaparilla (10 percent ripped, 9 percent clipped), annual fleabane (15 percent ripped, 18 clipped), pale corydalis (15 percent ripped, 40 percent clipped), and bicknells cranesbill (25 percent ripped, 28 percent clipped) was browsed by both mammals. Bush honeysuckle (12 percent ripped) was only reported to be browsed by deer, whereas sedge species (13 percent clipped), and lance-leaf goldenrod (30 percent clipped) was browsed by hare. It is important to note that all browse data associated with snowshow hare occurred within burned treatment plots (data not shown). Among the four treatment types (SOH, SOHB, WTH, UNH), stem density didn't differ within and outside exclosures (Table 6, Figure 7). Stem densities were higher outside exclosures for SOHB and WTH paired plots, but were higher inside exclosures in SOH and UNH.

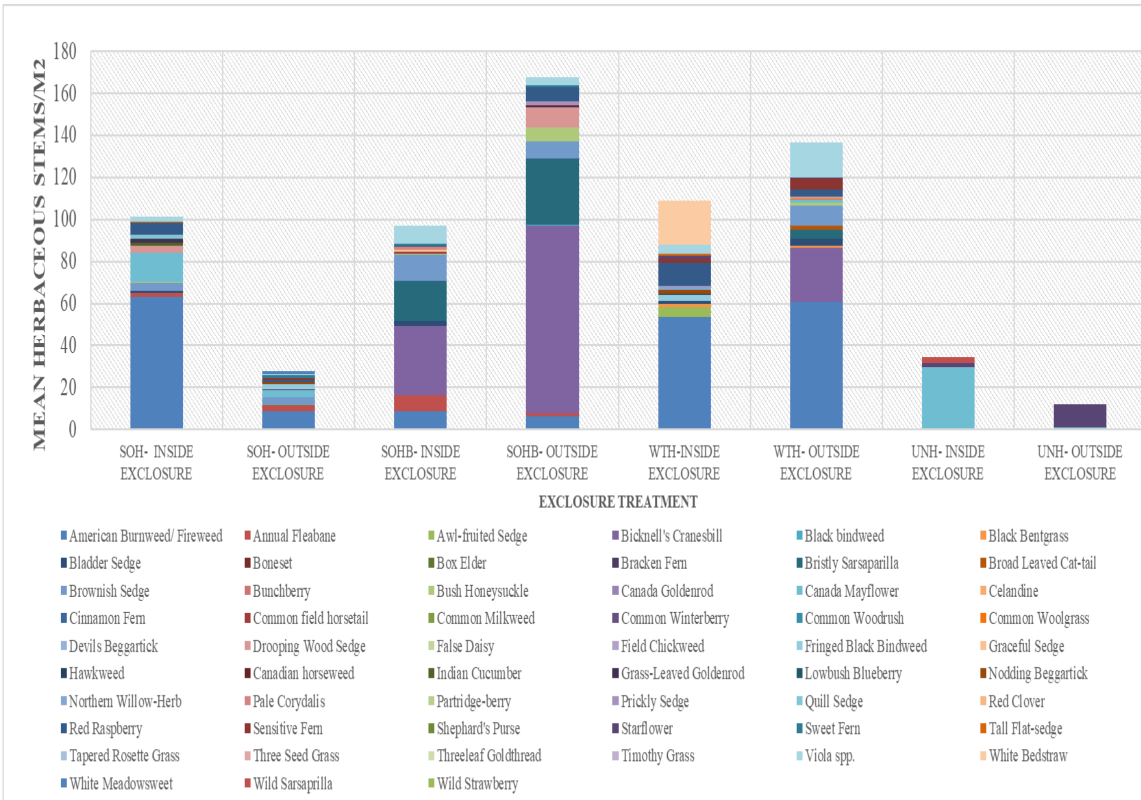

Figure 7. Mean non-arboreal stems per m^2 throughout treatment types in Compartment 33, Penobscot Experimental Forest. These estimations are based off of both excolusre (within exclosure) and paired plot (outside exclosure) data. All non-arboreal stems below 2 m were inventoried and included in stem count summaries. Treatment types are equivalent to: stem only harvest (SOH), stem only harvest burn (SOHB), whole tree harvest (WTH), and unharvested reference (UNH).

Non-Arboreal Plant Ecological Integrity

Further statistical analysis of non-arboreal exclosure and paired plot data denotes a significant difference between the two treatment groups (Table 6). Metrics of abundance, richness, diversity indices, and FQA show that these computations are significantly different within, and outside exclosure environments. As previously stated within non-arboreal plant density results, mean stem density per hectare did not differ due to browse (P=0.601).

Table 6. Statistical significance of the effect of mammalian browse on non-arboreal plant communities, within Compartment 33, Penobscot Experimental Forest. Determined through a paired T-Test analysis of paired (outside exclosure) and exclosure (inside exclosure) plot data, for non-arboreal plant species inventories composed in June-July of 2019.

