Systematic Evaluation of Oak Regeneration in Lower Michigan

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Cover Photo: A thinned, oak-dominated forest on ice-contact terrain in Crawford County, Michigan, June 18, 2007. Photo by Jeffrey G. Lee.

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ABSTRACT

In order to document the current composition and abundance of dry and dry-mesic oak forests in the Lower Peninsula of Michigan, 105 sites were sampled. These sites were roughly evenly distributed between north and south regions on four major landforms: ice-contact terrain, moraine, outwash, and lake plain. These sites also represented varying management histories including unmanaged, cut (clearcut, shelterwood, selection, thinning), and burned. The primary objective was to document current oak regeneration as related to ecological properties and past management practices. Therefore overstory, understory, and groundcover vegetation were recorded in 10 nested plots at each site. Additional measures of vegetation heights and tree ages, canopy closure, soil properties, physiography, and deer browse pressure were recorded.

Findings showed that there were significant differences among forested oak ecosystems at both regional (i.e., north and south) and landform-level scales. The north region as compared to the south region exhibited 1) smaller overstory basal area, 2) greater understory stem density, 3) lower overstory and understory species richness, 4) greater overstory and understory basal sprouting, 5) greater oak understory density (i.e., regeneration), 6) greater groundcover coverage, 7) greater shrub abundance, 8) more open canopy structure, 9) lower incidence of deer browse, and 10) lower soil pH and exchangeable cation concentrations (i.e., lower soil nutrient availability).

Among landforms within each region, oak regeneration was distinctively greater on outwash and sand lake plain than on ice-contact terrain or moraine. Outwash and lake plain landforms generally corresponded with 1) lower red maple competition, 2) lower soil moisture, pH, and exchangeable cation concentration, and 3) a more open canopy than the ice-contact or moraine landforms.

Oak regeneration appears to be negatively related to deer abundance in the south region but did not show a consistent pattern among oak species in the north region. Red maple regeneration did not appear to be affected by any level of deer abundance in either region, which may provide it with a competitive advantage over oak where deer densities are high.

In general, management of forested oak ecosystems was more intensive in the north than the south region and partially accounts for higher average understory oak stem density in the north. The effect of active management, especially those activities that consisted of clearcuts, shelterwood cuts, or combined cut and burned treatments on outwash or lake plain landforms, generally stimulated oak regeneration through clonal sprouting. However, the likelihood of sustaining a population of oak advanced regeneration was observed to be dependent on controlling understory competition and limiting overstory shading, specifically from red maple. These factors, in turn, were intimately related to landform-mediated differences of soil moisture and nutrient concentrations. More mesic sites, especially those on ice-contact and moraine landforms, were prone to heavy understory sprouting of red maple following treatment compared to drier sites on outwash or lake plain landforms.

Logistic regression models indicated several factors that were crucial in determining the presence of adequate understory oak stem density (i.e., oak regeneration success). Factors that promoted oak regeneration included 1) low soil exchangeable cation concentration, 2) low overstory basal area, 3) low understory basal area, especially of red maple, 4) low groundcover coverage, 5) low shrub abundance, 6) high oak seedling abundance, 7) occurrence on outwash or lake plain landforms, and 8) presence of sandy subsurface soil horizons (i.e., somewhat excessively-drained to excessively-drained soil). Specific management techniques for the purpose of facilitating oak regeneration are dependent on landform, initial ecological conditions, and ability to invest time, money, and effort for the required management intensity. Less effort is required to encourage oak regeneration when the conditions listed above are satisfied. Conversely, a greater commitment of resources is required when conditions are amenable to growth of mesophytic competition.

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INTRODUCTION

Background

As a taxonomic group, oaks (*Quercus* spp.) are cosmopolitan in nature, and worldwide, there are approximately 400 species (Johnson et al. 2002). In North America a search of the NatureServe ecological community database returned 37 systems, 902 associations, and 147 alliances in which oak species occur in substantial abundance (NatureServe 2008). In the eastern United States, specifically the area bounded by central Maine to northern Minnesota and north central Florida to eastern Texas, the eastern deciduous biome can be simplified into the Northern Hardwood, Central Hardwood, and the Southern Pine-Hardwood Regions (Bailey 1997). Upland oaks occur in each one of these regions and in both glaciated and unglaciated terrain. Soil substrate ranges from inceptisols along the Mississippi River, deep alfisols in the Mid-Atlantic and Mid-Western states, and acidic spodosols in the northeast and Lake States (Abrams 1996). Mean summer temperatures range from 16 °C in the upper Great Lakes to over 27 °C in the south; annual precipitation ranges from 43 cm in North Dakota to 140 cm in Louisiana; and growing season length ranges from 90 days in the upper Great Lakes to 300 days in the southeastern Coastal Plain (Abrams 1996).

The genesis of upland oak forests in the eastern U.S. is attributed to a vegetation shift away from spruce (*Picea* spp.) dominance during the Holocene, approximately 10,000 years B.P (Webb III 1988). Both pine (*Pinus* spp.) and oak increased in abundance, but between 6,000 and 4,000 years B.P., a shift from pine to oak dominance coincided with a drier climate than previous (Abrams 2002). Also, paleoecological studies have shown a corresponding increase in charcoal found in sediment cores during this period that suggests high incidence of fires (Winkler et al. 1986, Szeicz and MacDonald 1991). The expansion of oak ecosystems up to the very recent can be linked to these recurring disturbances in conjunction with dry conditions.

In Michigan, the most common upland oak species are white oak (*Quercus alba*), northern pin oak (*Q. ellipsoidalis*), northern red oak (*Q. rubra*), and black oak (*Q. velutina*), all of which occur in the Northern Hardwood and Central Hardwood Regions described by Bailey (1997). General Land Office (GLO) survey notes (Comer et al. 1995) indicate that oaks formed communities that varied greatly in vegetation composition, structure, and degree of canopy closure. Circa 1800s oak communities were classified as black oak barrens, mixed oak forest, mixed oak savanna, mixed pine-oak forest, oak-hickory forest, oak-pine barrens, and eastern white pine (*Pinus strobus*)-white oak forest. Michigan Natural Features Inventory (MNFI) currently recognizes five open-canopy communities and six closed-canopy, forested communities in which oak species are commonly present in the overstory (Kost et al. 2007). The particular ecosystems in which these oak species occur in Michigan are dependent on climate, physiography, soil, intrinsic ecophysiological attributes and tolerances, both natural and anthropogenic disturbance history, and competing vegetation (Denton and Barnes 1987, Barnes and Wagner 2004).

Presently, closed-canopy oak forests comprise the vast majority of oak communities in Michigan (Figure 1). Forested communities where oak is the dominant or co-dominant species include dry northern forest, dry-mesic northern forest, dry southern forest, and dry-mesic southern forest (Kost et al. 2007). The two southern forest communities, occurring south of Michigan's climatic tension zone in Region VI, Southern Lower Michigan (Albert 1995), were dominated by oaks in the past and are dominated by oaks today (Kost et al. 2007, Lee 2007). In contrast, the two northern forest communities, occurring north of the tension zone in Regions VII, VIII, and IX are defined historically as pine or pine-hardwood–dominated forests in which oaks were primarily sub-dominant (Cohen 2002a, Cohen 2002b, Kost et al. 2007). In Region VII, Northern Lower Michigan, intensive and widespread logging of pine occurred from 1870 to 1890 with ensuing slash fires (Whitney 1987). This dramatic change of the northern landscape resulted in the depletion of the pine seed source but favored oaks because of their ability to sprout from the root collar following fire (Crow 1988, Abrams 1992). Consequently, the oak-dominated dry and dry-mesic northern forests today, especially in the northern Lower Peninsula, are artifacts of the logging era and subsequent slash fires, and they have been sustained by modern era logging (Whitney 1987, Leahy and Pregitzer 2003, Courteau et al 2006, Schulte et al. 2007). Regardless of region, however, none of the pre-European settlement oak forests exist today as they once did, and the current forests can only hint at past conditions. Even in the southern Lower Peninsula, many closed-canopy oak forests are converted oak openings or oak barrens that have increased in tree density due to the cessation of wildfires beginning in the mid 1800s and continuing today (Crow 1988, Cohen 2004, Abrams 2005). Fire suppression, landscape fragmentation, agriculture, and urban development greatly altered the landscape-scale disturbances that were needed to maintain the composition, structure, and function of oak ecosystems of the past.

Although knowing whether current oak forests resemble those that were present before European manipulation is important, especially for the sake of restoration, a more elementary problem for managers today concerns the regeneration of oak trees to ensure their persistence into the future. Throughout the eastern United States, much consideration has been given to the noticeable paucity of oak regeneration in forests currently dominated by dry and dry-mesic oak species, specifically white oak, northern red oak, and black oak (Loftis and McGee 1993, Hutchinson et al. 2008, Nowacki and Abrams 2008). Despite their increase following the logging and burn operations in the late 19th and early 20th centuries in northern Lower Michigan and the fire-suppressed conversion of oak savanna to oak forest in southern Lower Michigan, surveys of forest understories indicate a successional shift away from oak dominance in dry and dry-mesic ecosystems. Because attention has been given to northern red and white oak regeneration on more mesic systems, both in the context of silvicultural methods (Walters and Auchmoody 1993, Miller 1997, Dillaway and Stringer 2006) and past Native American activities (Albert and Minc 1987), regeneration on drier ecosystems is emphasized in this study.

Since European settlement, changes in land use have challenged long-term vegetation sustainability. For instance, homogenization of once diverse forest ecosystems in the Lake States to those comprised mainly of early-successional aspen (*Populus* spp.) and wide-ranging maple (*Acer rubrum* and *A. saccharum*) have greatly simplified compositional makeup (Schulte et al. 2007). Anthropogenic cessation of wildfires has contributed to the reduction of disturbance-mediated regeneration of fire-dependent species, especially oaks. Perpetuation of oak recruitment is also jeopardized by intense deer-browse pressure. The ramifications of decreased oak abundance in favor of an increased fire-intolerant but shade-tolerant species assemblage could be realized at multiple ecosystem scales. Soil fertility and calcium cycling may be affected (Washburn and Arthur 2003) as a greater proportion of less combustible and more rapidly decomposed, mesophytic litter displaces recalcitrant oak litter. If, over time, an "asbestos-like" red maple overstory were to assume dominance in place of oaks, ecosystem flammability would decrease due to mesophytic litter buildup and cooler and more humid microclimatic conditions resulting from heavy shade (Nowacki and Abrams 2008). Consequently, a stable-state consisting of self-replacing red maple would exclude further oak recruitment. Once the senescence of the remaining oak overstory progresses, it becomes difficult to return the system to its prior condition without costly restoration methods.

Managers of dry and dry-mesic oak forests recognize the implications of mesophytic succession. Oak species provide a critical food source for mammals and birds through acorn mast production (Van Dersal 1940, Rodewald 2003) and for leaf-chewing insects (Forkner et al. 2006). Unlike maple samaras, oak acorns are high in energy content, have high digestibility, and can be cached over the winter. Furthermore, the relatively slower decomposition rate of oak wood compared to that of soft maple (i.e., red maple) affords greater potential habitat in the form of long-standing snags and coarse woody debris. Oak wood retains higher specific gravity at all levels of decomposition than red maple (Adams and Owens 2001), and thus provides greater structural integrity for mammal utilization. In addition to providing food and habitat to popular game species, such as white-tailed deer (*Odocoileus virginianus*), wild turkey (*Meleagris gallopavo*), and ruffed grouse (*Bonasa umbellus*), numerous rare animal species are also dependent on oak forests (see Courteau et al. 2006). Additional values associated with oak forests include timber production, recreation, and aesthetic beauty. Under a climate change scenario of increased average surface temperature and elevated CO_2 levels, oak-hickory and oak-pine forest types are projected to expand according to some models (Iverson and Prasad 2001, Iverson et al. 2008b). Therefore, oaks are likely to make an important contribution to CO_2 sequestration by serving as carbon sinks through biomass accretion.

Study Justification and Research Approach

Because of the aforementioned values intrinsic to oak forests, studies involving regeneration strategies are numerous and often targeted at land managers. Specifically, silvicultural techniques employing varying cutting regimes or prescribed burns have added to the ever-growing literature of oak regeneration successes and failures (Hill and Dickmann 1988, Loftis 1990, Brose et al. 1999). Most of these studies involved experiments in which one or several variables believed to influence oak regeneration were manipulated at a specific site. Though useful, it is difficult, if not imprudent, to apply techniques that were deemed successful at one ecosystem type to another with a different suite of biotic and abiotic properties. Abrams (1992, 1996, 2002, and 2005) has provided excellent reviews of oak forest development, disturbance-dependent regeneration, and projected succession for most eastern states. Additionally, symposia have been convened to compile and disseminate recent findings and facilitate partnerships among experts (Loftis and McGee 1993, Dickinson 2006). In Michigan, information is available pertaining to pre-European settlement vegetation composition and disturbance regimes (Whitney 1987, Frelich 1995, Leahy and Pregitzer 2003, Cleland et al. 2004); landscape ecosystem classification (Archambault et al. 1989, Archambault et al. 1990); reproduction and succession as influenced by management and ecological factors (Host et al. 1987, Hill and Dickmann 1988, Abrams and Scott 1989, Hartman et al. 2005); and general management guidelines (Botti and Mech 2000).

Currently, a comprehensive evaluation of Michigan's dry and dry-mesic oak forest ecosystems does not exist that incorporates both ecological attributes and forestry practices to explain the paucity of oak regeneration. Lower Michigan's forested public lands are mostly contained within state game areas, state recreation areas and parks, state forests, and national forests. Boundaries delineating each area are usually political and seldom consider ecological contiguity. Unfortunately, managers are typically confined to the management area over which they have jurisdiction when making decisions. When the same ecosystem type crosses disparate management units, communication among managers is necessary to ensure that the goals for that ecosystem are achieved uniformly and consistently. Even within a state forest management unit, land is further divided into arbitrary compartments for ease of mapping and inventory. To properly address the lack of oak regeneration, it is useful to examine the problem at the landscape scale rather than within the confines of site-level boundaries. A clear understanding of the variability of forested oak ecosystems throughout Lower Michigan is therefore necessary. Acknowledging the differences regarding landform, soil type, drainage, disturbance history, and competing vegetation will form the foundation upon which management techniques may be applied to best promote oak regeneration. The overarching goal of this study is to document the current status of oak regeneration in ecologically defined landform units and, where regeneration is present, to elucidate its dependency on the interaction among ecosystem factors and forestry practices. Dissemination of this knowledge can help foster ecosystem management across jurisdictional boundaries and tailor planning efforts that best reflect ecological landscapes.

Objectives

The specific objectives of this study are as follows:

1) document composition and abundance of overstory, understory, and groundcover species in recently managed (i.e., within approximately 30 years) and unmanaged oak-dominated dry and dry-mesic forests stratified across ecologically defined regions in southern and northern Lower Michigan.

2) measure ecological properties in these forests such as soil exchangeable cations, canopy closure, percent slope, aspect, deer browse, and other vegetation characteristics.

3) relate findings from Objectives 1 and 2 to that of recent silvicultural and management activities to reveal the most salient variables influencing oak regeneration.

STUDY AREA

Region Overview

The study area is located within Region VI (Southern Lower Michigan) and Region VII (Northern Lower Michigan) under Albert's (1995) landscape ecosystem classification (Figures 1 and 2). The study was purposely restricted to the Lower Peninsula because the natural ranges of white oak and black oak do not commonly extend into the Upper Peninsula (Barnes and Wagner 2004). Sites were located on landforms that generally supported somewhat excessively-drained to excessively-drained soil and were stratified according to sub-subsections. However, sites were not evenly distributed among sub-subsections (Table 1a), landforms (Table 1b), or management areas (Table 1c).

In Region VI, elevation ranges from 175 to 390 m and is distinguished primarily from Region VII by the frequency with which warm southern and cold northern air masses cross the region, average positions of air mass boundaries, and latitude (Albert 1995). Compared to Region VII, Region VI has more warm humid air masses from the Gulf of Mexico and fewer cold dry air masses of continental origin. Consequently, Region VI is warmer throughout the year, has a longer and less variable growing season, and has a lower heat sum prior to last spring freeze (i.e., less danger of experiencing late spring freeze damage for plants). Additionally, Region VI has higher potential evapotranspiration and precipitation, and the ratio between these factors is also higher. More solar radiation strikes Region VI than Region VII, and snowfall is lower as well. Within the region, however, there is markedly less climatic variation than the northerly regions. Soil types in Region VI are mostly derived from underlying limestone, shale, and sandstone and are typically calcareous and loamy alfisols. Oak savanna and oak-hickory forests were likely the most prevalent pre-European settlement vegetation communities (Comer et al. 1995).

In Region VII, elevation ranges from 177 to 526 m, and cold, continental air masses from the north strongly influence the highly variable climate (Albert 1995). Late spring freezes impact many plants growing in Region VII as does the shorter growing season compared to Region VI. A greater proportion of precipitation falls as snow than in Region VI, and because of cooler temperatures, the ratio of potential evapotranspiration and precipitation is lower. The region is highly modified by Lake Michigan, especially on its western edge. Though bedrock is similar to that of Region VI, the combination of cool temperatures and high leaching of sandy, outwash-derived soil has caused formation of acidic spodosols. The most common pre-European settlement upland vegetation communities listed in order of increasing soil moisture and decreasing fire frequency were jack pine (*Pinus banksiana*) forests, eastern white pine-red pine (*Pinus resinosa*) forests, and northern hardwood forests (Comer et al. 1995).

Landform and Sub-Subsection Overview

The sub-subsections represent the finest scale of ecosystem distinction at the regional ecosystem level (Figure 3). In Michigan, terrestrial ecosystem classification has proceeded from the top down, delineating the most inclusive regional ecosystems and progressing downward to finer-scale physiographic systems, landform-level ecosystems, and landscape ecosystem types (Spies and Barnes 1985, Albert et al. 1986, Zogg and Barnes 1995). Every attempt was made to locate sites in all sub-subsections where oak forests are ubiquitous because within a particular sub-subsection, climate and geology are fairly uniform. Furthermore, they are generally dominated by one specific landform feature. In both Region VI and VII, the landforms that typified oak-dominated forests were ice-contact terrain (e.g., kames), moraine (e.g., end and ground), outwash (e.g., plains and channels), and lake plain (e.g., sand, sand-over-clay, and clay lake plains and sand dune features).

Ice-Contact Terrain

Ice-contact features are common in sub-subsections VI.1.3 (Jackson Interlobate) and VII.2.2 (Grayling Outwash Plain) (Albert 1995). In southern Michigan, kames are the most prominent landforms that support oak-hickory forests. They are relatively steep, high-relief features that often occur along with ice-contact features such as depressional kettle swamps and lakes. Parent material consists of coarse-textured, poorly-sorted sandy loam and gravel (Appendix 1a). Pinckney-Waterloo State Recreation Area (SRA) occurs in sub-subsection VI.1.3 and consists of large tracts of oak- and oak-hickory–dominated forests. In northern Michigan ice-contact terrain typically takes the form of irregular ridges juxtaposed by flat outwash expanses or pitted outwash (i.e., ice block-derived kames interspersed throughout a larger outwash plain). Glacial meltwater streams have steeply dissected these ridges, and the unsorted parent material has given rise to sandy soil mixed with gravel (Appendix 1b). The Grayling and Roscommon State Forest Management Units (FMU) occur in sub-subsection VII.2.2 and consist of large tracts of oak- and oak-pine–dominated forests.

Moraine

Dry-mesic and dry oak forests, when occurring on moraine, typically occur on rolling or steep coarse end moraines and are common in sub-subsections VI.2.2 (Cassopolis Ice-Contact Ridges), VI.3.1 (Berrien Springs), VI.5.2 (Lum Interlobate), VII.2.1 (Cadillac), and VII.2.3 (Vanderbilt Moraines) (Albert 1995). In southern Michigan, the end moraines often form steep narrow bands that abut poorly drained outwash deposits with kettle lakes. Parent material consists of unsorted sandy loam to gravelly sand (Appendix 1a). Barry State Game Area (SGA), Allegan SGA, and Lapeer SGA occur in sub-subsections VI.2.2, VI.3.1, and VI.5.2, respectively, and consist of oak- and oak-hickory–dominated forests. In northern Michigan, steep sandy end moraine ridges occur, but they less commonly abut wetlands due to thick till deposits between ridges. Parent material is largely devoid of clay deposits, and well-drained loamy sand to excessively-drained sand is common (Appendix 1b). The Cadillac and Atlanta FMUs occur in sub-subsections VI.2.1 and VII.2.3, respectively, and consist mostly of northern red oak–dominated forests.

Outwash

Some of the driest oak ecosystems occur on flat outwash, and they can be found commonly in sub-subsections VI.1.3 (Jackson Interlobate) and VI.2.1 (Battle Creek Outwash Plain) and subsection VII.3 (Newaygo Outwash Plain) (Albert 1995). In southern Michigan, flat outwash surrounds end and ground moraines or extends outward from the base of ice-contact kames. Lakes and wetlands often occupy the ice-block kettles and outwash channels. Parent material consists of well-sorted loamy sand to sand (Appendix 1a). Pinckney-Waterloo SRA and Fort Custer SRA occur in sub-subsections VI.1.3 and VI.2.1, respectively, and consist of oak- and oak-hickory–dominated forests. The most dry-tolerant oak species, northern pin oak, is encountered frequently on the sandiest outwash soil. In northern Michigan, outwash plains are pitted with ice-block depressions causing localized frost pockets. Scattered lakes and wetlands also occupy these depressions. Parent material consists of well-sorted sand (Appendix 1b). Huron-Manistee National Forest (NF) occurs in subsection VII.3 and consists of oak- and oak-pine-dominated forests.

Lake Plain

Oak forests that develop on lake plain are some of the flattest and driest forested ecosystems in Michigan. They can be found commonly in sub-subsections VI.1.1 (Maumee Lake Plain), VI.3.2 (Southern Lake Michigan Lake Plain), VI.5.1 (Sandusky Lake Plain), VII.1.1 (Standish), and subsection VI.6 (Saginaw Bay Lake Plain) (Albert 1995). In southern Michigan, oak forests are most common on sand lake plain and sand-over-clay lake plain but are encountered less frequently on clay lake plain due to a perched water table that results in a prolonged period of inundation during spring. In the otherwise undistinguishable topography of a flat landscape, oak forests are imperceptibly elevated above adjacent wetlands, such as coastal plain marshes, wet prairies, wet meadows, emergent marshes, and lowland swamps. A slight rise or thicker deposit of lacustrine sand can determine the development of upland versus wetland vegetation. On the sand lake plain, parent material is sorted fine sand without a coarse fraction. On the clay lake plain, clay forms the parent material and, when overlain with sand through past wave action, it forms sand-over-clay lake plain. Additionally, some sites occur on parent material derived from dune sands, where topographic relief is greater than elsewhere on the lake plain (Appendix 1a). Oakwoods Metropark and Algonac SGA occur in sub-subsection VI.1.1 on clay lake plain and sand-over-clay lake plain; Allegan SGA occurs in VI.3.2 on sand lake plain; Port Huron SGA and Rush Lake SGA occur in VI.5.1 on sand-over-clay lake plain and sand dune, respectively; and Bay City SRA occurs in VI.6 on sand dune. Forests are nearly always white and black oak–dominated. In northern Michigan, oak forests occur on wide expanses of sand lake plain. Hardwood and hardwood-conifer swamps are situated in lower areas and together with upland oak forests, created a landscape mosaic. Parent material is sorted sand with a general lack of coarse fraction (Appendix 1b). Gladwin FMU and Huron-Manistee NF occur in sub-subsection VII.1.1 and consist of oak- and oak-pine–dominated forests.

METHODS

Field Procedures

Site Selection

Site selection and field reconnaissance of Lower Michigan oak forests took place from March to June 2006, October to November 2006, and April to June 2007. The overarching goal of selecting sites was to encompass varying landform-level ecosystems across a broad regional area of southern and northern Lower Michigan. Differences in soil texture, moisture and nutrient availability, and topographical aspect and slope were of great interest. Furthermore, variations regarding floristic diversity, stand basal area, canopy closure, and historic and current disturbance regimes were also considered important. Within similar ecosystems, it was ideal to find both managed and unmanaged stands. Most managed stands had previously received some type of cutting treatment (e.g., selection, thinning, shelterwood, or clearcut) or prescribed burn. Stands with well-documented management records were deemed to have highest sampling priority. Stands that occupied large, contiguous areas of intact oak forest, exhibited a low occurrence of invasive species, and had not experienced very recent catastrophic disturbances were preferred. Unmanaged stands chosen for sampling had intact overstory canopies and had not been subjected to recent large-scale cutting (e.g., overstory removal). Every effort was made to assure that these stands were unmanaged as far back in time as possible. For some unmanaged stands, however, only a 10-year interval from date of sampling can be confidently assumed. The most common overstory tree species among all sites were black oak, white oak, northern red oak, red maple, bigtooth aspen (*Populus grandidentata*), black cherry (*Prunus serotina*), sassafras (*Sassafras albidum*), red pine, eastern white pine, pignut hickory (*Carya glabra*), and northern pin oak.

Vital in the process of site selection was aid from DNR Wildlife Division (WD), DNR Forest, Mineral, and Fire Management Division (FMFMD), DNR Parks and Recreation Division (PRD), MNFI, and U.S. Forest Service (USFS). They provided great assistance in finding management records and suggestions for visiting appropriate oak stands. When necessary, remote site selection was facilitated by GIS applications in which current IFMAP land cover data (MDNR 2001) was compared to circa 1800 land cover data generated from GLO records (Comer et al. 1995). Areas that were typed as oak-dominated forests in both the GLO and IFMAP land cover data sets were further investigated on the ground during field reconnaissance.

Plot Establishment

Plot establishment and field data collection took place from June to September 2006 and 2007 with a four-person crew. Systematic sampling with a random starting point was used for this study. Sampling units for each site consisted of 10 circular plots systematically distributed along a transect placed to capture the standard condition of the ecosystem. Distance to the first plot along each transect was randomly chosen, and all subsequent plots were located 30 m from the center of the previous plot along the azimuth selected for the transect. Relative homogeneity of dominant overstory trees, shrubs, and ground cover typified the transect, and certain anthropogenic disturbances such as roads, trails, and weedy patches were avoided (Mueller-Dombois and Ellenberg 1974). The transect was usually a unidirectional straight line, but, under some circumstances, it was rerouted away from undesirable features (e.g., roads and trails). Within each site (i.e., forest stand) plots captured a single ecosystem type within a uniformly-managed area.

Vegetation Sampling

Each plot consisted of an outer ring measuring 200 m^2 in which all overstory woody plants ($\geq$ 9.1 cm dbh) were identified, counted, and measured for diameter at breast height (dbh) (Figure 4). In a nested inner ring measuring 50 m^2, all understory woody plants ($\geq$1.5 cm dbh and <9.1 cm dbh) were identified, counted, and measured for dbh. Canopy closure was estimated at the plot's center using a spherical densiometer. In both overstory and understory plots, both live and dead stems were measured but recorded separately. Additionally, stems of multiple-stemmed clones (i.e., sprouts) were measured as individuals, provided they satisfied the dbh size criterion for the overstory or understory plot, but the number of stems for each clone was recorded. A clone is defined as an individual with a single stem measured at dbh or an aggregate of multiple stems of the same genotype sharing a common root system. A stem, whether single-stemmed or multiple-stemmed, was counted and measured only if half or more of its trunk was contained within the plot. Lastly, representative trees of distinct cohorts in both the overstory and understory strata were cored at dbh or clipped approximated 10 cm from the ground for aging purposes. Dominant trees of each species, especially oaks and red maple, were always cored, and clippings using a lopper were taken for young tree saplings, when present. The number of stems cored or clipped was not based on random sampling but instead aimed at constructing a suitable compilation of tree age classes for the purpose of successional forecasting of a site. Rings were counted in the field, when possible, and core samples were stored in straws and placed in paper bags. To verify field counts in the lab, some cores were smoothed with sandpaper, sprayed with water, and viewed under a dissecting microscope.

In a 4 m^2 strip plot placed north from the plot's center (Figure 4), all woody species were counted and categorized by height class and evidence of deer browse. Each woody species was categorized as either browsed or unbrowsed by deer according to visual evidence and recorded in one of eight height classes: (1) 0-25 cm, (2) 26-50 cm, (3) 51-100 cm, (4) 101-150 cm, (5) 151-200 cm, (6) 201-250 cm, (7) 251-300 cm, and (8) 300 cm and greater. Browse evidence by other mammals was ignored. Distinguishing among black oak, northern pin oak, and northern red oak seedlings was difficult, and, therefore, they were assumed to reflect the oak overstory composition. When the overstory demonstrated an approximate equal mix of these species (a rare occurrence), seedling designation was assigned to the nearest overstory oak species.

Two 1 m^2 groundcover plots were placed 8 meters from plot center on opposite sides of a north-south–oriented bisecting line (Figure 4). Ground cover was defined to be any stem less than 1.5 cm dbh regardless of its height. A 10 cm^2 sampling frame was used to determine coverage classes based on the number of frames occupied by each species. Each frame of occupancy corresponds to 0.1% of the total groundcover plot area. Percent coverage for each groundcover species (e.g., ferns, forbs, graminoids, and woody plants) was then estimated on a modified octave scale based on these coverage classes (Lapin and Barnes 1995). Each coverage class represents a range of percent plot coverage as follows: (1) trace-0.005, (2) 0.005-0.01, (3) 0.01-0.1, (4) 0.1-0.5, (5) 0.5-1, (6) 1-2, (7) 2-4, (8) 4-8, (9) 8-16, (10) 16-32, (11) 32-64, and (12) 64-100. Coverages of mosses, lichen, litter, coarse woody debris (fallen wood measuring at least 9.1 cm across), and bare mineral soil were similarly estimated. However, no attempt was made to distinguish the various species of mosses or lichen.

Physiography and Soil Description

To provide fine-scale physiographic context, slope percent, slope position, and aspect were recorded at the center of all plots. Five soil samples were collected to a depth of 10 cm using a soil punch with a 2.54 cm opening diameter. Each sample was taken from a random distance and azimuth from the plot center and combined for lab analysis by Michigan State University's Crop and Soil Science Laboratory. A qualitative description of the ecosystem's overall edaphic environment was accomplished through excavation of a soil pit at the sixth plot along the transect. Because transects encompassed a rather homogeneous area within a single ecosystem, one soil pit was believed to be sufficient to describe general soil conditions of the entire site. Dimensions of the soil pit usually measured 1 m deep and 0.50 m wide. However, ultimate depth was often shallower due to the presence of coarse material such as cobbles or cemented clay horizons. Properties that were noted include litter depth, delineation of soil horizons and thickness, texture, color, pH, depth of coarse and fine rooting, and presence of mottling and coarse fraction. Acidity was estimated for each layer using a color-indicating Orbeco-Hellige Truog soil reaction (pH) tester.

Data Analyses

At the onset of this study, the intended unit of data summary was the sub-subsection (Table 1a), and sites would form the replicates in which various variables would be averaged within a sub-subsection. However, upon recognizing the low and unbalanced number of sites distributed among 17 sub-subsections in 2 different regions, it was deemed more prudent to group sites among landforms within each region. Therefore, each site is simply recognized as belonging to ice-contact terrain, moraine, outwash, or lake plain in either the south or north region. This condensed grouping is believed to be justified for the purpose of characterizing dry and dry-mesic oak-dominated forests and for evaluating oak regeneration; this simplification, however, may not be appropriate if the goals are detailed ecosystem classification and mapping. The purpose of grouping sites, regardless of scale, is the belief that within-group variation of an attribute is less than the variation among sites from disparate groups. Consequently, field reconnaissance and personal observation affirmed that differences among oak forests were more pronounced when viewed by different landforms rather than different sub-subsections. Data is presented in four main groupings: 1) by north and south regions disregarding landform and management prescription, 2) by landform within each region disregarding management prescription, 3) by level of categorical deer abundance, and 4) by management prescription for each landform within a region.

For the first two groupings, between north and south regions and among landforms within each region, data is presented to address objectives 1 and 2. For these groupings, the following variables were considered: overstory and understory composition and abundance; groundcover composition and coverage; vegetation richness; seedling, sapling, and shrub abundance; height class distribution; percent deer browse; percent overstory and understory clonal sprouting; oak and red maple regeneration; physiographic measures; and soil exchangeable cation concentration. For most variables, plot data was averaged for each site to give one value and these collective site values formed the sample sizes for comparison between regions or among landforms within regions. Data was aggregated (i.e., not averaged) when reporting groundcover composition and species coverage and height class distributions.

For the third grouping, by level of categorical deer abundance, oak and red maple regeneration is compared among three nominal levels of deer abundance: low, medium, and high. Levels were categorized based on county-level antlered buck harvests provided by the DNR and averaged for the 2001 through 2006 hunting seasons. To standardize hunter effort and provide a surrogate measure of a county's deer density, the mean number of harvested antlered bucks was divided by the number of hunter-days (number of days all hunters collectively spent hunting). K-means clustering of three groups using Euclidean distance provided an initial categorization of the counties. Values were standardized by Z-score before running the clustering algorithm. Each county's categorical designation was then revised by expert opinion from Brian Frawley, DNR WD. A site within a particular county was assigned the same categorical level of deer abundance as the county.

For the fourth grouping, by management prescription for each landform within a region, data is presented to address objective 3. The focus of this analysis is oak and red maple regeneration and their relative abundances among different management prescriptions, but measures of soil, vegetation, and physiography are also provided. For each landform within a region, site averages were compared among varying categories of unmanaged, cut, burned, or both cut and burned sites. Twenty three sites were excluded in these comparisons to minimize within-prescription variation of sites due to intrinsic ecological properties (e.g., exclusion of a site with subsurface clay banding in an otherwise sandy lake plain landform). In many instances, a limited sample size of sites within a prescription category prevented further statistical comparison. In order to elucidate the effects of management at a more detailed scale, a subset of these selected sites was used for case studies for each landform within a region. Every effort was made to select sites that were as ecologically similar as possible but had different management prescriptions. Occasionally, sites exhibited both distinct ecological properties and management prescriptions. Depending on landform, between two to four sites were compared, and plots were used as the replicate samples. Data was aggregated (i.e., not averaged) when reporting height and age class distributions. For age class distributions, age estimates taken at dbh height (i.e., 1.5 m) were used for those samples collected from coring, and ground-line age was used for those collected from clippings. This was deemed acceptable because the primary interest was the relative relationship among varying age classes and not exact dates of growth events associated with suppression, release, or disturbance. Age class distributions are given for species groups, as defined in Table 2, when comparing among all sites within a landform of a region but only given for oaks and red maple when comparing among the subset of selected sites.