METRIC	INSIDE EXCLOSURE $\bar{x}$ (se)	OUTSIDE EXCLOSURE $\bar{x}$ (se)	T_9	P-value
RICHNESS	6.0 (1.0)	7.0 (1.0)	7.477	<0.001
DENSITY (STEMS/m^2)	1.68 (0.43)	1.76 (0.09)	0.532	0.601
SHANNONS INDEX	1.22 (0.13)	1.18 (0.21)	1.838	0.082
SIMPSONS INDEX	2.88 (0.39)	3.14 (0.63)	3.891	<0.001
SHANNONS EVENNESS	0.68 (0.05)	0.58 (0.09)	7.579	<0.001
FQA	0.38 (0.05)	0.39 (0.10)	8.781	<0.001

DISCUSSION

Strip Clear-Cutting with and without Slash Removal Effects

Plant Density and Composition

Historically, C33, investigators have observed changes in forest on initial regrowth response five years post-harvest, in which they assessed plant regeneration and forage damage. Rinaldi (1970) found that hardwood species densities increased in both slash removal scenarios as well as in instances where forests were treated with prescribed burning. He observed that aspen species became prevalent throughout the compartment, and the forest at this stage began the transition to increased proportion of hardwood species to softwood species (Rinaldi, 1970). In comparisons between this 2019 study and Rinaldi (1970) findings, possible difference in arboreal composition can be derived from post-treatment inventory time frames. Rinaldi (1970) reported on vegetation observed five years post-harvest, whereas this study inventory only occurred one year post-harvest and less than one year post-burn on the study area. Whereas Rinaldi (1970) reported higher aspen densities than this study, this difference in hardwood density could be associated with more growing seasons post-harvest in the Rinaldi study.

After 50-years post-harvest, Muñoz Delgado et al (2019) reported finding differences in species composition across treatments. Hardwood composition was proportionally highest in prescribed burning treatments, consistent with what was initially found five years after the first treatment (Muñoz Delgado et al., 2019; Rinaldi, 1970). As C33 was primarily spruce-fir in composition prior to its harvest in 1964-65, a shift in species composition towards predominantly northern mixedwood was observed in 2014-

15 (Czpowskyj.et al., 1976; Muñoz Delgado et al., 2019). At the time of this study's inventory in 2019, following the second rotation of harvesting and burning, species composition was dominated by hardwoods, particularly gray birch, red maple, and quaking aspen.

This 2019 investigation described regenerating tree composition of C33 today as that of a hardwood forest type. Hardwood regenerative species dominated with nearly 87 percent of the mean stems/ha observed. According to Helms (1998), to be classified as a mixedwood stand, neither softwood nor hardwood components can comprise more than 75-80% of the forest stand's overall composition. Thus, this compartment has transitioned from a spruce-fir dominated stand in the early 1960s to a mixedwood composition in the 2010s, and eventually becoming the hardwood-dominated forest it is today.

Unharvested reference plots in this study had the highest density of softwoods relative to the harvested and burn treatments. This compositional difference may be due to the unharvested reference area being a different developmental stage compared to harvested strip cuts. The unharvested reference plot was not treated in 2018, and therefore can be denoted as representative of 2014-2015 mixedwood forests in C33 (Munoz-Delgado et al., 2019).

Regenerative compositions across this compartment were largely determined by species-specific responses to disturbance. In mixedwood forests, pioneer species, such as red maple and aspen, have an advantage immediately following disturbances compared to later successional species such as most softwoods (Kneeshaw and Bergeron, 1996). With repeated biomass removal on a regular rotation, it is evident that this forest ecosystem has converted to a hardwood-dominated forest.

Shade intolerant, pioneering hardwood species consistently regenerate faster and quickly occupying growing space, thus negatively impacting softwood abundance over time. An additional advantage of some arboreal hardwood species is their availability to regenerate vegetatively from below-ground roots and stumps providing them with a developmental advantage to monopolize growing space in a short time span post-harvest in comparison to softwood species. Red maple, being one of these species, was most commonly observed within the 2019 inventory as aggregated groups, around harvested stumps.

Compositional changes could potentially be related to the changing climate. Studies show that the natural ranges of 70 percent of tree species are shifting due to climate migration (Rains et al., 2010). Species shifting northward included balsam fir, red and black spruce, quaking and big tooth aspen, eastern hemlock, northern white cedar, and northern red oak (Rains et al., 2010). With the exception of aspen species, which were among the six most prevalent species within the treatment plots, these species represent a low proportion of regeneration density within the study area.

The most common non-arboreal species across the treatments, American burnweed, is a common species found across the United States post-harvest. In an experiment with both whole tree harvest and stem-only harvest, American burnweed was the densest species among the harvest treatments, regardless of arboreal residue retention (Mann, 1984).

Ecological Integrity

When assessing plant community diversity and integrity, there are several modes of comparison available to the science community. This investigation chose to use several diversity indices and a floristic quality index; the latter was used because it considers not only species abundance, but also species' sensitivity to disturbance. Diversity indices, such as Shannon's index, commonly fail to include the difference of species resilience to various land use (Wilhelm and Masters 1995; Mirazadi et al., 2017). FQA as an index can be used to not only discern diversity but also forest plant diversity response to anthropogenic disturbance (Bell et al., 2017). FQA can be problematic with small species sample sizes in that when a plot features few species present, the coefficient of conservatism is weighed more heavily than for sites with more species present. This investigation found this to be a useful index in most cases, except for vegetation sample plots where only one to a few plant individual species were observed. In those instances, FQA was skewed higher in value due to the individual species COC weighting in computations.

Many forest stewards implement silvicultural techniques that will benefit forest ecosystem health in all developmental stages of the stand's life cycle. Forestry aims to address both ecosystem protection and health-related goals, while still providing society with invaluable timber resources. Though FQA values were highest in unharvested areas, it is not practical to imply that all forest stands should remain unharvested. The triad approach to forest management planning suggests that both low and high-intensity timber harvesting, balanced with biological reserves, are integral to the field of forestry (Seymour and Hunter, 1992). Timber harvesting allows for stands that are diverse in developmental stages, compositions, and structures, which should be represented across the landscape to preserve gamma diversity. This experiment can provide insight into two even-aged tree removal methods of varying harvest intensity that affect ecological integrity and vegetation composition.