For some variables, clarification on their meaning and interpretation is necessary. Seedlings and saplings recorded in the 4 m^2 strip plot are defined as 1-150 cm tall (classes 1-4) and 151-300+ cm tall (classes 5-8), respectively. Shrub and tree designation of a woody species measured in the 4 m^2 strip plot follows the physiognomy given in Herman et al. (2001). Plant nomenclature also follows Herman et al. (2001). Percent slope is reported in negative values because the clinometer measured upslope and downslope as positive and negative, respectively. Small values (i.e., more negative) correspond to steep slopes. Aspect, though measured as an azimuth clockwise from north in the field, was transformed to reflect site productivity. For the purpose of inclusion as an independent variable in statistical models, aspect was transformed following the procedure of Beers et al. (1966):

$$A' = \cos(0.785398163397448 - A) + 1 \tag{1}$$

where A' is the transformed aspect and A is the azimuth in radians. A' ranges from 0.00 to 2.00. A northeast aspect (45 deg or 0.785398163397448 rad) is assigned the highest value of 2.00 and is assumed to be the most favorable for plant growth.

Statistical Analyses

Assumption Verification and Data Transformation

All statistical analyses were performed using SYSTAT version 12.0 (SYSTAT 2007). Due to the sampling design, data from each group was obtained independently and randomly. Assumptions of normality and homoscedasticity were verified visually with dot density (dit) histograms and box plots, respectively. For parametric statistical analyses that require satisfying the assumption of normality, data transformations were commonly performed on data sets that were often right skewed. Reported values in tables, however, are in the non-transformed, original scale. The logarithmic transformation for non-zero variables is as follows:

$$X' = \log_{10}(X) \tag{2a}$$

where X' is the transformed value, and X is the original value. For variables containing zeroes, the following transformation was used:

$$X' = \log_{10} (X + 1) \quad (2b)$$

The following arcsine transformation was usually applied to percent canopy closure because of its appropriateness for variables measured as percentages or proportions (Zar 1999):

$$p' = \arcsin \sqrt{(p)} \quad (3)$$

where p' is the transformed value in radians, and p is the original proportion from 0 to 1.

Univariate Statistics

Two-sample independent t-tests and single-factor analysis of variance (ANOVA) were applied for most comparisons between regions, among landforms, among categories of deer abundance, or among management prescriptions. A two-tailed test was employed to test whether two groups were equal with respect to the variable under consideration. A paired t-test was employed for testing whether oak and red maple stem densities were equal within a group. For ANOVA, the test merely indicated a significant difference of at least one group from another, if present. Tukey's HSD was employed to uncover pairwise differences when ANOVA indicated significance. Significance was set at $\alpha = 0.05$ in most instances for both t-tests and ANOVA. Groups were reported to be significantly different at $\alpha = 0.10$ when particular variables and situations indicated ecological interest.

Analogous non-parametric tests, the Mann-Whitney and Kruskal-Wallis, were used in place of the t-test and ANOVA, respectively, when transformations failed to satisfy the assumption of normality. These tests were most commonly employed when the data set exhibited a disproportionate number of zero values. A Tukey-type multiple comparison, the Nemenyi test, uncovered pairwise differences when Kruskal-Wallis indicated significance (Zar 1999); calculations were adjusted for tied ranks and unequal sample sizes.

Multivariate Statistics

Throughout this report, regeneration refers to individuals or populations of juvenile trees rather than the ecological process of seed production, dispersal, germination, and establishment. Advanced regeneration can be defined as saplings and seedlings of the forest understory that accelerate growth when released by disturbance (Barnes et al. 1998). A pre-existing pool of these juveniles, whether of seedling or clonal sprout origin, is generally assumed to be vital if future replacement of the parent overstory is desired (Johnson et al. 2002). For the current study, oak and red maple regeneration is equivalent to their respective understory stem densities (stems ha^{-1}). Seedling (1-150 cm tall) and sapling (151-300+ cm tall) abundance (stems per 4 m^2 plot) are secondarily important when evaluating a site's regeneration potential for a targeted species.

To further explore objective 3, logistic regression was selected to best model the effects of multiple independent variables on oak regeneration. Multiple linear regression was determined to be inappropriate because of the preponderance of sites that lacked any oak regeneration, thus causing an inflated-zero distribution for the dependent variable. With logistic regression, no assumption of normality is necessary, and the distribution of the dichotomous dependent variable is sigmoidal and takes on only two values, 0 or 1 (i.e., absence or presence). Consequently, oak regeneration measured as a continuous variable in stems ha^{-1} must be coded as 0 or 1 for each site.

Instead of conceptualizing oak regeneration as absent or present, however, it is best to think of it as unsuccessful or successful based on initial conditions and site potential. A decision rule or cutoff value based on the values of the continuous variable (i.e., understory stem density of oak species) served as a first approximation for deciding whether oak regeneration at a site was unsuccessful (0) or successful (1). Any site that averaged ≥ 691.9 stems ha^{-1} of oak understory stem density was automatically classified as successful (Matt Sands, USFS, personal communication, June 5, 2007). This cutoff value represents an estimated silvicultural criterion for perpetuating a closed-canopy oak forest, and comparable numbers can be found in Johnson et al. (2002). A lower understory stem density would be expected for management of more open-canopied oak woodland or savanna communities. Thirteen sites were chosen by this first approximation (i.e., 691.9 stems ha^{-1} cutoff), and an additional 22 were added for a total of 35 sites identified as being likely to promote successful oak regeneration. The process of including an additional 22 sites was accomplished objectively by evaluating stem densities of oak seedlings and saplings and subjectively by personal observations in the field accounting for overstory canopy closure, understory and groundcover competition, and soil drainage class. Thirteen sites, all categorized as unsuccessful, were excluded from the logistic regression model because management activity was too recent to have a measurable effect on oak regeneration; management history was not completely known; or sites exhibited very different soil properties from the majority of sites in a landform category (e.g., exclusion of clay lake plain sites from the generalized lake plain landform).

Several logistic regression models were constructed using the most ecologically salient variables believed to explain oak regeneration success. These models included different variable combinations as subsets of the 11 variable, 14 parameter global model. Ten logistic regression models were considered, but two were selected to best explain and predict oak regeneration success. Final model selection was based on Akaike information criterion (AIC) of the ten models and their relative Akaike weights, w_i (Burnham and Anderson 2004). Parameter significance, model significance, goodness-of-fit, and classification success were used to describe the final models. Interpretation of parameters and their effects on oak regeneration success was accomplished with odds ratios (Hosmer and Lemeshow 2000).

Continuous variables selected in the above logistic regression models were then used in discriminant analysis of landforms within each region. The same 92 sites used in logistic regression were used in the discriminant analysis. Additional variables were also added to the discriminant analysis and selected by an automated, backward elimination procedure with a probability of 0.15 to remove (Table 3). The relationship among landforms was depicted in ordination space along the first two canonical variates. To aid interpretation, Pearson product-moment correlations were computed between input variables and canonical variates (Spies and Barnes 1985). Such correlations are necessary because canonical coefficients may not be representative of the true weight of the input variables on the canonical variate (Williams 1981).

RESULTS AND DISCUSSION

The following results are presented according to the four groupings outlined in the methods: 1) by north and south regions disregarding landform and management prescription, 2) by landform within each region disregarding management prescription, 3) by level of categorical deer abundance, and 4) by management prescription for each landform within a region. The format is intended to mirror that of a reference manual, and, therefore, each section may be read independently of the others. Furthermore, managers who wish to see example comparisons of study sites under the fourth grouping (by management prescription for each landform within a region) that are applicable to forested oak ecosystems they manage may turn to the appropriate region and landform in this section. Following the fourth grouping, results from multivariate logistic regression and discriminant analysis are presented to succinctly summarize the major factors influencing oak regeneration and the primary ecosystem characteristics distinguishing landforms within each region, respectively.

Grouping 1 – By North and South Regions

Vegetation Abundance, Sprouting, and Regeneration

In the overstory, black oak was dominant in the south and northern red oak was dominant in the north (Table 4). Northern red oak, a species usually common in more mesic settings in the south occurring with American beech (*Fagus grandifolia*), sugar maple, and basswood (*Tilia americana*), tends to be a dry-mesic species in the north occurring with red pine and eastern white pine. Species conspicuously absent from the north but present in the south were pignut hickory, shagbark hickory (*Carya ovata*), and bitternut hickory (*C. cordiformis*). Northern pin oak, red pine, eastern white pine, and jack pine were more frequent in the north than the south. Average dbh of red maple in the south (16.6 cm) and north (14.1 cm) was considerably less than that of most oak species (> 30.0 cm), suggesting that red maple formed the leading sub-dominant overstory stratum. Though not as dominant as oaks, red maple relative densities in the south (22.8%) and north (19.5%) were comparable to those of white oak (16.0% and 16.3%, respectively). Average canopy closure and total basal area in the south (92.19% and 26.8 m^2 ha^{-1}, respectively) was significantly greater than the north (75.36% and 18.7 m^2 ha^{-1}, respectively), and overstory richness averaged one species more in the south (3.06 species) than the north (2.01 species) (Table 5). The disparity in regional overstory canopy closure and basal area was likely due to greater historical logging and wildfire events and current forest management practices in the north compared to the south. Further supporting this evidence was the significantly greater percentage of overstory stem sprouting in the north than the south for all species, oaks, and red maple (Table 6). In fact, sprouting was consistently nearly twice as great in the north as the south for these groups. Of note was the greater sprouting percentage of red maple than oaks in both regions (19.68% red maple stems compared to 14.01% oak stems in the south and 40.91% red maple stems compared to 31.75% oak stems in the north).

In the understory, red maple was dominant in both the south and north (Table 7). Red maple relative dominance in the south (29.8%) and north (32.4%) were more than twice as great as white oak in these regions (14.6% and 14.8%, respectively). Average dbh of red maple in the understory, unlike the overstory, was comparable to oak species in both the south (4.3 cm) and north (3.4 cm) regions. Flowering dogwood (*Cornus florida*), pignut hickory, and bitternut hickory were present in the south but not the north, and pine species made up a greater proportion of the understory in the north than the south. Average total stem density in the north (1875.2 stems ha^{-1}) was significantly greater than the south (1320.8 stems ha^{-1}), but average understory richness was significantly greater in the south (2.15 species) than the north (1.62 species) (Table 5). Similar to the overstory, understory sprouting in the north was about twice as great as the south for all species, oaks, and red maple (Table 8). Again, this finding can be explained by greater past logging and fire events and current forest management practices of the north compared to the south. Unlike the overstory, red maple exhibited greater sprouting frequency than oaks only in the north (58.77% and 40.21%, respectively). In the south, sprouting percentage was approximately equal for red maple and oaks (19.63% and 19.60%, respectively). For regeneration, oak and red maple average stem densities were generally greater in the north than the south (Table 9a). When analyzed by oak species, however, the significance was only apparent for northern red oak, which is a species that does not occur as frequently in dry and dry-mesic forests in the south as the north. Oftentimes, absolute stem densities are not indicative of regeneration potential but should be viewed relative to stem densities of competitive species. Table 9b provides a direct comparison of oaks and its chief understory competitor, red maple, by subtracting the understory stem density of red maple from oaks. There was no significant difference from zero within each region and no significant difference when comparing values between regions. However, negative values in both regions (-49.81 stems ha^{-1} in the south and -216.54 stems ha^{-1} in the north) suggest a tendency for greater regeneration of red maple than oak.

In the ground cover, bracken fern (*Pteridium aquilinum*) exhibited greatest average coverage in both regions (Table 10a), whereas Pennsylvania sedge (*Carex pensylvanica*) exhibited greatest frequency (Table 10b). Both species can form dense carpets in the ground cover and Pennsylvania sedge has been reported to hinder oak and pine seedling germination (Abrams et al. 1985, Johnson 1992, Nielsen et al. 2003). The most distinctive compositional difference in the ground cover between regions was the prevalence of ericaceous shrub species in the north compared to the south. Though present in the south, wintergreen (*Gaultheria procumbens*), huckleberry (*Gaylussacia baccata*), low sweet blueberry (*Vaccinium angustifolium*), and Canada blueberry (*V. myrtilloides*) were more widespread in the north. Average richness was not significantly greater in south than the north (Table 5), but 242 species were found collectively among all groundcover subplots in the south compared to 156 species in the north

(Tables 10a, b). However, percent groundcover coverage was significantly greater in the north (31.69%) than the south (15.61%) (Table 5) due to the large abundance of bracken fern in the north.

Vegetation Height and Deer Browse

Height data recorded from the 4 m^2 strip plot indicates that the south and north regions had similar average oak, red maple, and tree sapling abundances (Table 11). Significantly greater average oak seedling, red maple seedling, and shrub abundances occurred in the north (7.96, 12.89, and 60.46, respectively) than the south (3.95, 3.70, and 18.12, respectively). The ericaceous species are designated as shrubs by Herman et al. (2001), and their prevalence in the north explains the regional disparity in shrub abundance. Wintergreen counts nearing 400 individual stems per plot were not uncommon.

Height class distributions for two physiognomic groups, shrubs and trees, show typical reverse J-curves from shortest to tallest height classes in both the south and north regions (Figures 5 and 6). Shrubs were a larger component of the 0-25 cm height class in the north (58%) than the south (32%). In general, the proportion of shrubs to trees decreased with height class, but this decrease was not realized in the south until the 201-250 cm height class, whereas it occurred at the 26-50 cm height class in the north. The dramatic decrease in the latter was due to size limitations of the abundant, low ericaceous shrubs. Height class distributions of oaks and red maple also show typical reverse J-curves in both regions (Figures 7 and 8). Red maple was a larger component of the 0-25 cm height class in the north (12%) than the south (9%). There was a greater proportion of oaks to red maple in most height classes in the south except for the 0-25 cm, 251-300 cm, and 300+ cm classes. Though not depicted graphically, these two species groups accounted for approximately 25% of woody plants recorded within each height class of the south. Consequently, the seemingly greater proportion of oaks to red maple may give a misleading conclusion that adequate oak regeneration was present. However, many other woody shrubs and trees that comprised the other 75% are also important oak competitors. In the north, only the 26-50 cm and 51-100 cm classes had a greater proportion of oaks to red maple. These two species groups in the north accounted for approximately 41% (not shown) of woody plants recorded within each height class. Red maple, therefore, may be the chief competitor to oaks in this region.

Evidence of deer browse was significantly an order of magnitude greater in the south than the north (Table 12). Percent of stems browsed for all species, oak species, and red maple was 13.58%, 12.93%, and 14.57%, respectively, in the south. In contrast, one percent or fewer stems in the north were browsed by deer. These findings are expected because of the north’s greater snowfall frequency and depth than the south (Albert et al. 1986). The colder temperatures and greater snow pack hampers winter foraging and reproductive fecundity. The greater browsing pressure in the south region, then, may have contributed to lower oak regeneration (Table 9a), oak and red maple seedling abundance (Table 11), and shrub abundance (Table 11) in the south region compared to the north region.

Soil and Physiography

Average soil pH and exchangeable cations were all significantly lower in the north than the south (Table 13), indicating less favorable edaphic conditions for growth in the north. Highly-leached sandy soil, a cooler average temperature, coniferous needle litter, and historical slash-induced fires in the north can explain these nutrient differences. Concentrations of P, K, and Mg were approximately twice as great in the south as the north, but Ca was three times as great (376.11 $\mu g\ g^{-1}$ and 128.04 $\mu g\ g^{-1}$, respectively).

No significant difference of aspect or percent slope was detected. Percent slope was -8.39% in the south and -6.76% in the north and represented averages among all landforms that encompassed the sometimes steep ice-contact kame and end moraine to the very flat outwash and lake plain.

Grouping 2 – By Landform

Vegetation Abundance, Sprouting, and Regeneration

Overstory

In all landforms of the south region, black oak was the dominant overstory species with a relative dominance that ranged from 37.5% on ice-contact terrain to 50.9% on the lake plain (Table 14). White oak, northern red oak, and red maple were the most common sub-dominants. Average dbh of red maple was consistently about half as large as oak species among all landforms, signaling likely changes in future overstory composition as red maple matures and oaks senesce. There were no significant differences between average overstory canopy closure (Table 15), total stem density, or total basal area among all southern landforms (Table 14). However, the lake plain averaged one fewer species (2.36 species) than the others (Table 15). Weak significant differences for percent overstory stem sprouting occurred only for all species combined between ice-contact and moraine (6.51% and 19.38%, respectively) and between ice-contact and outwash (6.51% and 17.34%, respectively) (Table 16).

In the north, the overstory was dominated by northern red oak on ice-contact and moraine landforms (59.1% and 61.7% relative dominance, respectively) (Table 14). However, outwash and lake plain landforms had greater dominance by black oak (35.6% and 24.5%, relative dominance respectively) than northern red oak (14.8% and 13.4%, relative dominance respectively). It should be noted that these two oak species are known to hybridize (Barnes and Wagner 2004), especially where their ranges cross near the southern part of the north region. Sites sampled on outwash (e.g., Newaygo County) and lake plain (e.g., Arenac County) represent the northernmost range of black oak, and the morphological characters of black oak begin to blur with northern red oak in these areas. White oak was co- or sub-dominant in all landforms of the north. On the lake plain, northern pin oak (24.1%, relative dominance) shared dominance with white oak (25.4%, relative dominance) and black oak (24.5%, relative dominance) but was not a major component in the overstory of other landforms. Red maple was most prevalent on ice-contact and moraine landforms with relative dominance values of 7.3% and 13.1%, respectively. Average overstory canopy closure was significantly lower on outwash (62.76%) and lake plain (63.92%) than on moraine (85.29%) (Table 15). Sites on outwash and lake plain were more intensively cut than sites on ice-contact terrain and moraine, but no significant differences were detected for average total stem density and basal area (Table 14), overstory richness (Table 15), and percent stem sprouting (Table 16) among all northern landforms.

Understory

In all landforms of the south region, with exception of the lake plain, red maple was the dominant understory species with a relative dominance that ranged from 17.2% on the lake plain to 42.0% on moraine (Table 17). Both white oak and black oak were well represented in the understory on outwash and lake plain, but only the lake plain exhibited greater oak than red maple dominance (31.6% for white oak and 17.2% for red maple, relative dominance respectively). Shrubs and small trees, such as witch-hazel (*Hamamelis virginiana*) and sassafras, appeared to be more common on ice-contact and moraine landforms. There were no significant differences concerning average total understory stem density (Table 17), basal area (Table 17), richness (Table 15), or percent understory stem sprouting (Table 18) among southern landforms. For regeneration of oak species and red maple, there were no significant differences of average understory stem densities among southern landforms (Table 19a). However, regeneration of all oak species collectively tended to be greatest on the lake plain (650.00 stems ha^{-1}) and least on ice-contact terrain (60.00 stems ha^{-1}). Conversely, red maple tended to be greatest on moraine (629.33 stems ha^{-1}) and least on the lake plain (190.00 stems ha^{-1}). The average difference between oak and red maple understory stem densities indicates significantly greater regeneration of red maple than oak on moraine (-548.00 stems ha^{-1}) (Table 19b). Though the average difference on lake plain (460.00 stems ha^{-1}) was significantly greater than on moraine, it was not significantly different from zero within the lake plain itself. Therefore, these results do not definitively indicate that regeneration of oak was significantly greater than red maple on the lake plain.

In the north, oak species represented at least one of five most dominant species in each of the four landforms (Table 17). Again, black oak was primarily restricted to the most southerly northern landforms, namely on outwash and lake plain. Red maple relative dominance ranged from 21.1% on the lake plain to 39.5% on moraine, and only on outwash did white oak exhibit dominance over red maple (45.8% and

22.0%, respectively). Interestingly, eastern white pine was the most dominant understory species on ice-contact terrain, suggesting a possible future reversion to a pine-hardwood–dominated forest. Average total understory stem density was significantly greater on moraine (2601.8 stems ha^{-1}) than on lake plain (637.8 stems ha^{-1}), but no significant differences were detected for average total understory basal area or richness among northern landforms (Table 15). Percent understory sprouting of red maple in the lake plain was significantly lower at 5.00% than the other three northern landforms (Table 18), but this finding was based on a small sample size (n = 5) and may not be widely applicable. For regeneration of oak species and red maple, significant differences among northern landforms occurred for all oak species collectively, black oak-northern pin oak, and red maple, with weaker significance for northern red oak (Table 19a). In general, oak regeneration on outwash (1327.56 stems ha^{-1}) was significantly greater than on moraine (242.73 stems ha^{-1}), and red maple regeneration on moraine (1058.18 stems ha^{-1}) was significantly greater than on either outwash (379.56 stems ha^{-1}) or lake plain (106.67 stems ha^{-1}). The average difference between oak and red maple understory stem densities indicates significantly greater regeneration of oak than red maple on outwash (948.00 stems ha^{-1}, at $\alpha = 0.10$) but significantly greater regeneration of red maple than oak on ice-contact terrain (-332.73 stems ha^{-1}, at $\alpha = 0.05$) and moraine (-815.46 stems ha^{-1}, at $\alpha = 0.05$) (Table 19b). Among landforms, the average difference on outwash was significantly greater than on either ice-contact terrain or moraine.

Ground Cover

Groundcover species in the southern landforms typified dry and dry-mesic oak forests (Tables 20a, b). Arranged by average coverage, bracken fern was most abundant on moraine and lake plain, whereas mapleleaf viburnum (*Viburnum acerifolium*) and sassafras were most abundant on ice-contact terrain and outwash, respectively (Table 20a). Sassafras appeared to be most consistently represented by being one of five species with the highest average coverage in three of the four landforms. However, red maple was the most frequently encountered species on ice-contact, moraine, and outwash landforms (Table 20b) but was uncommon on the lake plain where upland sites had little proximity or influence by more mesic ecosystems. Other frequently occurring species included Pennsylvania sedge, clustered-leaved tick-trefoil (*Desmodium glutinosum*), and black cherry. Each of these species was one of five most frequently encountered species in three of four landforms. There was no significant difference in species richness among southern landforms, but percent coverage on lake plain (20.59%) was significantly greater than on moraine (10.94%) (Table 15).

Dominant groundcover species in the north region included bracken fern, Pennsylvania sedge, and low sweet blueberry (Tables 20a, b). Each of these species was one of four species with the highest average coverage and frequency in all northern landforms. On outwash, white and black oak accounted for one of five species with the highest average coverage and frequency. Red maple was most frequently encountered on moraine but was also common on ice-contact terrain and lake plain (Table 20b). There were no significant differences of species richness or percent coverage among northern landforms (Table 15).

Vegetation Height and Deer Browse

Height data recorded from the 4 m^2 strip plot indicates few vegetation differences among southern landforms (Table 21). Average seedling and sapling abundance of oak species, red maple, and trees were comparable. The lake plain (29.81 stems), however, did have significantly greater average shrub abundance than moraine (6.89 stems) due to prevalence of ericaceous species on the lake plain. In contrast to the south, landforms of the north exhibited much greater among-group variation (Table 21). For example, there were significant differences among northern landforms for all height variables except oak saplings. A distinct pattern emerged when pair-wise comparisons were scrutinized following the initial multi-sample tests. In general, height variables between outwash and lake plain were not significantly different, but these two landforms were often significantly different from moraine for the same variables. The moraine typically had lower average abundances of oak seedlings and shrubs but higher average abundances of red maple and tree seedlings and saplings than either outwash or lake plain.

Exceptions include pair-wise comparisons between outwash and moraine for oak seedlings and shrubs, where differences were non-significant. The ice-contact landform exhibited intermediate qualities between moraine and outwash or lake plain. Most often, height variables for ice-contact terrain were not significantly different from the three other landforms. For some height variables, such as red maple and tree seedlings, ice-contact (19.42 and 24.36 stems, respectively) was more similar to moraine (18.39 and 27.23 stems, respectively) than either outwash (2.31 and 5.52 stems respectively) or lake plain (3.21 and 7.21 stems, respectively). For oak seedlings, however, ice-contact (11.01 stems) was more similar to outwash (8.90 stems) and lake plain (10.97 stems) than moraine (4.77 stems).

Height class distributions for oaks and red maple in the southern landforms show typical reverse J-curves from shortest to tallest height classes (Figures 9-12). Figure 10 suggests poor oak regeneration, relative to red maple, on moraine, as evidenced by greater relative abundance of red maple than oaks for all height classes. Figures 9 and 11 suggest approximately equal amounts of oak and red maple regeneration on ice-contact terrain and outwash for most height classes. Figure 12 suggests good oak regeneration, relative to red maple, on lake plain for all height classes. These results are consistent with the comparative regeneration measure (i.e., difference between oak and red maple understory stem densities) presented in Table 19b.

Height class distributions for oaks and red maple in the northern landforms also show typical reverse J-curves (Figures 13-16). With exception of the two height classes spanning 26-100 cm on ice-contact terrain (Figure 13), height class distributions suggest poor oak regeneration, relative to red maple, on ice-contact terrain and moraine (Figure 14). On outwash (Figure 15) and lake plain (Figure 16), however, oak relative abundance was greater than red maple for all height classes and suggests seemingly good oak regeneration on these two landforms. These results are again consistent with the comparative regeneration measure presented in Table 19b. It should be emphasized that the height class distribution and the comparative regeneration measure for the lake plain clearly exemplifies a bottleneck effect, whereby oak growth between seedling and sapling stages is severely limited relative to many non-oak species (Abrams and Downs 1990, Nowacki and Abrams 1992). Figure 16, then, indicates good oak seedling abundance, but the sharp decrease after the 101-150 cm height class and the low positive difference between oak and red maple understory stem densities (Table 19b) suggest, at best, only a moderate level of oak regeneration on the northern lake plain.

There were no significant differences among landforms in either south or north regions concerning percent of stems browsed for all species, oak species, and red maple (Table 22). Browse for all species ranged from 11.08% on southern outwash to 15.81% on southern moraine and 0.19% on northern outwash to 1.84% on northern moraine.

Soil and Physiography

Average soil pH and exchangeable cations in the southern landforms were generally highest on ice-contact terrain and lowest on lake plain, while moraine and outwash values were intermediate between the two (Table 23). Ice-contact soil typically had sandy loam to sandy clay loam Bt horizons within one meter of the surface and was more capable of adsorbing nutrient cations while resisting hydrogen ion leaching compared to the coarse-textured, sandy soil of the Allegan lake plain (Appendix 1a). As a result, average soil pH, K, Ca, and Mg concentrations on ice-contact were significantly greater than on lake plain. In the north, soil profiles among landforms were much more uniform than those found in the south (Appendix 1b). Sand to loamy sand soil comprised the majority of subsurface horizons, and average values for pH and exchangeable cations were comparable among northern landforms (Table 23). However, slightly greater average P (39.68 $\mu g\ g^{-1}$) and K (26.38 $\mu g\ g^{-1}$) concentrations were found on northern moraine soil, and these values were significantly different from those on the lake plain (12.55 and 20.97 $\mu g\ g^{-1}$, respectively).

No significant difference of aspect was detected among landforms in either south or north regions (Table 23). Ice-contact kames were the steepest landforms in the south with an average percent slope of -17.11%, while end moraine features were the steepest in the north with an average of -10.21%. With respect to topographic relief, ice-contact terrain and moraine were more similar to each other than they were to outwash or lake plain. Likewise, the generally flat landscapes of outwash and lake plain were often very similar.

Grouping 3 – By Deer Abundance

Among all sites included in this study, there was a positive relationship between observed percentage of stems browsed by deer and the category level of deer abundance (Table 24, Figures 17a-c). In general, higher deer abundance corresponded with a higher incidence of browsed stems. Percentage of all stems browsed ranged from 0.64% to 10.69% in sites categorized as having "low" and "high" deer abundance, respectively.

Inspection of oak and red maple regeneration as a function of deer abundance among all study sites does not indicate consistent trends (Table 25). While deer abundance does appear to influence oak and red maple seedling abundance, its effect on understory stem density and sapling abundance for these species was ambiguous. A negative relationship would be expected between average understory stem densities and deer abundance. This held true only for northern red oak and red maple when comparing between "low" and "medium" or between "low" and "high" levels. Average white and black oak-northern pin oak understory stem densities, however, were highest on sites classified as having "medium" deer abundance, though values were not significantly higher than sites with "high" deer abundance. Possible confounding factors, other than deer abundance alone, likely explain this discrepancy. Also, it may be more appropriate to condense both "medium" and "high" levels into one category, as regeneration of oak and red maple does not differ between these categories at the scale of the state. Deer density across the entire Lower Peninsula is higher than in previous eras, and regarding oak regeneration, counties categorized as "medium" may be functionally "high."

Investigating the effects regionally shows a more consistent pattern in the south region (Table 26). No southern counties in which sample sites were located were considered to have "low" deer abundance, and this may have contributed to the ambiguity relating deer abundance and overall oak regeneration throughout the Lower Peninsula (Table 25). In the south region, significantly higher average understory oak stem densities occurred in the "medium" sites for all oak species (598.10 stems ha^{-1}), white oak (443.81 stems ha^{-1}), and all oak saplings (0.42 stems per 4 m^2 plot) compared to "high" sites (92.50 stems ha^{-1}, 39.38 stems ha^{-1}, 0.12 stems per 4 m^2 plot, respectively). Average red maple understory stem density was not significantly different between categories, but average red maple seedling abundance was significantly greater in "high" sites (4.46 stems per 4 m^2 plot) than "medium" sites (2.54 stems per 4 m^2 plot).

In the north region, the relationship between regeneration and deer abundance appeared to be positive for most species (Table 27). Though average northern red oak understory stem density and red maple seedling abundance were highest on sites classified as having "low" deer abundance, average understory stem densities of all oak species, white oak, and black oak-northern pin oak were highest on sites with "high" deer abundance. These "high" sites were located in the southern half of the north region in Iosco, Montcalm, and Newaygo counties and thus accounted for the relatively high deer abundance. Additionally, 5 of 10 sites were located on very sandy outwash or lake plain landforms that often corresponded to good oak regeneration (*see* Grouping 2 – By Landform). Deer abundance alone, then, may not be an appropriate predictor for oak regeneration success since other factors, such as those that are landform-mediated, may exist. Even the decrease in northern red oak regeneration with increasing deer abundance must be interpreted with caution. Though there is a probable negative effect on oak regeneration caused by deer browsing, many "high" sites were dominated by black oak and not northern red oak. Therefore, the low understory stem density of northern red oak on "high" sites may reflect a natural geographic limitation in its distribution.

The effects of deer browse are known to be a limiting factor on oak regeneration success (Strole and Anderson 1992, Walters and Auchmoody 1993, Fredericksen 1998, MacDougall 2008), and evidence of its importance is shown in the south region of the current study. The inconsistent findings in the north region may be attributed to a scale mismatch of data. The categorical levels of deer abundance were derived from coarsely-scaled, county-level data, but its use was extended to the much finer-scaled site level. Because many factors influence local deer populations, a gross estimation of deer numbers by county may not reflect actual deer abundance at a site. Coupling data sets of differing scales is procedurally problematic. Still, this was the only viable option for relating some measure of deer browse pressure to oak regeneration. A simple linear regression of oak understory stem density on percent of stems browsed was not possible due to normality violation of both dependent and independent variables.

Grouping 4 – By Management Prescription: Example Case Studies

All Selected Sites Combined

Among the broad management categories of unmanaged, cut, burned, and both cut and burned, all vegetation variables showed significant differences at $\alpha = 0.10$ or $\alpha = 0.05$ (Table 28). Pairwise comparisons indicate that cut sites (i.e., encompassing clearcut, selection, shelterwood, and thinning) exhibited the greatest departure from unmanaged sites. Of 12 variables, only the following 3 were not significantly different between cut and unmanaged sites: understory species richness, understory basal area, and tree sapling abundance. As can be expected, cut sites had lower average canopy closure, overstory species richness, and overstory stem density and basal area but higher understory stem density and percent understory sprouting than unmanaged sites. The high average understory stem density (2831.04 stems ha^{-1}) and percent understory sprouting (61.72%) of cut sites compared to unmanaged sites (1073.51 stems ha^{-1} and 27.08%, respectively) is a natural response of the understory to disturbance and increased irradiance.

For burned-only sites, average values for many variables were between those of unmanaged and cut sites (Table 28), indicating that burning affected vegetation structure to a lesser degree than cutting but to a greater degree than non-management. For example, burned sites averaged 86.41% canopy closure compared to 92.96% and 74.50% for unmanaged and cut sites, respectively. Similarly, overstory basal area for burned sites averaged 23.34 m^2 ha^{-1} compared to 27.81 m^2 ha^{-1} and 15.35 m^2 ha^{-1} for unmanaged and cut sites, respectively.

The average values for variables of sites that were both cut and burned were comparable to cut-only sites. Due to the low sample size of the former ($n = 4$), however, pairwise differences were not usually detected when comparing between other management categories (Table 28). Exceptional variables included percent canopy closure (59.37%) and overstory basal area (11.60 m^2 ha^{-1}), which were lowest in cut and burned sites and significantly lower than unmanaged sites.

Higher average oak and red maple understory stem densities occurred on cut sites (758.52 and 995.85 stems ha^{-1}, respectively) than on unmanaged or burned sites (Table 29). Average red maple sapling abundance appeared to be highest on cut sites as well. Lowest average red maple understory stem density occurred on burned (96.36 stems ha^{-1}) and cut and burned (85.00 stems ha^{-1}) sites, though a significant difference was detected solely between the burned-only (96.36 stems ha^{-1}) and cut-only (995.85 stems ha^{-1}) pairwise comparison. The average difference between oak and red maple understory stem densities indicates significantly greater regeneration of red maple than oak for unmanaged sites (-245.41 stems ha^{-1}) (Table 30). A cut-only management prescription appears to favor red maple over oak regeneration, whereas a burn-only and cut and burn prescription appears to show the converse. However, these values were not significantly different from zero. Average oak and red maple understory stem density difference was significantly different (at $\alpha = 0.10$) among management categories. To summarize, a decision of non-management will likely result in greater regeneration of red maple than oak over time. Active management, whether through cutting, burning, or a combination of these two will yield varying results that cannot be predicted by management alone.

Appendix 2 displays age class distributions for oaks, pines, early-successional, mid-successional, and late-successional species groups among management prescriptions. Note the unimodal distribution for oaks under non-management and the bimodal distributions under a cutting or burning management regime. A peak occurring between 60 and 90 years for oak corresponds to release events resulting from two decades of widespread fire suppression from 1910 to 1930 (Hutchinson et al. 2008) and low deer abundance. For red maple, which is included in the mid-successional species group, peaks generally occur for age classes younger than 40 years.