The most diverse plots were WTH and SOH. Shannon's and Simpson's, diversity indices were higher in the two silvicultural treatments that only removed biomass but did not burn. In UNH, FQA was higher for both arboreal and non-arboreal species compared to harvested treatments. From this, we can conclude that strip-clearcutting increases plant diversity on the landscape, but it does not necessarily preserve ecological integrity. This result was found to be true in both arboreal and non-arboreal datasets, with the exception that Shannon's diversity indexes for SOH were not ranked second most diverse in non-arboreal plots, and SOH plot diversity was on average less diverse. Rather, since Shannon's index places a higher weight on richness of species, these plots had fewer species present, with higher quantities of those species in comparison to SOHB plots.

The unique nature of investigating multiple harvest regimes in one location distinguishes Compartment 33 from other forest harvest studies. In addition, few studies discuss the effects of an intensive, silvicultural prescription after multiple harvest rotations regarding stem density, species abundance and composition. From a forester perception, these are integral metrics to discern ecosystem health and future impacts. Forest managers do not always have high productivity sites, in which they still must implement the best techniques to promote ecosystem health and biomass removal. C33, a low productivity site with poor soil drainage, provides an example of forest response after multiple harvest entries in sensitive forest areas. Bjorkman and Frank (1968) were amongst the first to discover decreased spruce-fir regeneration within plant communities after intensive forest harvesting within C33, providing a baseline for research conducted today within the PEF.

Although this investigation did not focus on soil productivity or carbon sequestration, they are important to consider. Thiffault et al. (2011) discussed the impact of intensive harvests on global carbon concentrations. Ecotone forests, such as the PEF located between boreal and broadleaf temperate forest ecosystems, impact carbon stocks if these regions are intensively harvested on regular rotations. Johnson and Curtis (2001) discussed concerns of whole tree harvesting on low productivity sites, like C33. Whole tree harvests decreased soil productivity, whereas stem only harvests had a positive correlation with carbon and nitrogen soil stocks, and fire having little to no effect on soil properties (Johnson and Curtis, 2001).

Prescribed Burning Effects

Plant Density

In the formulation of the original experimental design, prescribed burning in Maine was framed as a paradigm shift from fire as a management concern to a new, beneficial management tool needing investigation (Patterson, 1967). Fifty-five years later Maine, and New England, is still posed with questions as to the potential of prescribed burning as a mitigation tool that can benefit our forests in this changing climate. In this study, all metrics assessed differed between burned and unburned SOH units, with the exceptions of density within non-arboreal species and Shannon's index within arboreal species.

Aspen was reported as the dominant species within five-year post-harvest inventories (Rinadli, 1970). Aspen is considered a successional species, that when regenerated by fire, will remain prevalent until outcompeted by late-successional species (USFS, 2019). Aspen typically regenerates post-disturbance or fire by sprouting shoots from pre-existing root growth. Aspen was underrepresented in this inventory, especially in relation to Rinaldi's (1970) inventory where aspen was a greater proportion of C33 composition. This could be due to a greater intensity of fire in 2018 versus 1964-65, or a lower density of mature aspen individuals in 2017 to support post-harvest regeneration. To discern if aspen populations have been affected, another inventory in four years should be conducted to more directly compare results of the most recent treatment to results reported by Rinaldi (1970). This would allow for a more direct comparison of stem density by species between the two studies to be conducted during the same timeframe in stand development.

For forest managers who wish to increase regenerating tree density, burning will not achieve that outcome. It is also notable that burning resulted in the lowest density of white pine, and other coniferous species, among all study treatments. Depending on the timing of a burn in relation to good seed production years for arboreal species, this can affect the density of regeneration observed post-disturbance for both hardwood and softwood species. Patterson (1967) reported that conifer seed beds were mostly depleted post-fire and the initial year of treatment (1965) was a poor softwood seed year, whereas hardwood seeds were abundant (Patterson, 1967).

Among non-arboreal species, some are prolific germinators after fire such as Bicknell's cranesbill which was dense in burned areas relative to unburned SOH areas. Bicknell's cranesbill, the second most prevalent non-arboreal species across the compartment, is germinated through high temperatures achieved through fire applications. This species' seeds have been found to be dormant in seed banks for over 200 years (USDA, 2006). Similarly, bristly sarsaparilla and sedge species were in greater densities within SOHB treatments than in either SOH or WTH. Bristly sarsaparilla is a commonly reported species post-fire in New England type forests (Lynham and Stocks, 1989; Small et al., 2003). Similarly, sedges are often common pioneer species post-fire (Kruger and Reich, 1997). Red raspberry, the only other non-arboreal species to occur more than five percent throughout the study site and most commonly within burned areas, is reported as commonly occurring throughout the PEF (Dibble, 2010).

Ecological Integrity

FQA values for both arboreal and non-arboreal species within harvest treatments in this study were highest within the burned (SOHB) units among harvested treatments (Table A6-A7). Thus, forest managers can infer that prescribed burning did not affect ecological integrity negatively. Low severity prescribed fire can remove arboreal residue from the forest floor, which can prevent future high severity forest fires that may be ecologically damaging (Fernandes and Botelho, 2003). Fire can also restore ecological productivity, as the application of fire on forest biomass can affect nitrogen pools within soil, which is a nutrient that in low quantities can prove to be a limiting factor to arboreal species growth (Carter and Foster, 2004). Given C33's low production quality pre-harvest, increased nutrient concentration within the site's soil could prove beneficial to ecological integrity and arboreal regeneration.