Selected Southern Ice-Contact Sites

A broad comparison of oak and red maple regeneration and age class distributions for oaks, early-successional, mid-successional, and late-successional species groups for unmanaged and burned sites are given in Appendices 3a and 3b. Three ice-contact sites in Pinckney SRA were chosen for a more detailed case study (Table 31). These three sites were adjacent to one another and linearly situated between Crooked and Pickerel Lakes in Washtenaw County (NE S8 T1S R4E). Two sites, P-PICK and P-BURN, received a prescribed burn in 2001, while the third site, P-EO-E, remained unburned. P-PICK and P-BURN had coarser, sandier soil and flatter topographic relief than P-EO-E, which had more clay in the soil and was generally steeper (Table 31).

Of the three sites, P-PICK, exhibited the driest soil conditions and most open landscape that made it appear similar to a black oak barren. It occurred on top of a kame and had significantly lower average percent canopy closure (72.34%), overstory basal area (14.58 m^2 ha^{-1}), understory stem density (400.00 stems ha^{-1}), groundcover species richness (2.90), and shrub abundance (0.00) than P-BURN or P-EO-E (Table 31). Most strikingly, understory density was an order of magnitude less than P-BURN (1600.00 stems ha^{-1}) or P-EO-E (1340.00 stems ha^{-1}). Average soil pH and exchangeable cations, with exception of phosphorus, were generally low on the highly leached soil of P-PICK. For vegetation characteristics, P-BURN was very similar to P-EO-E, as the only significant difference was lower average groundcover species richness in the former site. Average soil pH and exchangeable cations, with exception of phosphorus, were significantly lower in P-BURN than P-EO-E. It is difficult to attribute differences in soil nutrient concentrations among sites to the effect of burning alone, since there are inherent soil differences associated with parent material and texture. However, Viro (1974) found that phosphorus, unlike other exchangeable cations, tended to be more abundant on the least fertile soil, and that leaching loss of phosphorus from the humus to lower mineral horizons occurred immediately after burning. Because soil samples from the current study were extricated from the first 10 cm of the soil, thus including the humus and upper mineral horizon, these findings may partially explain the elevated phosphorus concentration in the two burned sites, P-PICK and P-BURN, relative to the unburned site, P-EO-E. The more fertile soil and sandy clay loam soil texture of P-EO-E likely explains higher pH and K, Ca, and Mg concentrations compared to the other sites.

Only P-PICK exhibited successful oak regeneration (Table 32a). Specifically, black oak was the primary oak species at this site. Though P-BURN was similarly burned as P-PICK, oak regeneration was nonexistent, and the abundance of red maple understory stems and saplings was greatest among the three sites. The average difference between oak and red maple understory stem densities indicates significantly greater regeneration of oak than red maple for P-PICK only (Table 32b). For P-BURN and P-EO-E, in contrast, red maple regeneration was significantly greater than oak regeneration. Surprisingly, the degree in which regeneration of red maple was greater than oak was significantly greater in P-BURN than P-EO-E. This suggests that a single burn will have little effect on the dynamics of oak regeneration and that landscape factors, such as soil condition, may be more important. Nonetheless, prescribed burning does have ecological benefits beyond oak regeneration that include invasive species control, leaf litter reduction, and transient nutrient release into the soil with subsequent sequestration by vegetation (Viro 1974, Reich et al. 1990, Courteau et al. 2006). Appendices 3c and 3d display height and age class distributions for P-PICK, P-BURN, and P-EO-E.

Selected Southern Moraine Sites (Sandy Clay Loam Soil)

A broad comparison of oak and red maple regeneration and age class distributions for oaks, early-successional, mid-successional, and late-successional species groups for unmanaged and cut sites are given in Appendices 4a and 4b. Two sandy clay loam moraine sites were chosen for a more detailed case study (Table 33). S1-CUT was located in Barry SGA, Barry County (NE S1 T2N R10W) and experienced a partial shelterwood (i.e., overstory removal never completed) in 1989. An unmanaged site, 7L-3S, was located in Seven Lakes SP, Oakland County (NE S29 T5N R7E). Though these sites were a great distance away from each other with corresponding differences in climate and specific landform type (S1-CUT occurs on end moraine and 7L-3S occurs on ground moraine), soil texture and landscape context were similar. Both had sandy clay loam soil and occurred with inclusions of wet-mesic to wet ecosystem types. The transition from upland oak forest to adjacent wetland was more subtle in 7L-3S, where a slight relief change dramatically altered soil moisture conditions, than S1-CUT, where steep, kame-like hills were distinct from wetland depressions.

Though average overstory basal area of S1-CUT (14.30 m^2 ha^{-1}) was significantly less than 7L-3S (30.01 m^2 ha^{-1}), the difference between percent canopy closure of the two sites was not appreciably different; total canopy closure characterized both sites (approximately 98%) (Table 33). The most striking vegetation difference between S1-CUT and 7L-3S was the nearly three times greater average understory stem density of S1-CUT (4220.00 stems ha^{-1}) compared to 7L-3S (1580.00 stems ha^{-1}). Average soil pH and exchangeable cations were generally lower for S1-CUT than 7L-3S, and the significant difference of percent slope reflects the greater steepness of end moraine compared to ground moraine.

There was complete lack of oak regeneration in both sites (Table 34a). About 70% of the total understory stem density at S1-CUT was attributed to red maple regeneration (2960.00 stems ha^{-1}), and many of the red maple stems were of clonal sprout origin. The average difference between oak and red maple understory stem densities indicates significantly greater regeneration of red maple than oak for S1-CUT (Table 34b). This difference was not significantly different from zero for 7L-3S, which had considerable but significantly fewer understory stems of red maple (300.00 stems ha^{-1}) than S1-CUT. These two sites represent some of the most challenging ecological conditions for a land manager wishing to sustain future oak dominance. The pool of advanced oak regeneration was absent, oak seedling abundance was limited, and soil conditions were conducive to growth of mesophytic competition. Under such an ecological context, a simple thinning of the overstory results in heavy sprouting of existing red maple stems, as seen in S1-CUT. Though a decision of non-management, such as in 7L-3S, does not slow the invasion and in-growth of red maple, cutting without herbicide application or prescribed burning for understory control often results in sprouting and accelerated growth of red maple or other non-oak species. Appendices 4c and 4d display height and age class distributions for S1-CUT and 7L-3S.

Selected Southern Moraine Sites (Loamy Sand – Sandy Loam Soil)

A broad comparison of oak and red maple regeneration and age class distributions for oaks, early-successional, mid-successional, and late-successional species groups for unmanaged and managed sites are given in Appendices 5a and 5b. Two loamy sand moraine sites in Barry SGA, Barry County were chosen for a more detailed case study (Table 35). S24CC1 (SW S24 T3N R10W) experienced a clearcut between 1960 and 1970 followed by an arson fire a decade later. An unmanaged site, S19-1 (NW S19 T3N R9W), was located approximately 2 km northeast of S24CC1. Both sites occurred on moderately steep-sided end moraine hills without wetlands in proximity. S24CC1 had a slightly coarser soil texture of medium sand compared to S19-1, which had loamy sand.

Few notable differences, other than past disturbance and management, existed between the two sites (Table 35). Average percent canopy closure, though significantly different, was above 90% in both sites. Average overstory basal area was comparable, but average overstory stem density of S24CC1 was nearly twice that of S19-1. Soil exchangeable cations were nearly identical between sites with only slight differences detected for P (70.00 $\mu g\ g^{-1}$ for S24CC1 and 108.60 $\mu g\ g^{-1}$ for S19-1) and Mg (38.70 $\mu g\ g^{-1}$ for S24CC1 and 31.60 $\mu g\ g^{-1}$ for S19-1). S24CC1 had a slightly steeper slope (-13.90%) than S19-1 (-9.60%), and, combined with the slightly coarser soil texture, was likely more prone to droughty conditions.

Average understory stem density of oaks in S24CC1 appeared to indicate low to moderate regeneration (240.00 stems ha^{-1}) (Table 36a). However, when viewed on the ground, oak regeneration at this site was actually very good. Because the initial clearcut and arson fire occurred 30-40 years ago, many of the re-sprouting oaks had grown to the size of small overstory trees. Therefore, their numbers are reflected in overstory stem density rather than understory stem density (Table 35). In contrast, there was a complete lack of oak regeneration in S19-1 with correspondingly high red maple regeneration (700.00 stems ha^{-1}) (Table 36a). The average difference between oak and red maple understory stem densities indicates significantly greater regeneration of red maple than oak for S19-1 (Table 36b). Compared to S24CC1, S19-1 was located on lower slopes of a more northerly aspect, had more understory shade, had finer soil texture, and did not experience recent stand-replacing disturbance. These factors contributed a fairly moderated and moist microclimate within the understory of S19-1 that was more favorable for regeneration of red maple than oak. Appendices 5c and 5d display height and age class distributions for S24CC1 and S19-1.

Selected Southern Outwash Sites

A broad comparison of oak and red maple regeneration and age class distributions for oaks, pines, early-successional, mid-successional, and late-successional species groups for unmanaged and burned sites are given in Appendices 6a and 6b. Two loamy sand outwash sites in Fort Custer SRA, Kalamazoo County were chosen for a more detailed case study (Table 37). FC-BRN1 (NE S11 T2S R9W) experienced three prescribed burns in 1999, 2002, and 2004. An unmanaged site, FC-WAY2 (SE S11 T2S R9W), was located approximately 400 m south of FC-BRN1. Both sites were located on flat to slightly rolling topography at least 400 m away from the nearest wetland.

Likely due to the frequency and intensity of the three recent prescribed burns in FC-BRN1, average canopy closure, overstory stem density, and understory stem density and basal area were all significantly lower than FC-WAY2 (Table 37). With the exception of a single pignut hickory stem, complete understory mortality resulted from the burns. Only two years elapsed from the most recent burn in 2004 to the time of plot sampling, thus making it difficult to project understory response or successional trajectory. However, a strong herbaceous rebound of groundcover species was apparent; groundcover species richness and coverage averaged 11.25 and 16.03% in FC-BRN1, respectively, compared to 4.50 and 5.71%, respectively, in FC-WAY2. Furthermore, shrub abundance in the ground cover was significantly higher in the burned site (37.50) than the unmanaged site (7.20). Significantly higher soil pH and Ca and Mg concentrations were found on FC-BRN1 than FC-WAY2, possibly due to a transitory nutrient pulse in the humus following fire (Viro 1974).

Unfortunately, it is difficult to conclude whether three prescribed burns spanning five years was beneficial for oak regeneration. Still, strong oak seedling response was found in FC-BRN1 (Table 38a). Of interesting note was the abundant white oak and black oak regeneration found in the unmanaged site, FC-WAY2 (500.00 and 480.00 stems ha^{-1}, respectively). Because understory red maple stems were not present, the average difference between oak and red maple understory stem densities was significantly greater than zero (Table 38b). The presence of open-grown "wolf" oak trees in FC-WAY2 suggests that this site may have formerly been an open pasture or remnant oak savanna. Additionally, there were many 10-20 year old understory oaks averaging 4.5 cm dbh and 30-40 year old overstory oaks averaging only 20.0 cm dbh, indicating that the site likely experienced management in the past that was not documented for this study. Appendices 6c and 6d display height and age class distributions for FC-BRN1 and FC-WAY2.

Selected Southern Sand Lake Plain Sites

A broad comparison of oak and red maple regeneration and age class distributions for oaks, pines, early-successional, mid-successional, and late-successional species groups for unmanaged, cut, and burned sites are given in Appendices 7a and 7b. Four loamy sand lake plain sites in Allegan SGA, Allegan County were chosen for a more detailed case study (Table 39). The four sites were analyzed as independent samples, but they were actually two distinct pairs, separated by approximately 3 km. A11-5B(s) and A11-5B(n) formed one pair, while A18-N and A18-S formed the other. Sites of the former pair (NE S14 T2N R15W) were delineated by a shallow fire break, while sites of the latter pair (SE S7 T2N R14W and NE S18 T2N R14W) were delineated by a two-track dirt road. Though more appropriately analyzed by separate paired t-tests, ANOVA was applied so that all four sites could be compared at once. This does not likely affect interpretation of results. All sites were characterized by loamy sand soil on very flat topography, and all occurred at least 0.50 km from the nearest water body. Both A11-5B(s) and A11-5B(n) experienced an arson fire May 8, 1988, but the latter was subjected to an additional wildfire September 3, 1996. A18-N experienced a shelterwood cut in 1996, and A18-S was left unmanaged.

Extreme differences of vegetation structure existed among sites due to the varied disturbance histories (Table 39). Percent canopy closure ranged from 78.58% in A11-5B(n) to 93.66% in A18-S, but differences were non-significant. In general, lowest average overstory stem density (50.00 stems ha^{-1}) and basal area (10.77 m^2 ha^{-1}) occurred in A18-N, which would be expected after final overstory removal of a two-stage shelterwood cut. Conversely, highest average overstory stem density (490.00 stems ha^{-1}) and basal area (32.20 m^2 ha^{-1}) occurred in the unmanaged site, A18-S. Understory stem density appeared to have increased in response to mechanical and fire disturbance. Highest understory stem densities were found for A18-N after a shelterwood cut (3640.00 stems ha^{-1}) and A11-5B(s) after a single, high-intensity burn (3020.00 stems ha^{-1}). Once again, lowest values occurred in the unmanaged site A18-S (740.00 stems ha^{-1}). The relatively high groundcover species richness (9.00) in A18-N may be attributed to increased light availability at the forest floor following overstory removal. Soil conditions were fairly uniform among sites and generally characterized by high acidity and low exchangeable cation concentrations. These are typical soil properties of the droughty, sand lake plain that historically supported oak-pine barrens and white pine-white oak forests (Comer et al. 1995). The only noticeable difference among sites was a significantly lower calcium concentration (56.60 µg g^{-1}) in A11-5B(s) than the others, which all had concentrations greater than 100.00 µg g^{-1}. Management history, rather than soil condition, probably structured the current vegetation.

Excellent oak regeneration occurred in A11-5B(s) (2940.00 stems ha^{-1}), A11-5B(n) (1740.00 stems ha^{-1}), and A18-N (2220.00 stems ha^{-1}) (Table 40a). Among these three sites, no significant differences existed for oak understory stem density (all oak species). However, black oak-northern pin oak stem density was significantly lower in A11-5B(n) (140.00 stems ha^{-1}) than A11-5B(s) (920.00 stems ha^{-1}). The unmanaged site, A18-S, had significantly lower oak regeneration (160.00 stems ha^{-1}) than the other sites. Because understory red maple stems were practically absent, the average difference between oak and red maple understory stem densities was greater than zero for all sites (Table 40b). Significance, however, was only applicable for the three managed sites. Consequently, it appears that managing for oak regeneration on sand lake plain is straightforward, especially in the absence of red maple understory competition. Single or multiple burns and shelterwood cuts can be prescribed successfully on this particular landform with these ecological conditions. Where the primary management objective is oak regeneration, judicious use of prescribed burning is warranted, since the two intense fires in 1988 and 1996 in A11-5B(n) may have caused an undesirable amount of black oak-northern pin mortality. Furthermore, there is value in promoting eastern white pine regeneration in the southern sand lake plain, given that much of the pre-European settlement landscape consisted of an oak-pine overstory. Because the pine seed source in this region is currently limited, prescribed burns should be carefully planned to avoid extensive mortality of pine seedlings and understory pine trees. Appendices 7c and 7d display height and age class distributions for A11-5B(s), A11-5B(n), A18-N, and A18-S.

Selected Northern Ice-Contact Sites

A broad comparison of oak and red maple regeneration and age class distributions for oaks, pines, early-successional, mid-successional, and late-successional species groups for unmanaged, cut, and both cut and burned sites are given in Appendices 8a and 8b. Ice-contact sites chosen for detailed case studies were divided between two groups based on Kotar habitat classification of the sites (Burger and Kotar 2003, available at: http://www.mcgi.state.mi.us/forestHabitatTypes/). Four sites comprised the PArVHa / PArVVb group, which is classified as having dry, poor nutrient soil conditions (Table 41). GRAY12 (SE S31 T25N R4W) occurred on loamy sand soil in Grayling FMU, Crawford County and experienced a shelterwood cut November 21, 2002. GRAY15 (NE S32 T25N R4W) occurred on coarse sand soil in Grayling FMU, Crawford County and experienced a thinning February 13, 2001. ROSC1 (SE S36 T24N R3W) occurred on loamy sand over clay loam soil in Roscommon FMU, Roscommon County and experienced two prescribed burns (2003 and 2004) and vegetation removal (i.e., aspen and red maple removal 1996 and thinning 2004). An unmanaged site, GAYL2 (SW S9 T34N R2W) occurred on medium sand soil in Gaylord FMU, Cheboygan County. Sites were often within 320 to 530 m from lowland conifer swamps.

Three sites comprised the PVCd / PArVHa group, which is classified as having very dry, very poor nutrient soil conditions (Table 43). GRAY23 (NW S29 T27N R2W) occurred on loamy sand soil in the Grayling FMU, Crawford County and experienced a shelterwood cut February 4, 2004. GRAY26 (SE S28 T27N R2W) occurred on loamy sand soil in the Grayling FMU, Crawford County and experienced a selection cut January 29, 2002. GRAY3 (NE S20 T26N R3W) occurred on loamy sand soil in the Grayling FMU, Crawford County and experienced a thinning March 5, 2003. All sites occurred without wetlands in proximity.

Among sites of the PArVHa / PArVVb group, overstory and understory vegetation structure reflected the intensity of management (Table 41). Average percent canopy closure and overstory stem density and basal area were lowest in the two most intensively managed sites, GRAY12 (75.30%, 190.00 stems ha^{-1}, 9.18 m^2 ha^{-1}, respectively) and ROSC1 (76.29%, 200.00 stems ha^{-1}, 19.34 m^2 ha^{-1}, respectively). Highest average understory stem density, mainly due to sprouting of red maple, occurred in the shelterwood cut site, GRAY12 (3400.00 stems ha^{-1}). In ROSC1, management goals included removal of all red maple and bigtooth aspen stems. Therefore, average understory stem density was lowest at this site (80.00 stems ha^{-1}). The two sites that received low-intensity management (i.e., thinning) or no management, GRAY15 and GAYL2, respectively, exhibited similar vegetation structure with exception of a significantly lower overstory stem density in GRAY15 (415.00 stems ha^{-1}) than GAYL2 (710.00 stems ha^{-1}). Concerning soil properties, GAYL2 exhibited lowest values for average pH and exchangeable cations that were often significantly different from the other sites. Nonetheless, it appears that northern ice-contact soil was fairly consistent as pH ranged from 4.26 in GAYL2 to 4.57 in ROSC1, and the largest absolute difference detected for cation concentrations was only 90.90 µg g^{-1} for calcium between GAYL2 (55.40 µg g^{-1}) and ROSC1 (146.30 µg g^{-1}). Percent slope among sites was significantly different, but all were considered to have gently rolling terrain.

Almost no oak regeneration was present in the four sites of the PArVHa / PArVVb group (Table 42a). Red maple regeneration, in contrast, was most evident in GRAY12 (920.00 stems ha^{-1}) and GRAY15 (680.00 stems ha^{-1}). Though average oak seedling abundance was highest in GRAY15 (20.60), differences among sites were generally non-significant. Average red maple seedling and sapling abundance in GRAY15 (26.80 and 1.20, respectively), however, were generally significantly greater than other sites. It is interesting to note the low abundance of oak seedlings and saplings at ROSC1, where, over eight years of intensive management for the purpose of stimulating oak regeneration, red maple and black cherry clonal sprouting continued to be problematic. The subsurface clay loam horizon and the retention of soil moisture likely favored rapid growth of oak competitors. It remains to be seen whether continuing annual burns and active red maple removal will facilitate oak regeneration in the future. Despite the sprouting of red maple and black cherry, very few weedy or non-native species were found at ROSC1, and for this reason, the prescribed burn program should be ongoing. At all sites, the average difference between oak and red maple understory stem densities was less than zero because understory oak stems were practically absent (Table 42b). These differences were significantly different from zero for all sites (at $\alpha = 0.10$ for GRAY12 and GAYL2 and at $\alpha = 0.05$ for GRAY15) except ROSC1. Appendices 8c and 8d display height and age class distributions for GRAY12, GRAY15, ROSC1, and GAYL2.

Among sites of the PVCd / PArVHa group, the most intensively (i.e., shelterwood cut) managed site, GRAY23, had the lowest average percent canopy closure (44.57%) and overstory stem density and basal area (120.00 stems ha^{-1} and 6.71 m^2 ha^{-1}, respectively) (Table 43). Corresponding values for GRAY3, the site least impacted by management (i.e., thinning), were significantly higher than GRAY23 (73.12% canopy closure, 325.00 stems ha^{-1} overstory stem density, and 16.00 m^2 ha^{-1} overstory basal area). For GRAY26, where a selection cut had occurred, these values were intermediate those of GRAY23 and GRAY3. Average understory stem density ranged from 820.00 stems ha^{-1} in GRAY26 to 2220.00 stems ha^{-1} in GRAY23, but the difference among sites was non-significant. Once again, northern ice-contact soil was fairly consistent as pH ranged from 4.39 in GRAY26 to 4.67 in GRAY3, and the largest absolute difference for cation concentrations was only 88.90 µg g^{-1} for calcium between GRAY23 (84.30 µg g^{-1}) and GRAY3 (173.20 µg g^{-1}). A significantly flatter topography occurred on GRAY26 (-2.90%) than the other sites.

Sites of the drier PVCd / PArVHa group appeared to have more oak regeneration than the PArVHa / PArVVb group (Table 44a). Average oak understory stem density ranged from 340.00 stems ha^{-1} in GRAY23 (shelterwood) to 740.00 stems ha^{-1} in GRAY3 (thinning), but differences among sites were non-significant. Red maple regeneration was not significantly different among sites, but red maple seedling abundance was significantly higher in GRAY26 (38.50) (selection) than the other sites. Despite the moderate degree of oak regeneration, average differences between oak and red maple understory stem densities were not significantly different from zero (Table 44b). However, values for GRAY26 and GRAY3 were positive. From a management perspective, northern ice-contact sites on dry soil types (i.e., PVCd) will have greater potential for successful oak regeneration compared to those on moister soil types (i.e., PArVVb). Red maple understory control will still be necessary regardless of soil condition, but having an existing pool of oak advanced regeneration, as exemplified in GRAY23, GRAY26, and GRAY3, will help ensure successful oak regeneration. Appendices 8c and 8d display height and age class distributions for GRAY23, GRAY26, and GRAY3.

Selected Northern Moraine Sites

A broad comparison of oak and red maple regeneration and age class distributions for oaks, pines, early-successional, mid-successional, and late-successional species groups for unmanaged and cut sites are given in Appendices 9a and 9b. Four moraine sites were chosen for a more detailed case study (Table 45). ATL12 (SW S16 T33N R2E) occurred on sandy loam to sandy clay loam soil in Atlanta FMU, Presque Isle County and experienced a clearcut in 1996. MAN4B (NE S31 T13N R12W) occurred on loamy sand soil in Huron-Manistee NF, Newaygo County and experienced a shelterwood cut in 1994. CAD7 (SE S18 T18N R11W) occurred on sandy loam to sandy clay loam soil in Cadillac FMU, Lake County and experienced a thinning around 1999. An unmanaged site, CAD26 (SW S2 T18N R9W) occurred on sandy loam to sandy clay loam soil in Cadillac FMU, Osceola County. With exception of a wetland 170 m southwest of CAD26, wetlands were not in proximity to the sites.

The clearcut site, ATL12, expectedly had lowest average percent canopy closure (35.05%) and overstory stem density and basal area (30.00 stems ha^{-1} and 0.32 m^2 ha^{-1}, respectively) (Table 45). Increased understory light availability probably explains the relatively high average groundcover species richness (9.35), groundcover coverage (53.62%), and shrub abundance (108.40) at this site. The unmanaged site, CAD26, had the highest average percent canopy closure (96.88%) and overstory stem density and basal area (530.00 stems ha^{-1} and 39.09 m^2 ha^{-1}, respectively). Correspondingly, this site had the lowest average groundcover species richness (4.65), groundcover coverage (8.17%), and shrub abundance (4.40). MAN4B (shelterwood) and CAD7 (thinning) attained intermediate values for these vegetation properties. Average understory stem densities were highest in the two most intensively managed sites, ATL12 (4140.00 stems ha^{-1}) and MAN4B (4020.00 stems ha^{-1}), though it is unknown whether significant differences exist among sites. In general, soil conditions were fairly consistent among sites despite MAN4B exhibiting the coarsest texture. Soil pH ranged from 4.43 in MAN4B and CAD26 to 4.68 in ATL12, and most exchangeable cation concentrations were comparable among sites. Calcium concentrations for ATL12 (215.50 µg g^{-1}) and CAD7 (217.20 µg g^{-1}) were three times greater than MAN4B (67.70 µg g^{-1}) and CAD26 (77.60 µg g^{-1}).

Oak regeneration was clearly greatest in the clearcut site, ATL12 (2680.00 stems ha^{-1}), and was comprised entirely of northern red oak (Table 46a). Surprisingly, red maple regeneration was only moderate (680.00 stems ha^{-1}) given the moisture-retaining, sandy clay loam subsurface soil horizon. All other sites exhibited poor oak regeneration but excellent red maple regeneration. Shelterwood and thinning cuts on moraine stimulated high red maple understory stem densities from clonal sprouting (2360.00 stems ha^{-1} for MAN4B and 1580.00 stems ha^{-1} for CAD7). It is unclear as to why red maple understory stem density on the clearcut site was comparatively lower. Average differences between oak and red maple understory stem densities were significantly different from zero for all sites except CAD26 (Table 46b). Only ATL12 exhibited greater regeneration of oak than red maple; all other sites exhibited the converse and were not significantly different from one another. Appendices 9c and 9d display height and age class distributions for ATL12, MAN4B, CAD7, and CAD26.

Selected Northern Outwash Sites

A broad comparison of oak and red maple regeneration and age class distributions for oaks, pines, early-successional, and mid-successional species groups for unmanaged, cut, burned, and both cut and burned sites are given in Appendices 10a and 10b. Four outwash sites were chosen for a more detailed case study (Table 47). BRAD1B (SE S30 T13N R12W) occurred on loamy sand soil in Huron-Manistee NF, Newaygo County and experienced a clearcut sometime between 1977 and 1987. MAN9B (NW S23 T18N R15W) occurred on loamy sand soil in Huron-Manistee NF, Mason County and experienced a shelterwood cut in 1995. MAN1B (SE S19 T21N R15W) occurred on fine sand soil in Huron-Manistee-NF, Manistee County and experienced a prescribed burn in 2001. An unmanaged site, BRAD1 (SW S30 T13N R12W) occurred on loamy sand soil in Huron-Manistee NF, Newaygo County. BRAD1B and BRAD1 occurred adjacent to one another. All sites occurred without wetlands in proximity.

Near total canopy closure (94.38%) resulting from a clearcut 20 to 30 years ago in BRAD1B indicates excellent vegetation response to this treatment (Table 47). Small-diameter overstory oak trees, originating from clonal sprouts, contributed to low-canopy shading. Average overstory stem density and basal area were 575.00 stems ha^{-1} and 7.19 m^2 ha^{-1}, respectively. Understory response of oaks was equally impressive, accounting for all of the understory stem density (3840.00 stems ha^{-1}) and basal area (8.69 m^2 ha^{-1}). MAN9B received a similar management prescription to BRAD1B but occurred much later. The fairly recent shelterwood cut of MAN9B in 1995 resulted in significantly lower average percent canopy closure (38.28%) and overstory stem density (35.00 stems ha^{-1}) and basal area (2.85 m^2 ha^{-1}) than most of the other sites. Though overstory response has yet to recover to levels comparable to BRAD1B, average understory stem density (2800.00 stems ha^{-1}) was not significantly different between the two sites. Increased light availability at the forest floor following overstory removal likely explains high groundcover coverage (44.71%) in MAN9B. Between sites that were minimally managed by a prescribed burn (MAN1B) or left unmanaged (BRAD1), no significant differences were detected for vegetation structure. Average percent canopy closure, overstory stem density and basal area, understory stem density and basal area, and groundcover species richness and coverage were not significantly different between MAN1B and BRAD1. Northern outwash soil was fairly consistent as pH ranged from 4.34 in BRAD1 to 4.71 in MAN9B, and the largest absolute difference detected for cation concentrations was only 38.40 µg g^{-1} for calcium between BRAD1 (52.40 µg g^{-1}) and MAN9B (90.80 µg g^{-1}). Percent slope among sites was significantly different, but all were considered to have flat terrain.

High oak regeneration with minimal competition from red maple was commonly encountered throughout the northern outwash landscape (Table 48a). Among sites, it appears that intensive cutting, either by clearcuts (BRAD1B) or shelterwood cuts (MAN9B), stimulates regeneration of oaks through stump sprouting. Average understory oak stem densities for BRAD1B and MAN9B were 3840.00 and 2720.00 stems ha^{-1}, respectively. Because of the inherent lack of red maple understory, there was virtually no influence of understory competition following treatment. A single burn (MAN1B) or non-management (BRAD1) did not appear to be sufficient to stimulate oak regeneration, as average understory oak stem densities in both sites were less than 100.00 stems ha^{-1}. Average differences between oak and red maple understory stem densities were significantly greater than zero for all sites except BRAD1, indicating greater regeneration of oak than red maple for all managed sites (Table 48b). In the sampled sites of northern outwash, wetlands that support populations of red maple were not in proximity. Therefore, colonization of uplands by red maple through seed rain from adjacent wetlands has not been realized. It appears that a decision of non-management favors neither oak species nor red maple. Nonetheless, it is prudent for managers to institute a prescribed burn program possibly in conjunction with silvicultural treatments to ensure future oak regeneration and the inhibition of red maple colonization and possible red maple in-growth from seedling to sapling layers. Prescribed burning can also facilitate pine regeneration by exposing mineral soil for germination. This is particularly important when a mixed oak-pine overstory is desired, which was the typical forest composition of these sites circa 1800 (Comer et al. 1995). Appendices 10c and 10d display height and age class distributions for BRAD1B, MAN9B, MAN1B, and BRAD1.

Selected Northern Sand Lake Plain Sites

A broad comparison of oak and red maple regeneration and age class distributions for oaks, pines, early-successional, and mid-successional species groups for unmanaged, cut, and both cut and burned sites are given in Appendices 11a and 11b. Four sand lake plain sites were chosen for a more detailed case study (Table 49). GLA1C (NW S11 T19N R4E) occurred on coarse sand soil in Gladwin FMU, Arenac County and experienced a clearcut in 1999. GLA3B (NE S17 T19N R5E) occurred on mottled loamy sand soil in Gladwin FMU, Arenac County and experienced a shelterwood about 2003. HUR3C (NE S6 T23N R9E) occurred on medium sand soil in Huron-Manistee NF, Iosco County and experienced a series of wild and prescribed fires, jack pine removal, and grass planting from 1984 to present. An unmanaged site, GLA8 (SW S31 T20N R5E) occurred on medium sand soil in Gladwin FMU, Arenac County. GLA3B occurred within a larger matrix of upland rises and wet swales that were often inundated during early spring. The remaining sites occurred without wetlands in proximity.

Significant differences existed for all vegetation variables among sites (Table 49). The recently clearcut site, GLA1C, expectedly had the lowest average canopy closure (19.92%) and overstory stem density (70.00 stems ha^{-1}) and basal area (1.49 m^2 ha^{-1}). Understory response to clearcutting was reflected in the high average understory stem density (1680.00 stems ha^{-1}) and basal area (1.67 m^2 ha^{-1}). Correspondingly, GLA1C also had the highest average groundcover coverage (73.57%) due to increased light availability at the forest floor following overstory removal. Among the other three sites, few significant differences in vegetation were apparent despite very different management histories; average overstory stem density, understory stem density and basal area, and percent groundcover coverage were not significantly different. As expected, average percent canopy closure (84.92%) and overstory basal area (22.43 m^2 ha^{-1}) were highest in GLA8, where no management had occurred. Significantly greater groundcover species richness (8.55) was found in GLA3B, presumably due to fluctuations in soil moisture throughout the growing season. At this site, xeric species, such as bracken fern, were commonly located on upland rises adjacent to wet swales that supported wet species, such as sensitive fern (*Onoclea sensibilis*). The highest values for soil pH and exchangeable cation concentrations occurred in GLA1C and were generally significantly different from other sites. However, only calcium for GLA1C, which registered 250.80 $\mu g\ g^{-1}$, seemed exceptional. Values among GLA3B, HUR3C, and GLA8 were comparable with pH ranging from 4.08 in GLA3B to 4.60 in HUR3C, and the largest absolute difference detected for cation concentrations was only 14.4 $\mu g\ g^{-1}$ for calcium between HUR3C (84.50 $\mu g\ g^{-1}$) and GLA8 (98.90 $\mu g\ g^{-1}$). Terrain for all sites was considered flat, and there were no significant differences in percent slope among sites.

Oak regeneration was evident in all sites except GLA3B, where the shelterwood cut was too recent (2003) for young oaks to be included in understory stem counts (Table 50a). The clearcut site, GLA1C, had the greatest average understory oak stem density (820.00 stems ha^{-1}), but this was not significantly different from HUR3C (320.00 stems ha^{-1}), which was cut and burned, or GLA8 (240.00 stems ha^{-1}), which was left unmanaged. Red maple regeneration was detected only for GLA3B (140.00 stems ha^{-1}), where soil moisture fluctuations were common. Average differences between oak and red maple understory stem densities were significantly different from zero for all sites (Table 50b). GLA1C, HUR3C, and GLA8 had greater oak then red maple regeneration; in contrast, GLA3B exhibited the converse. Similar to excessively-drained outwash, sites on the sand lake plain tend to be favorable for oak regeneration. However, lacustrine sand deposits are often variable in depth across the lake plain landscape. Where deposits are thin, the water table remains close to the surface (Albert et al. 1986). Consequently, red maple competition may be problematic when soil moisture conditions improve, as exemplified by the mottled soil in GLA3B. Appendices 11c and 11d display height and age class distributions for GLA1C, GLA3B, HUR3C, and GLA8.