Mammalian Browse Effect

Plant Density

Deer can have a greater impact on tree mortality due to browse compared to other environmental and climatic effects (Boerner and Brinkman, 1996). In a deer exclosure study in central Adirondack northern hardwood forests, researchers found similar results in which deer were a limiting factor for arboreal and non-arboreal species population densities (Tierson et al., 1966). Due to foraging preference of herbivores, some plant species may be more or less prevalent than others in certain ecosystems. It has been reported that both arboreal and non-aboreal species diversity and abundance are affected by deer damage (Carson, 2005). In this investigation, softwood species, specifically northern white cedar, had the lowest representation across the study area. This could potentially be due to deer, and occasionally showshoe hare, often choosing northern white cedar over other species as a source of nutrition (Johnston, 1972). Another species that was found to be underrepresented in this forest ecosystem was northern red oak. Deer browse is known to be problematic for oak species in particular, by affecting seedling mortality due to foraging (Marquis et al., 1976). Deer forage of aspen stump sprouts can directly result in not only mortality, but a reduction on sapling growth and vigor (USFS, 2019). Birch species, reported in this 2019 inventory as the aboreal species most frequentlybrowsed by deer, is rated as infrequently browsed based off of palatability reports (Kopp, 2007). Aspen, browsed secondmost within this inventory, was recorded as occasionally browsed (Kopp, 2007). Whereas the arboreal species browsed in this study do not represent commonly preffered deer forage, herbivore patterns and impacts are often highly variable and context-dependent (Holland et al., 2012). As well, variations in browse by snowshoe hare and white-tailed deer can differ by regional attributes as well as timing during the year (Rinaldi, 1970).

Non-arboreal species were more frequently browsed, by both deer and hare, than arboreal species in this study. In general, early successional plants such as non-arboreal species are more palatable to herbivores compared to late successional species (Maiorana, 1978). Species observed to be browsed five year post harvest by Rinaldi (1970) that were also found to be browsed in this 2019 inentory included gray birch, rasberry, and sedge species.

Ecological Integrity

Shannon's diversity index within exclosures was greater than outside exclosures among treatments. Evenness, richness, and FQA were all significant metrics in the comparison between arboreal and non-aboreal species datsets inside and outside exclosures.In all species within all treatment types, FQA was higher outside exclosures, in direct comparison of plots inside exclosures. Arboreal species resulted in a signficance of Shannon's index, whereas non-arboreal species resulted in Simpson's index being significant. This is due to the fact that aboreal species had increased richness across plots, in which there was a greater species richness outside exclosures compared to inside exclosures. Non-arboreal species had increased evenness across plots, in which plots located within exclosures had greater evenness compared to outside exclosures .This difference in diversity results may also be due to small sample size, in which there was only ten deer-hare exclosures installed throughout the entire 26 hectare compartment.

Deer browse was only observed in 2019 on burned treatment plots. Increased deer browse, caused by a trend of increasing deer populations, can have impacts on ecosystem health in regards to the growth and survival of arboral and non-arboreal species, modifying overall vegetation dynamics (Cote et al., 2004). This 2019 investigations revealed deer had only browsed non-aboreal species. White-tailed deer, in large populations, through extensive browse has been reported to alter diversity, and density in herbaceous communities (Royo et al., 2010). Maine has a high density of deer population present throughout the state, and observations in C33 confirmed that browse can have significant effect on diversity and density (MDIFW, 2020).

Hare browse was only observed within this inventory on SOH and SOHB harvest types. Studies conducted in northern boreal forests have shown that increased timber harvesting can increase hare populations (Darveau et al., 1998). In areas of SOHB, although most above ground biomass was burned, both coarse and fine arboreal debris remained post-burn. Residual arboreal slash could influence snowshoe hare forage dynamics, as it has the potential to create a multi-layered understory more suitable to hare habitat, that also provides protection from predators (Livaitis et al., 1985). In this scenario, prescirbed burning and mammalian browse may have interacting effects on plant communities and ecological integrity. Arboreal species, grey birch and quaking aspen, underwent clipped browse damage at approximately five to fifty percent per individual stem recorded in inventories . Individual plant species that undergo browse damage may grow at slower rates, taking longer to outgrow forage height for most herbivores, extending the time frame until they can begin to reproduce (Zamora et al., 2001). Forest regeneration, and the density and composition of regenerating arboreal species directly relates to forest ecosystems and their health (McWilliams et al., 2015). Extensive hare damage observed one year post-harvest has the potential to ecologically compromise the arboreal species present ability to progress in stand development.

Recomendations for Future Work.

Recomendations for future work include continuing the inventory of C33 in conjunction with other PEF vegetative surveys for long-term study. Continuous monitoring of regeneative plant communities by using mean stem densities will provide greater insight into treatment effects over time. This study identified presence of similar species as in the first inventory conducted post-harvest by Rinaldi (1970), but also highlighted key individual species that were missing from 2019 inventories. An inventory in four years would provide crucial observations five-years post-disturbance, providing an opportunity to directly compare the same developmental stage observed by Rinaldi (1970).

The effect of browse could be expanded in future work. Increased number of deer-hare exclosures plots could provide increased validity in the effects of browse within C33. This study only had nine exclosure structures within harvest treatments, and one erected in unharvested reference plots. A more robust browse dataset could provide insight to not only density of plant species browsed, but density of mammals present. Palatability charts, including rankings of species most browsed to least browsed, could be generated using browse data collected and stored in the PEF database. Through analysis of percent browse observations for each individual plant and species, categorical indices of palatability could be generated for species present and that are site-specific to local mammal preferences. Categorical indices of palatability are commonly used to address the preference of a mammalian species for one floral species relative to another (Kopp, 2007). The product would be a ranking of both snowshoe hare and white-tailed deer browse species preference for each plant species observed in C33 and that may have application elsewhere on the PEF.