Comprehensive Summary – Multivariate Models

Logistic Regression

Of 10 logistic regression models tested, 2 were selected that best incorporated multiple variables to explain oak regeneration success (Table 51). Models C and I have AIC weights, w_i, of 0.302 and 0.325, respectively. AIC weights can be interpreted as the "weight of evidence" in favor of a particular model. In this case, models C and I have a 62.7% collective probability of being the two best models given the data. Because the AIC difference ($\Delta i = AIC_i - AIC_{min}$) between these two models is small (0.144), preference for one model over the other can be based on the desired ecological applicability (Burnham and Anderson 2004). In this case, the chosen models differ in one slightly modified variable: understory basal area. Model C (Tables 52a, b) utilizes total understory basal area excluding oak species, whereas Model I (Table 53a, b) utilizes red maple understory basal area. Because p-values for both variations of the variable are greater than 0.05 and comparable (0.106 and 0.096 for models C and I, respectively), neither one is statistically better than the other. However, the models do provide complementary information on oak regeneration, with model C elucidating the effect of the overall pool of understory competition and model I highlighting the influence of red maple as the primary competitor of oaks in most locations. Ecologically, there is no reason to suspect that a red maple understory would serve as sole inhibitor to oak regeneration success exclusive of all other understory species. Therefore, model C will be assumed to be a more inclusive model than model I and is explained below.

In the model, six continuous variables (total soil cation concentration, overstory basal area, understory basal area excluding oak species, percent groundcover coverage, shrub abundance, and oak seedling abundance) and two categorical variables (landform and soil classification) are included (Table 52a). Landform consists of four nominal levels: ice-contact, moraine, outwash, or lake plain; soil classification is based on perceived soil coarseness and consists of two nominal levels: sandy or loamy. Designation of a site as sandy versus loamy was interpreted from soil pits. Those with a primarily pure sand or coarse loamy sand B or C horizons were classified as sandy. Sites with fine loamy sand, sandy loam, sandy clay loam, or clay B or C horizons were classified as loamy. Overall model evaluation indicates model significance ($\chi^2 = 86.576$, p = 0.000), and McFadden's Rho-squared ($P^2 = 0.708$), a measure conceptually analogous to R^2 for simple linear regression (Menard 2001) indicates very good fit of the model. A classification matrix (Table 52b) displays observed and predicted frequencies. Sensitivity, the proportion of correctly classified events (i.e., successful oak regeneration), is 88.6%, while specificity, the proportion of correctly classified non-events (i.e., unsuccessful oak regeneration) is 93.0%. False positive, proportion of observations misclassified as events over all of those classified as events, is 11.4%. False negative, proportion of observations misclassified as non-events over all of those classified as non-events is 7.0%. Correct classification of the overall model is high at 91.3%.

Parameters that do not appear to be statistically significant in predicting oak regeneration are understory basal area excluding oak species (p = 0.106), shrub abundance (p = 0.171), and lake plain landform (p = 0.785). Parameters with moderate significance are ice-contact landform (p = 0.055) and outwash landform (p = 0.056). All other parameters are strongly significant with p-values equal to or less than 0.05. An odds ratio indicates whether an increase in a parameter's value (in the case of continuous variables) or a present condition (in the case of nominal categorical variables) promotes or inhibits oak regeneration: parameters with odds ratio value greater than one promote oak regeneration (i.e., regeneration success), and parameters with values less than one inhibit oak regeneration (i.e., regeneration failure). Therefore, site conditions for successful oak regeneration can be summarized as follows:

1) occurring on sandy outwash
2) low total soil cation concentration (i.e., low soil nutrients)
3) low overstory basal area
4) low groundcover coverage
5) high abundance of oak seedlings

Conversely, site conditions that often correspond with poor oak regeneration:

1) occurring on fine-textured (i.e., loamy soil classification) ice-contact terrain or moraine
2) high total soil cation concentration (i.e., high soil nutrients)
3) high overstory basal area
4) high groundcover coverage
5) low abundance of oak seedlings

Parameterization of moraine landform and loamy soil classification is not explicitly shown in Table 52a due to the nominal coding procedure of categorical variables. However, these two parameters are statistically significant at $\alpha = 0.05$, and their condition tends to inhibit oak regeneration. Though non-significant, odds ratios for understory basal area excluding oak species, shrub abundance, and lake plain landform are 0.525, 0.979, and 1.417, respectively. One may cautiously suggest that increased values of the first two variables may inhibit oak regeneration (Lorimer et al. 1994) while the third condition may promote it.

It must be stressed that these variables and their associated parameters may not represent direct causative agents of oak regeneration. Some are recurring properties that often accompany sites that exhibit successful oak regeneration and are merely correlative. For instance, it cannot be said that negative effects are directly imposed on oak regeneration by fine-textured soil with high soil nutrients. More than likely, this condition favors growth of mesophytic species over oak species, which in turn, functions as the causative agent limiting oak regeneration (Kabrick et al. 2008). Nor should it be assumed that leaching of nutrients is a desirable ecosystem property that will facilitate oak regeneration. Rather, it likely impedes the growth rate of mesophytic species to a greater extent than oak species. Moreover, the model is not comprehensive, and certain factors known to impact oak regeneration were not addressed. Acorn predation, insect defoliation, disease, leaf litter composition and chemistry, and competition from invasive species are additional concerns for managers (Courteau et al. 2006). Interactions among various ecological variables are probable but were not modeled in the logistic regression. Modeling interactions, though appropriate, adds complexity that diminishes the ease of interpretation and potential usefulness.

In general, the model isolated parameters that make logical sense for predicting oak regeneration. Drought-prone landforms and coarse-textured soil have been linked to the presence of oak regeneration in Michigan (Host et al. 1987, Archambault et al. 1990), and reduction of overstory basal area to allow greater understory light infiltration is an accepted silvicultural technique for oak management (Johnson et al. 2002, Iverson et al. 2008a). Abundant ground cover, such as Pennsylvania sedge, ericaceous shrubs, brambles (*Rubus* spp.), and bracken fern, can impede acorn germination and stifle oak seedling growth (Abrams et al. 1985, Johnson 1992, Nielsen et al. 2003). Finally, an abundant population of oak seedlings is obviously necessary for in-growth to the sapling stage and subsequent recruitment into the overstory.

For oak managers and restoration practitioners, not all parameters listed above can or should be manipulated. Most notably, acidification of the soil for the sake of reducing red maple competition would be considered an extreme and biologically risky proposition by most. Reducing groundcover coverage should also be approached judiciously. If the main culprits impeding oak regeneration are invasive, non-native species such as garlic mustard (*Alliaria petiolata*), Japanese barberry (*Berberis thunbergii*), autumn-olive (*Elaeagnus umbellata*), exotic honeysuckles (*Lonicera maackii*, *L. morrowii*, *L. tatarica*, or *L.* x*bella*), common buckthorn (*Rhamnus cathartica*), or multiflora rose (*Rosa multiflora*), intensive removal and herbicide application may be justified. On the other hand, native species, especially those that characterize oak openings and barrens may warrant protection for purposes of species diversity. Reducing the abundance of common native species such as Pennsylvania sedge, ericaceous shrubs, brambles, and bracken fern is potentially risky because it liberates growing space for non-native species colonization. However, carefully-timed prescribed burns may decrease overall groundcover coverage but promote expression of the native seed bank while simultaneously excluding non-native species. Any prescription that is able to produce greater oak seedling and sapling establishment, and therefore future oak regeneration, while increasing native species diversity would be demonstrating a commitment to holistic ecosystem management.

It is more prudent to manipulate the overstory basal area on sites located on outwash or lake plain landforms that have a viable, pre-existing population of oak seedlings and oak saplings (i.e., oak advanced regeneration). Under this scenario, management for oak regeneration would proceed with a high probability of success according to the logistic regression model. Reduction of basal area can be accomplished with various silvicultural methods (e.g., shelterwood cuts or clearcuts) or a series of prescribed burns. Promoting a suitable oak seedling presence may be accomplished with active seeding or underplanting. Although understory basal area was not a significant parameter in the model, understory control of competing species, especially red maple (Table 53a), is imperative (Lorimer et al. 1994) and may be accomplished with mechanical removal, girdling, prescribed burns, or application of herbicides.

Discriminant Analysis

To emphasize the distinctness of landforms within south and north regions, discriminant analysis with their corresponding ordination graphs are presented in Tables 54 and 55 and Figures 18 and 19, respectively. The southern landforms show their greatest separation along the first canonical variate (horizontal axis), with ice-contact and moraine landforms grouped to the right and outwash and lake plain landforms grouped to the left (Figure 18). Variables with the greatest leverage on horizontal separation are soil pH (r^2 = 0.639), total soil cation concentration (r^2 = 0.772), overstory richness (r^2 = 0.700), understory basal area excluding oak species (r^2 = 0.575), oak seedling abundance (r^2 = -0.566), and shrub abundance (r^2 = -0.543) (Table 54). Positive correlations indicate a positive relationship between variable and canonical variate values, while negative correlations indicate a negative relationship. Therefore, sites on ice-contact terrain and moraine tend to have a higher soil pH, nutrient concentration, overstory richness, and understory basal area excluding oak species but lower oak seedling and shrub abundance than sites on outwash and lake plain. These finding are consistent with those presented previously in various tables (*see* Grouping 2 – By Landform). Though there is some degree of separation along the second canonical variate (vertical axis), landforms appear to overlap to a greater extent than along the first canonical variate (Figure 18). Additionally, most correlation coefficients of variables comprising the second canonical variate are weaker than the first canonical variate (Table 54). The correlation coefficient for soil pH is actually stronger along the second canonical variate (r^2 = 0.689) than the first and suggests that this variable is strongly correlated with both axes.

The northern landforms also show their greatest separation along the first canonical variate, with outwash and lake plain landforms grouped to the right, moraine to the far left, and ice-contact in between (Figure 19). Relative uniformity of northern landforms is evidenced by the greater degree of site overlap compared to those of southern landforms. Consequently, correlations between variables and the first canonical variate are fairly weak (Table 55). Variables with the greatest leverage on horizontal separation are tree seedling abundance (r^2 = -0.634), shrub abundance (r^2 = 0.561), and percent slope (r^2 = 0.825). Therefore, sites on outwash and lake plain tend to have a lower abundance of tree seedlings, a higher abundance of shrubs, and a flatter topography (since percent slope was measured in negative values) than sites on moraine. Sites on ice-contact terrain generally reflect intermediate qualities, and these findings are consistent with those presented previously (*see* Grouping 2 – By Landform, Tables 21 and 23). No clear vertical separation of northern landforms is evident (Figure 19), and correlation coefficients of variables comprising the second canonical variate are weak (Table 55).

GENERAL DISCUSSION

Occurrence of Oak Species among Landforms of the South and North Regions

Hierarchical Top-Down Approach

The ecological occurrence of oaks in Lower Michigan is usefully examined through a structured landscape ecosystem approach that characterizes ecosystems on the basis of climate, physiography, soil, and associated vegetation (Rowe and Barnes 1994). Implicit in this approach is a systematic top-down progression from broadly inclusive regional ecosystems to fine-scale local ecosystems. The south (Region VI) and north (Region VII) regions within Michigan's Lower Peninsula formed the first level of study, and within each, landforms encompassed two finer hierarchical levels (i.e., physiographic systems and landform-level ecosystems) (Figure 3). Initial attempts to analyze data by the broader hierarchical levels of subsections or sub-subsections were judged to be insufficient for evaluating the status of oak regeneration throughout the state. Instead, ice-contact, moraine, outwash, and lake plain landforms were chosen because each support oak-dominated upland forests formed under varying conditions that exhibit unique ecosystem properties. These landforms occur commonly throughout Michigan, and thus results from the current study likely have application elsewhere in the state. Although the current study does not provide a comprehensive ecological classification of forested oak ecosystems, a top-down conceptual framework guides the research.

Most oak forests characterized in this study were categorized as dry or dry-mesic southern forests or dry or dry-mesic northern forest community types (Kost et al. 2007). Some sites, due to clay loam subsurface horizons or landscape context, had better moisture retention capability and would be more appropriated identified with mesic southern forest or mesic northern forest. These sites were generally dominated by northern red oak and their classification as dry-mesic or mesic was not clear. Regardless, they added to the diversity of ecosystem properties by which to assess oak regeneration.

Regional Level

Forested oak ecosystems differed substantially at the regional level (*see* Grouping 1 – By North and South Regions). Variations of climate, soil, and disturbance and land use history distinguish oak forests in the south from the north. Sites in the south region experience longer growing seasons, greater precipitation, and markedly less climatic variation than sites in the north region (Albert 1995). In addition, soil fertility and moisture-holding capacity are generally more amenable to a wider range of plant species in the south than the north. Consequently, the south exhibited greater species richness and higher soil pH and exchangeable cations than the north. The effect of climate is most conspicuous for black oak, as its range is limited to the southern half of Lower Michigan (Barnes and Wagner 2004). This species is adapted to growing in long warm summers with warm nights and high water deficits. It is drought tolerant but susceptible to late spring freezes, which are common events in inland portions of the north region. The abrupt decrease of black oak abundance with increasing latitude reflects sensitivity to short growing seasons, low growing season heat sum, and frost damage (Nichols 1968, Denton and Barnes 1987). Similar physiological restrictions likely limit the distribution of hickory species to the south region.

Some of the findings from the current study that differentiate south and north regions may be explained by the differences of historical land use and current forest management practices. For instance, oak forests in the south region today reflect both the recruitment of oak advanced regeneration through past logging of existing forested oak ecosystems and the conversion of open oak savannas to closed oak forests through fire suppression (Abrams 1996, Cohen 2004). Oak-dominated forests in dry and dry-mesic conditions in the north region today, in contrast, typically reflect oak replacement of a pine-dominated overstory through past logging and subsequent slash fires; replacement of eastern hemlock (*Tsuga canadensis*), sugar maple, and American beech by northern red oak ensued on mesic conditions (Whitney 1987). Compared to the south region, sites in the north region are currently more often managed for timber production and are on shorter rotations because objectives focus on production of aspen pulpwood, regeneration of jack pine, and maintenance of oak-dominated forests (Whitney 1987). Consequently, average overstory basal area and percent canopy closure were found to be lower in the north than the south (Tables 4 and 5), and overstory oaks were found generally to be younger in the north as well. The prevalence of overstory and understory stem sprouting also reflected the more recent and greater cutting frequency of the north compared to the south (Tables 6 and 8). The slightly greater average oak regeneration found in the north (Table 9a) was attributed to the contribution of northern red oak understory stems on dry-mesic northern ice-contact and end moraine landforms. In the south, northern red oak was generally restricted to mesic southern forests occurring with sugar maple and American beech or dry-mesic southern forests that had clay loam subsurface soil horizons. These particular ecosystem types were not preferentially sampled in the south.

Landform Level

Evaluation of oak regeneration according to defined ecological units has been the basis for sampling protocols of many studies (Host et al. 1987, Archambault et al. 1990, Iverson et al. 2008a, Kabrick et al. 2008). These units are determined by unique landforms, slope positions, aspect, parent material, soil series, integrated moisture indices and soil drainage conditions, and plant communities and ecological species groups. Studies may choose to apply one or more of these ecosystem properties when structuring sampling design. For the current study, the finest unit was the landform (i.e., ice-contact, moraine, outwash, and lake plain), and each one exhibited certain soil characteristics (Appendices 1a, b).

A common ecological feature of all landforms in which oak forests occurred was well-drained to excessively-drained soil. Sand to sandy loam soil on topography that promoted water movement and drainage were typical. Oak forests developed on heavier-textured soil often had a substantial proportion of coarse fraction (i.e., pebbles and cobbles) or was situated on steep-sided slopes, both of which would have increased drainage. Percent slope ranged from nearly flat on outwash and lake plain landforms to -60% on ice-contact kames. End moraines were as steep as -34%. When occurring on high topographic relief, oak forests typically occupied ridge tops and upper and middle slopes. Despite some commonalities among landforms, each one exerted strong but differential influence upon oak regeneration.

Landform characteristics in both regions can be summed up as follows: outwash and lake plain landforms generally corresponded with 1) lower competition from red maple, 2) lower soil moisture, pH, and exchangeable cation concentration, and 3) a more open canopy than the ice-contact or moraine landforms. Distinctness of landforms was graphically depicted with ordination plots derived from discriminant analyses (Figures 18 and 19, Tables 54 and 55). For both south and north regions, outwash and lake plain landforms were grouped together on one side of the ordination plane, which indicated their similarity. Ice-contact terrain was grouped with moraine in the south region but was intermediate between moraine and the outwash-lake plain group in the north region. The variables that separated the landforms in ordination space did not include an explicit measure of oak regeneration. Namely, oak understory stem density was excluded from the analysis due to severe violations of normality within the data set resulting from a large number of sites lacking understory stems of oak. However, those variables used in the logistic regression model to predict oak regeneration success were included in discriminant analysis, and, in the south region, total soil cation concentration, overstory basal area, and oak seedling abundance were also important discriminant variables (Table 54). In the north region, no variable included in the logistic regression model correlated highly with either canonical variate from the discriminant function (Table 55). This suggests that among-landform variation in the north region was less pronounced than the south region, and, therefore, forested oak ecosystems in the north tended to be more homogenous than those in the south. From observations in the field, the soil among the northern landforms were generally light-colored, acidic, had little horizon formation, and contained thick deposits of sand. The relative uniformity of soil characteristics, the widespread, historical logging of pine species followed by even-age recruitment of the oak understory, and current logging practices employed by state and national forests had resulted in similar conditions throughout the northern landscape (Whitney 1987).