Consistent floristic quality assessments will provide information concerning ecological integrity over time. Using the 2019 floristic inventory as a baseline and if inventories are continued annually, investigators will be able to guage vegetative communities resliency to intensive harvesting over time. It will also be possible to identify spatial or treated areas of concern due to harvest effects, which can be beneficial for forest managers to prioritize crew and harvest work throughout the compartment. In a changing climate, this can be beneficial in aiding land managers with their decisions on how to best adapt forest management practices, potentially to include prescribed burning.

There are several interacting effects that occur within C33 that were not investigated within this study. The proximity to trails and roads provide extreme forest edge conditions. This in turn could affect plant composition, level of browse damage, and plant regeneration. Climate change, affects all environments and must be considered in long-term study sites such as C33. Climate change may change disturbance regimes within Maine and New England. Increased fire frequency may denote the importance of increased prescribed burn application.

Timber management in Maine is often directed to favor coniferous species, for both wildlife and merchantability purposes (Bryan, 2017; Luppold and Sendak, 2004). White pine, most abundant within reference areas, has increased in sawtimber production since 1959 in Maine (Luppold and Sendak, 2004). Within harvest treatments, hardwood species increased significantly. A prevalent species across all treatments types was aspen. Aspen, which has increased in densities across the state, requires site disturbances such as clearcut harvests to regenerate and thus has impacted Maine markets due to its rapid growth within the states forest stands (Luppold and Sendak, 2004). With a reduction in spruce-fir forests across the state, markets have transitioned to increasing production of hardwood pulp. C33 was first harvested in an attempt to increase spruce-fir forest associates, but instead, has transitioned to a northern hardwood-dominated stand. Investigators should discuss the direction of the experiment and whether to attempt to leave the compartment's forest to develop unimpeded or to manipulate composition for more desirable, merchantable softwood species.

CONCLUSIONS

This study is the first of its kind in northern hardwood forests, and currently one of the longest ongoing evaluations of whole tree harvesting on naturally regenerated stands in temperate forests worldwide. When forest managers perform timber harvests, their main concern is understanding the response of forest stands to their applied silvicultural prescriptions. Unharvested reference plots within C33 have high stem densities per hectare but featured low species diversity in comparison to harvested plots (SOH, WTH). Due to the nature of pioneer species, and prolific growth after disturbance, treated areas experienced both higher richness and abundance when compared directly to unharvest reference plots. SOH and WTH had consistently higher diversity indices, but lower ecological integrity based on FQA compared to areas without harvest. Czapoweskyj et al. (1976) concluded that clear-cut strips increased browse forage, and that prescribed burning reduces softwood regeneration. These conclusions were supported by this investigation's findings. Mammalian browse was found to be a key player in species richness within SOH and SOHB sites, but not a driver of stem density in regenerating hardwood forest. Browse damage varied heavily by harvest treatment type, and the plant community composition present. Prescribed burning, in conjunction with slash left on site post-harvest, decreased arboreal stem density, particularly that of softwood species, but did not harm ecological integrity and may increase it.

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APPENDIX

Table A1. List of Mammal Species in Compartment 33, Penobscot Experimental Forest.

Common Name	**Scientific Name**
White-Tailed Deer	Odocoileus virginianus
Snowshoe Hare	Lepus americanus

Table A2. List of arboreal Plant Species in Compartment 33, Penobscot Experimental Forest.

Common Name	**Scientific Name**
Balsam Fir	*Betula populifolia*
Big-Tooth Aspen	*Populus grandidentata*
Eastern Hemlock	*Tsuga canadensis*
Gray Birch	*Betula populifolia*
Glossy Buckthorn	*Frangula alnus*
Northern White Cedar	*Thuja occidentalis*
Quaking Aspen	*Populus tremuloides*
Red Maple	*Acer rubrum*
Red Oak	*Quercus rubra*
White Birch	*Betula papyrifera*
White Pine	*Pinus strobus*

Table A3. List of non-arboreal Plant Species in Compartment 33, Penobscot Experimental Forest.

Common Name	**Scientific Name**
American Burnweed/ Fireweed	*Erechtites hieraciifolius*
Annual Fleabane	*Erigeron annuus*
Awl-Fruited Sedge	*Carex stipata*
Bicknell's Cranesbill	*Geranium bicknellii*
Black Bindweed	Polygonum cilinode
Black Bentgrass	*Agrostis capillaris*
Bladder Sedge	*Carex intumescens*
Boneset	*Eupatorium perfoliatum*
Box Elder	*Acer negundo*
Bracken Fern	*Pteridium aquilinum*
Bristly Sarsaparilla	*Aralia hipsida*
Broad Leaved Cat-tail	*Typha latifolia*
Brownish Sedge	*Carex brunnescens*
Bunchberry	*Cornus canadensis*
Bush Honeysuckle	*Diervilla lonicera*
Canada Goldenrod	*Solidago canadensis*
Canada Mayflower	*Maianthemum canadense*
Celandine	*Chelidonium majus*
Common field horsetail	*Equisetum arvense*
Common Milkweed	*Asclepias syriaca*
Common Winterberry	*Ilex verticillata*

Table A3. Continued List of non-arboreal plant species

Common Name	Scientific Name
Common Woodrush	*Luzula multiflora*
Common Woolgrass	*Scirpus cyperinus*
Devils Beggartick	*Bidens frondosa*
Drooping Wood Sedge	*Carex Arctata*
False Daisy	*Eclipta prostrata*
Field Chickweed	*Cerastium arvense*
Fringed Black Bindweed	*Fallopia cilinodis*
Graceful Sedge	*Carex gracillima*
Hawkweed	*Hieracium flagellare*
Canadian Horseweed	*Conzya canadensis*
Indian Cucumber	*Medeloa virginiana*
Grass-Leaved Goldenrod	*Euthamia graminifolia*
Lowbush Blueberry	*Vaccinium angustifolium*
Nodding Beggartick	*Bidens cernua*
Northern Willow-Herb	*Epilobium ciliatum*
Pale Corydalis	*Corydalis sempervirens*
Partridge-Berry	*Mitchella repens*
Prickly Sedge	*Carex atlantica*
Quill Sedge	*Carex tenera*
Red Clover	*Trifolium pratense*
Red Raspberry	*Rubus idaeus*
Sensitive Fern	*Onoclea sensibilis*

Table A3. Continued List of non-arboreal plant species

Common Name	**Scientific Name**
Shephard's Purse	*Capsella bursa-pastoris*
Starflower	*Trientalis borealis*
Sweet Fern	*Comptonia peregrina*
Tall Flat-sedge	*Cyperus eragrostis*
Tapered Rosette Grass	*Dichanthelium acuminatum*
Three Seed Grass	*Carex trisperma*
Three-leaf Goldthread	*Coptis trifolia*
Timothy Grass	*Phleum pratense*
Viola spp.	*Viola spp.*
White Bedstraw	*Galium album*
White Meadowsweet	*Spriea alba*
Wild Sarsaparilla	*Aralia nudicaulis*
Wild Strawberry	*Fragaria virginiana*

Table A4. Non-arboreal species respective coefficient of conservatism (COC), which represent a value of individual species resilience to human land use.

Common Name	Scientific Name	COC
American Burnweed/ Fireweed	*Erechtites hieraciifolius*	2
Annual Fleabane	*Erigeron annuus*	2
Awl-Fruited Sedge	*Carex stipata*	3
Bicknell's Cranesbill	*Geranium bicknellii*	3
Black Bindweed	Polygonum cilinode	5
Black Bentgrass	*Agrostis capillaris*	3
Bladder Sedge	*Carex intumescens*	3
Boneset	*Eupatorium perfoliatum*	4
Box Elder	*Acer negundo*	0
Bracken Fern	*Pteridium aquilinum*	2
Bristly Sarsaparilla	*Aralia hipsida*	
Broad-leaved Cat-tail	*Typha latifolia*	
Brownish Sedge	*Carex brunnescens*	4
Bunchberry	*Cornus canadensis*	4
Bush Honeysuckle	*Diervilla lonicera*	3
Canada Goldenrod	*Solidago canadensis*	2
Canada Mayflower	*Maianthemum canadense*	2
Celandine	*Chelidonium majus*	0
Cinnamon Fern	*Osmundastrum cinnamomeum*	4
Common field horsetail	*Equisetum arvense*	2

Continued: Table A4. Non-arboreal species respective coefficient of conservatism (COC)

Common Name	Scientific Name	COC
Common Milkweed	*Asclepias syriaca*	2
Common Winterberry	*Ilex verticillata*	3
Common Woodrush	*Luzula multiflora*	2
Common Woolgrass	*Scirpus cyperinus*	2
Devils Beggartick	*Bidens frondosa*	2
Drooping Wood Sedge	*Carex Arctata*	4
False Daisy	*Eclipta prostrata*	0
Field Chickweed	*Cerastium arvense*	3
Fringed Black Bindweed	*Fallopia cilinodis*	5
Graceful Sedge	*Carex gracillima*	2
Hawkweed	*Hieracium flagellare*	0
Canadian Horseweed	*Conzya canadensis*	2
Indian Cucumber	*Medeloa virginiana*	5
Grass-Leaved Goldenrod	*Euthamia graminifolia*	2
Lowbush Blueberry	*Vaccinium angustifolium*	
Nodding Beggartick	*Bidens cernua*	0
Northern Willow-Herb	*Epilobium ciliatum*	3
Pale Corydalis	*Corydalis sempervirens*	6
Partridge-Berry	*Mitchella repens*	5
Prickly Sedge	*Carex atlantica*	6
Quill Sedge	*Carex tenera*	2

Continued: Table A4. Non-arboreal species respective coefficient of conservatism (COC)

Common Name	Scientific Name	COC
Red Clover	*Trifolium pratense*	0
Red Raspberry	*Rubus idaeus*	2
Sensitive Fern	*Onoclea sensibilis*	2
Shephard's Purse	*Capsella bursa-pastoris*	0
Starflower	*Trientalis borealis*	3
Sweet Fern	*Comptonia peregrina*	2
Tall Flat-sedge	*Cyperus eragrostis*	3
Tapered Rosette Grass	*Dichanthelium acuminatum*	4
Three Seed Grass	*Carex trisperma*	4
Three-leaf Goldthread	*Coptis trifolia*	6
Timothy Grass	*Phleum pratense*	0
Viola spp.	*Viola spp.*	6
White Bedstraw	*Galium album*	4
White Meadowsweet	*Spriea alba*	2
Wild Sarsaparilla	*Aralia nudicaulis*	4
Wild Strawberry	*Fragaria virginiana*	2

Table A5. Arboreal species respective coefficient of conservatism (COC), which represent a value of individual species resilience to human land use.

Common Name	**Scientific Name**	**COC**
Balsam Fir	*Abies balsamea*	3
Big-Tooth Aspen	*Populus grandidentata*	2
Eastern Hemlock	*Tsuga canadensis*	3
Gray Birch	*Betula populifolia*	2
Glossy Buckthorn	*Frangula alnus*	0
Northern White Cedar	*Thuja occidentalis*	3
Quaking Aspen	*Populus tremuloides*	2
Red Maple	*Acer rubrum*	2
Red Oak	*Quercus rubra*	2
White Birch	*Betula papyrifera*	3

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Table A6. Floristic Quality Assessment for arboreal species within vegetation plots, paired plots, and exclosure plots within Compartment 33, Penobscot Experimental Forest. Treatments refers to stem only harvest (SOH), stem only harvest with prescribed burning (SOHB), whole tree harvest (WTH) and unharvested reference plots (UNH)

ARBOREAL MEAN FLORISTIC QUALITY ASSESSMENT	
VEGETATION PLOTS	
Treatment	**Floristic Quality Assessment Index**
SOH	0.26
SOHB	0.40
WTH	0.27
UNH	0.51
PAIRED PLOTS	
Treatment	**Floristic Quality Assessment Index**
SOH	0.50
SOHB	0.99
WTH	0.49
UNH	0.60
EXCLOSURE PLOTS	
Treatment	**Floristic Quality Assessment Index**
SOH	0.55
SOHB	0.82
WTH	0.27
UNH	0.38

Table A7. Floristic Quality Assessment for non-arboreal species within vegetation plots, paired plots, and exclosure plots within Compartment 33, Penobscot Experimental Forest. Treatments refers to stem only harvest (SOH), stem only harvest with prescribed burning (SOHB), whole tree harvest (WTH) and unharvested reference plots (UNH)

NON-ARBOREAL MEAN FLORISTIC QUALITY ASSESSMENT

VEGETATION PLOTS	
Treatment	**Floristic Quality Assessment Index**
SOH	0.20
SOHB	0.20
WTH	0.13
UNH	0.45
PAIRED PLOTS	
Treatment	**Floristic Quality Assessment Index**
SOH	0.18
SOHB	0.51
WTH	0.32
UNH	0.84
EXCLOSURE PLOTS	
Treatment	**Floristic Quality Assessment Index**
SOH	0.38
SOHB	0.39
WTH	0.36
UNH	0.41

Table A8. Arboreal vegetation 202-m^2 plot diversity metrics. Per each 1 m^2 plot, Shannon's diversity and Simpson's diversity indices were calculated and reported. For unharvested reference data, plot totals were averaged and reported (U*).

1 m^2 PLOT	SHANNON'S D	SIMPSONS D
1B1	1.096	2.604
1B2	1.255	4.667
1B3	0.985	2.219
2B1	0.857	3.765
2B2	1.336	3.594
2B3	1.040	6.000
3B1	1.125	5.478
3B2	2.006	7.487
3B3	1.622	4.172
1L1	1.569	4.872
1L2	2.232	7.806
1L3	0.886	1.964
2L1	1.383	2.827
2L2	1.605	4.215
2L3	2.192	10.484
3L1	2.202	7.667
3L2	2.011	5.880
3L3	2.103	6.632
1R1	2.064	8.226
1R2	1.663	3.848
1R3	0.349	1.286
2R1	1.234	2.671
2R2	1.568	4.038
2R3	0.882	2.449
3R1	0.322	1.000
3R2	0.221	1.125
3R3	1.037	2.423
U*	0.615	1.749

Table A9. Non-arboreal vegetation 202-m^2 plot diversity metrics. Per each 1 m^2 plot, Shannon's diversity and Simpson's diversity indices were calculated and reported. For unharvested reference data, plot totals were averaged and reported (U*).'

1 m^2 PLOT	SHANNON'S D	SIMPSON'S D
1B1	1.678	2.989
1B2	2.670	10.027
1B3	2.451	8.413
2B1	2.540	8.768
2B2	2.364	7.800
2B3	1.781	2.946
3B1	1.439	3.163
3B2	2.302	6.932
3B3	1.310	2.462
1L1	2.002	7.235
1L2	1.882	4.193
1L3	1.454	3.156
2L1	1.345	5.888
2L2	2.291	10.225
2L3	1.198	7.383
3L1	1.721	3.102
3L2	2.465	3.552
3L3	2.386	11.704
1R1	2.734	7.676
1R2	2.850	10.949
1R3	2.322	13.983
2R1	1.997	7.358
2R2	1.773	4.928
2R3	1.597	3.626
3R1	1.462	3.592
3R2	1.973	3.058
3R3	0.846	5.855
U*	0.631	2.160

Table A10. Arboreal vegetation 202-m^2 plot metrics, including richness, abundance, and Shannon's Evenness. For unharvested reference data, plot totals were averaged and reported (U*).

1 m^2 PLOT	RICHNESS	ABUNDANCE	SHANNONS EVENNESS
1B1	5	24	0.681
1B2	4	8	0.906
1B3	4	23	0.711
2B1	2	17	0.937
2B2	5	34	0.857
2B3	15	40	1.336
3B1	3	4	0.946
3B2	4	27	1.559
3B3	3	6	0.790
1L1	6	16	0.910
1L2	7	36	0.898
1L3	9	42	0.913
2L1	8	36	0.780
2L2	6	20	0.876
2L3	13	122	0.870
3L1	4	11	0.639
3L2	7	49	0.711
3L3	8	37	0.772
1R1	11	26	0.914
1R2	14	69	0.834
1R3	14	151	0.762
2R1	13	36	0.820
2R2	9	51	0.939
2R3	10	73	0.722
3R1	2	9	0.503
3R2	6	40	0.689
3R3	7	21	0.806
U*	2.5	25.25	0.467

Table A11. Non-arboreal vegetation 202-m^2 plot metrics, including richness, abundance, and Shannon's Evenness. For unharvested reference data, plot totals were averaged and reported (U*).

1 m^2 PLOT	RICHNESS	ABUNDANCE	SHANNONS EVENNESS
1B1	14	15	0.636
1B2	27	326	0.810
1B3	20	249	0.818
2B1	22	98	0.822
2B2	20	344	0.789
2B3	24	402	0.560
3B1	10	318	0.625
3B2	15	158	0.850
3B3	10	330	0.569
1L1	9	42	0.911
1L2	18	162	0.651
1L3	8	130	0.699
2L1	8	87	0.647
2L2	15	105	0.890
2L3	19	182	0.778
3L1	4	44	0.864
3L2	16	282	0.621
3L3	14	80	0.934
1R1	23	230	0.761
1R2	27	166	0.829
1R3	24	146	0.897
2R1	18	398	0.803
2R2	18	346	0.691
2R3	19	434	0.602
3R1	9	51	0.727
3R2	11	522	0.610
3R3	12	87	0.794
U*	2.8	16.5	0.405

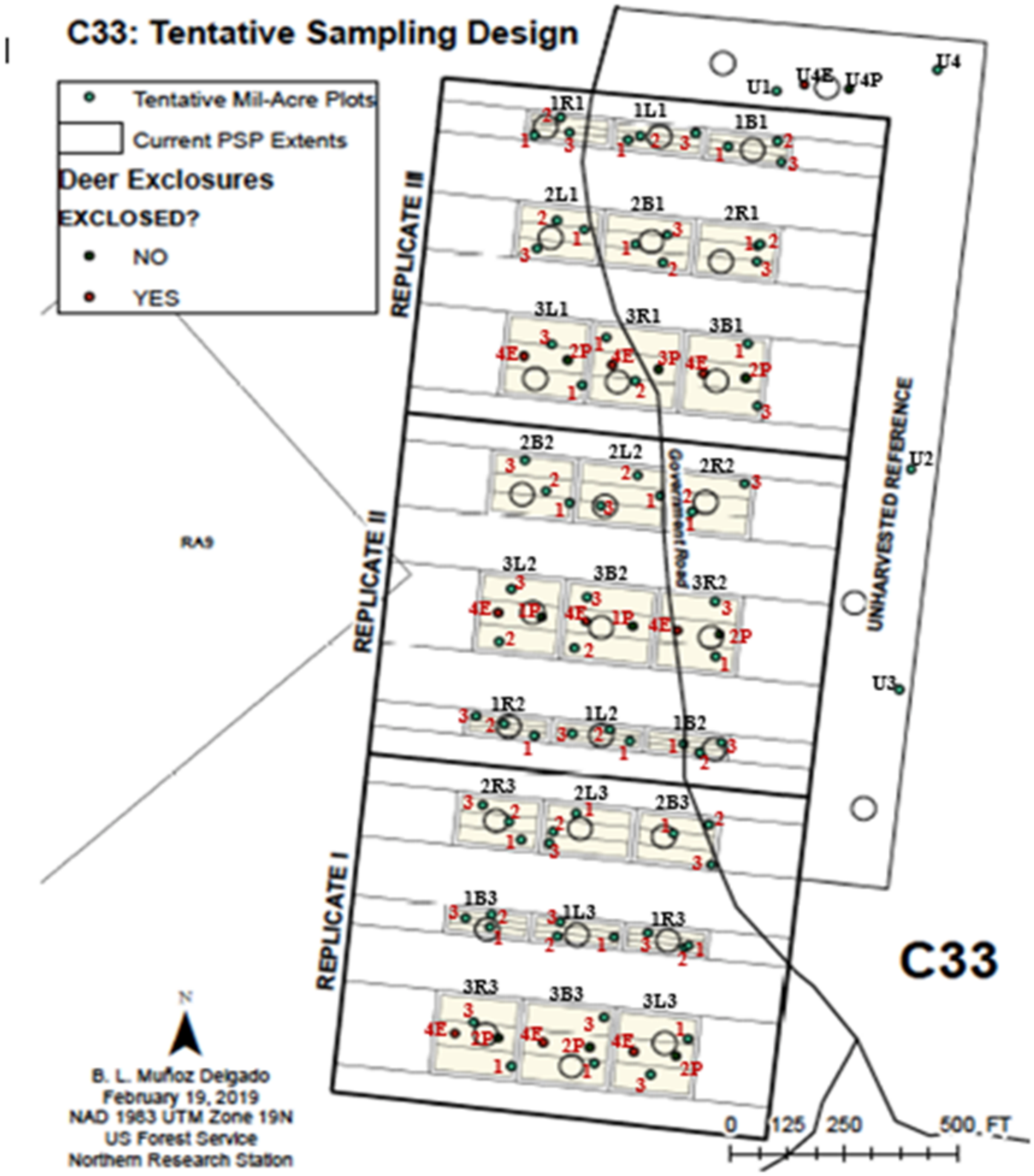

Figure A1. Compartment 33 experimental design. Denoted 1 m^2 sample plots indicate sites of 2019 summer inventory sites. Variables such as "L", "B" and "R" denotes treatment type and 202 m^2 plot (stem only harvest, stem only harvest with prescribed burning, whole tree harvest, and unharvested reference, respectively). "P" and "E" variables denotes if that plot was a paired or exclosure plot, used for browsing analysis.

AUTHOR'S BIOGRAPHY

Michaela L. Kuhn was born on Long Island, New York on April 21, 1998. She graduated from Sachem East High School, in New York in 2016. While attending the University of Maine, she lived in Orono with her husky Keanu and cat Greyson. Majoring in Forestry, Michaela has pursued several ecology-based internships and field positions, that allowed her to hone her ecological inventory and analysis skills. Throughout her undergraduate career she received a George L. Houston Scholarship through the School of Forest Resources, as well as an REU (Research Experience for Undergraduates) stipend from the National Science foundation to conduct soil research at Hubbard Brook Experimental Forest.

Upon graduation, Michaela plans to pursue a career in forestry, with a focus on forest ecosystem conservation.