Regardless of the variables that distinguish landforms, current oak regeneration was empirically observed to be highest on outwash and lake plain landforms and lowest on ice-contact and moraine landforms in both regions. These findings are consistent with those of other studies that compared oak regeneration among ecosystem types of varying soil drainage, soil fertility, site index, or any other measure of moisture condition. For instance, Kabrick et al. (2008) found that species of the red oak group (*Quercus* section *Lobatae*) regenerated best following clearcuts on ecological land types of lower site quality due to limited inter-specific competition. Similarly, Iverson et al. (2008a) observed increases in oak and hickory advanced regeneration on drier slope positions, as measured by an integrated moisture index, within a particular landform. More intense fires, greater canopy openings, and less competitive pressure distinguished these slope positions from those that exhibited a low abundance of oak and hickory advanced regeneration.

In the north region, Kotar habitat classification is currently used by foresters, wildlife biologists, and other land managers in Michigan (Burger and Kotar 2003, available at: http://www.mcgi.state.mi.us/forestHabitatTypes/). Habitat types correspond somewhat with landform designation, and their influence on oak regeneration can be summarized as follows: 1) areas with good oak regeneration tended to occur on the dry PVCd type on broad, flat outwash plains and flat sand lake plain, 2) areas with poor oak regeneration tended to occur on the more mesic PArVVb and AFO types on broad end and ground moraine ridges, and 3) areas with the most variable oak regeneration tended to occur on the intermediate PArVHa type on ice-contact ridges and pitted outwash plains (both are ice-contact features). It should be noted that regeneration of northern pin oak is, for the most part, not a primary goal or as much of a concern to managers as other oak species. This particular oak species is widely distributed in association with jack pine throughout the southern and northern lake plain and northern outwash. It readily germinates or sprouts on the PVCd type with or without frequent disturbance, and its occurrence on exposed, harsh landscape positions, such as non-pitted outwash plains, limit establishment of most competitive species. In contrast, poor to moderate regeneration of white oak and northern red oak on PArVHa, PArVVb, and AFO types was usually caused by competition from other species [e.g., bigtooth aspen, black cherry, and red maple in the tall understory and overstory strata and witch-hazel and serviceberry (*Amelanchier* spp.) in the shrub stratum].

Influence of Red Maple on Oak Regeneration

The failure of oaks to recruit into the overstory is not a direct effect of its understory intolerance per se, but rather its competitive disadvantage compared to other shade-tolerant species. Abrams (1996) has cited several studies showing the capability of oaks to respond to release after several decades of suppression. However, conditions for release occurred with limited understory competition and virtually no deer browsing. In today’s fire-suppressed oak forests, invasion by shade-tolerant, fire-sensitive, and browse-tolerant species has become ubiquitous. This scenario is especially pronounced on landforms that have soil with relatively high nutrient concentration and moisture holding capacity (Host et al. 1987). Oak forests on heavy-textured ice-contact soil and gently-sloping, well-drained moraine landforms are most susceptible to mesophytic invasion. Tall understory vegetation, both native [e.g., witch-hazel, hazelnut (*Corylus* spp.), dogwood (*Cornus* spp.), and serviceberry] and non-native [e.g., Eurasian honeysuckle (*Lonicera* spp.), common buckthorn, multiflora rose, and autumn-olive, and sweet cherry (*Prunus avium*)] and early-, mid-, and late-successional trees [e.g., bigtooth aspen, black cherry, sassafras, white ash (*Fraxinus americana*), red maple, and sugar maple] can cause substantial reduction in oak seedling survival and growth. Lorimer et al. (1994) found 70% mortality of planted oak seedlings under 97% understory foliar cover during a five-year period. Height growth of surviving oak seedlings averaged only 4-6 cm $year^{-1}$.

Of all fire-sensitive competitors, greatest attention has been given to red maple (Lorimer 1984, Host et al. 1987, Abrams and Nowacki 1992). Results from the current study indicate that dry and dry-mesic southern and northern forests were dominated by oak species in the overstory, but red maple was the most dominant non-oak species in both regions and most landforms within each region (Tables 4 and 14). Average overstory dbh of red maple was consistently about half as large as oak species, and red maple formed a sub-dominant stratum that hints at an eventual replacement of senescing oaks. In the understory, red maple was overwhelmingly dominant or co-dominant in both regions and most landforms within each region (Tables 7 and 17). Consequently a successional trend away from oak dominance towards a future of red maple dominance in the absence of active management is likely. The expansion and establishment of red maple in oak-dominated forests in both the south and north regions coincided with decades of fire suppression, commencing during the early 20th century (Whitney 1987, Hutchinson et al. 2008). As existing oak seedlings, saplings, and advanced regeneration recruited into the overstory stimulated by logging-created canopy openings and protected by the cessation of wildfires, red maple seeds were, over several decades, similarly able to colonize and germinate in the ground cover without harm from fire-related mortality. In Ohio, Hutchinson et al. (2008) found a direct relationship between time of fire cessation and the ensuing pulse of red and sugar maple establishment and decrease of oak regeneration.

Comparison of oak and red maple age class distributions among all sampled plots of the current study shows that oaks frequently exhibited a unimodal distribution for unmanaged sites and were mostly 50 to 100 years old (Appendix 2). Red maple, included in the mid-successional group of Appendix 2, usually exhibited a more dispersed distribution than oaks and were mostly 10 to 50 years old. This trend was most evident for unmanaged sites on ice-contact and moraine landforms in both regions (Appendix 3D, P-EO-E and Appendix 9D, CAD26). Height class distributions of seedlings and saplings were of limited use for comparing oak and red maple regeneration because germinants of both species were usually common in most landforms. Their ubiquitous presence in the 0-25 cm height class was usually followed by less frequent representation in taller height classes. However, some unmanaged sites did indicate greater abundance of red maple and other oak competitors, such as sassafras, compared to oaks throughout the entire range of height classes (Appendix 5C, S19-1). Because red maple is more shade tolerant than oak species (Curtis 1959), it can regenerate under the gap-phase dynamic disturbance regime of closed-canopy forests, where stand-replacing disturbances are very infrequent. Abrams (1998) has suggested that red maple is able to function as both an early-successional and a late-successional species by colonizing recently disturbed sites and also maintaining a positive carbon balance under full canopy cover. Under the latter scenario, red maple responds to release when light conditions become favorable, caused either by natural canopy disturbances or mechanical overstory removal.

The genetic plasticity that red maple possesses helps this species adapt to various environmental conditions (Abrams 1998). For example regeneration of red maple is impacted to a far lesser degree than oak species by deer browsing and gypsy moth defoliation (Abrams 1998, Sekura et al. 2005). Red maple competitively displaces oak species in fire-suppressed oak forests because it is capable of utilizing smaller canopy gaps to recruit into the overstory. Once in the overstory, red maple casts dense shade and produces copious amounts of seed that disperses widely. Germination occurs during the same year as dispersal, and multi-structured layers of red maple can form in formerly oak-dominated stands within several decades. It has also been suggested that red maple may inhibit oak nutrient uptake and growth by reducing mycorrhizal infection of fine oak roots (Dickie et al. 2002). In the current study, the effect of red maple on oak regeneration was tested with logistic regression (Table 53a). Regression model I indicates that high red maple understory basal area corresponds to impeded oak regeneration ($p = 0.096$). Once established in the tall understory, red maple is persistent and resilient to fire. Basal sprout density was found to increase with each subsequent fire following prescribed burns in Kentucky (Blankenship and Arthur 2006), and additional logging usually accelerates the rate of canopy dominance (Abrams and Nowacki 1992). Findings from the current study support these results, as red maple average understory stem densities showed large increases following management on southern moraine and northern ice-contact (PArVHa / PArVVb Kotar Habitat Type) and moraine landforms (*see* Grouping 4 – By Management Prescription: Example Case Studies, Tables 29, 34a, 42a, and 46a).

The inhibition of oak regeneration by red maple, though pervasive, was not ubiquitously encountered during the study. For most sites on ice-contact terrain or moraine in both south and north regions, red maple understory stem density was substantially more than that of oaks (Table 19b). On northern outwash and southern sand lake plain, however, several sites were completely devoid of both understory and overstory red maple. Not surprisingly, oak regeneration was most successful at these particular sites. Sites on southern outwash and northern lake plain were more variable than their regional counterparts, as red maple was abundant on some sites and less so on others. Even though red maple is not prevalent in every oak-dominated forested ecosystem, germinants and seedlings are seldom completely absent.

There is evidence that red maple is contributing to the rapid homogenization of the Great Lakes landscape (Schulte et al. 2007), and, if ignored, may irrevocably modify oak ecosystems into a self-replacing red maple stable state (Nowacki and Abrams 2008). Though climax communities (Clements

1916) are no longer recognized, vegetation communities existing in one of several stable states (Beisner et al. 2003) forms the basis of mechanistic ecological models. Under this setting, vegetation communities stay in particular states until a substantial shift in biotic or abiotic factors triggers a shift to a new stable state (Nowacki and Abrams 2008). For non-pyrogenic communities, large perturbations normally provide the impetus towards a state shift (Scheffer et al. 2001). For oak ecosystems, however, it is the lack of perturbation in the form of frequent fires, which causes this shift. Because red maple is capable of altering microclimates, soil and leaf litter chemistries, and pyrogenic properties (Washburn and Arthur 2003), its further increase in forested oak ecosystems will continue to disrupt and modify ecosystem processes as well as vegetation composition. As this occurs, successful reversal (i.e., restoration) back to the original stable state (i.e., oak-dominated forest) is dependent upon the elapsed time since the state shift, persistence of oak advanced regeneration and seed source, landscape context, and management intensity (Nowacki and Abrams 2008).

Management Considerations for Oak Regeneration

Example case studies for ice-contact, moraine, outwash, and lake plain landforms in both south and north regions (*see* Grouping 4 – By Management Prescription: Example Case Studies) indicate that active management generally had a positive effect on increasing oak regeneration compared to a decision of non-management. More specifically, management prescriptions that involved clearcuts, shelterwood cuts, or a combination of cuts and prescribed burns seemed to stimulate basal sprouting of existing oak stems. Some sites, especially those on outwash or lake plain landforms, appeared to require little management to sustain oak regeneration. Areas on the Allegan sand lake plain in the south region and the Newaygo outwash plain (e.g., Table 50a, GLA8) in the north region are good examples. Nevertheless, these cases were exceptions, and do not represent the majority of stands that managers encounter. The more common scenario were unmanaged stands with an oak-dominated overstory, the presence or absence of oak germinants, and a paucity of mid-structure oaks in the form of saplings and understory stems. Observation of sub-canopy overstory oaks were similarly uncommon.

The importance of active management for oak regeneration is implied in the logistic regression model C (Table 52a). To reiterate, characteristics that seem to confer the best probability of oak regeneration success are sites on outwash with sandy, low nutrient soil that have low overstory basal area and groundcover coverage, and high oak seedling abundance. Successful oak regeneration is not restricted or assured on sites that have all these characteristics, nor are all sites that lack these characteristics necessarily devoid of oak regeneration. The model merely suggests conditions that are most suitable for predicting oak regeneration success based on the sampled sites and the variables measured. Other factors such as acorn predation, insect defoliation, disease, leaf litter composition and chemistry, and competition from invasive species (Courteau et al. 2006) were not modeled but are important determinants of oak regeneration success or failure. In application, managers should first recognize the landforms and soil conditions on which their oak forests of interest are located and then proceed to identify those factors that can be manipulated. From the model, decreasing overstory and understory basal area, shrub abundance, and groundcover coverage (e.g., through prescribed burning) and increasing oak seedling abundance are plausible management prescriptions that are straightforward to implement. Altering soil chemistry and texture, however, is neither cost effective nor ecologically sound.

The most common form of oak management involves silvicultural practices that result in increased light transmittance to the understory and groundcover strata. In most cases, some method of overstory removal is usually applied. Only when canopy gaps are sufficiently large, with canopy cover reduced to about 50% (Brose et al. 1999, Hartman et al. 2005), are oaks able to recruit quickly into the overstory (Bazzaz 1979). The need for large canopy openings appears paradoxical at first given that oaks have fairly high photosynthetic rates, low to moderate respiration rates in shaded conditions, and low light compensation points (i.e., light level where photosynthetic rate equals respiration rate) compared to many non-oak species (Abrams 1996). All these physiological properties would seem to confer understory tolerance. However, their tolerance only manifests as persistence under conditions of episodic disturbance. Allocation of resources to underground reserves and production of defensive phenolic compounds (Abrams 1996) allow oaks to withstand several decades of unfavorable environmental conditions in the understory. When canopy openings occur, especially by fire, belowground reserves are then utilized for accelerated photosynthetic activity and shoot extension (Dillaway et al 2007). The importance of regular disturbance events to maintain partial canopy openings is demonstrated by the findings of Hartman et al. (2005), in which oaks regenerated poorly even under their own fully developed canopies.

In the current study, clearcuts and shelterwood cuts, both a method of even-age management (Johnson et al. 2002), were the most common treatments. Clearcuts usually involved complete overstory removal but reserve trees were sometimes retained. The majority of shelterwood cuts was typified by a progression from preparatory thinning, followed by 40 to 60% crown cover reduction, and then final overstory removal. Depending on the sites, the landforms on which they occurred, and the initial vegetation composition prior to treatment, these cuts increased understory stem density of oaks, increased understory stem density of non-oak species, or increased both oaks and non-oak competitors at varying ratios. In many sites on the Allegan lake plain (e.g., Table 40a, A18-N) or Newaygo outwash plain (e.g., Table 48a, BRAD1B), cutting was especially beneficial for oak regeneration, and very little competition from red maple was present. In contrast, cutting in moraine sites was beneficial for red maple regeneration, and little or no oak regeneration was observed (e.g., Table 34a, S1-CUT and Table 46a, MAN4B). Sites that showed varying levels of both oak and red maple regeneration after treatment often occurred on northern ice-contact terrain (e.g., Table 44a, GRAY23). Consequently, there appears to be a landform-mediated interaction that partially explains vegetation response following cutting. Other studies conducted in xeric ecosystems found that edaphic controls (i.e., low soil moisture, highly leached acidic soil, and wind-induced erosion and desiccation) can prevent mesophytic invasion. Study sites included excessively-drained outwash plains in Michigan (Host et al. 1987, Archambault et al. 1990), xeric ridges in the unglaciated Ozarks of Arkansas, and Appalachian oak forests of Virginia (Pallardy et al. 1998).

Unfortunately for managers, the most commercially valuable oak stands usually occur on loamy soil types that are amenable for growth of both oaks and other potentially dominant tree species. For instance, some northern red oak–dominated forests on loamy end moraine in Cadillac FMU and Atlanta FMU were historically occupied by more mesic northern hardwood species (e.g., sugar maple, American beech, and eastern hemlock), and red maple was likely a component. Sampled sites that had an abundant pool of red maple understory stems but low northern red oak advanced regeneration were susceptible to prolific sprout regeneration of red maple following cutting (Table 46a). Consequently, the success of silvicultural treatments that focus on overstory removal depends on favorable initial conditions of the understory (i.e., presence of adequate oak advanced regeneration prior to cutting) and controlling red maple, though black cherry, sassafras, and understory shrubs can be equally problematic. Both red maple and black cherry have greater plasticity than northern red oak to adjust leaf weight to leaf area ratio in changing light conditions (Gottschalk 1994). This plasticity translates into an adaptable crown response to cutting that places oaks at a competitive disadvantage when growing alongside red maple and black cherry, especially on rich soil types.

Recognizing that the growth response of non-oak species following cutting on higher quality sites may impede successful oak regeneration, some managers have conducted successive prescribed burns in conjunction with a variety of cutting treatments. Prescribed burns, in the context of oak management, are used to prepare mineral seedbeds for acorn germination and limit the growth of understory competitors. Rarely will prescribed burns alone be severe enough to induce overstory mortality and reduce canopy cover to levels that stimulate oak recruitment (Stan et al. 2006). Consequently, few burned-only sites in the current study showed any appreciable difference of oak regeneration compared to unmanaged sites, although the burns do appear to have stimulated the recovery of native groundcover species in some sites (e.g., Table 37, FC-BRN1). However, there is legitimate ecological value in prescribed burning (including controlling non-native species, expressing the native seed bank, stimulating flowering and seed production, reducing litter and populations of acorn predators, and altering soil chemistry and microclimate) that transcends a strict silvicultural objective of oak regeneration (Viro 1974, Reich et al.

1990, Courteau et al. 2006). Sites that were both cut and burned usually exhibited similar levels of oak regeneration as sites that were only cut, especially in cases where a single burn occurred. In several cases, the effect of burning appears to have stimulated red maple sprouting to a greater extent than oak sprouting, since understory red maple stems greater than 4.0 cm are capable of surviving low- to medium-intensity fires (Franklin et al. 2003). Adjusting the intensity of prescribed burns and the seasonality during which it is applied, as discussed below, is imperative if managers desire mortality of mesophytic oak competitors. The effectiveness of prescribed burns may also be amplified when combined with herbicidal treatments (e.g., "drill-and-fill").

The success of prescribed burns in stimulating oak regeneration is partially determined by the frequency, intensity, and timing of burns. Other equally important factors include ecosystem characteristics that affect the pyrogenicity of the managed unit and existing vegetation prior to treatment. For example, five years after a single prescribed burn at P-BURN on southern ice-contact terrain (Table 32a), understory red maple stems were prevalent and red maple seedling and sapling abundance were greater than that of oaks. The prescribed burn at P-BURN was low in intensity and severity, and red maple had established a substantial understory population prior to treatment. Oak advanced regeneration, on the other hand, was likely absent before treatment. Therefore, the effect of a single burn was minimal for stimulating oak regeneration or permanently eliminating red maple. In the Appalachian oak ridges of Kentucky, Blankenship and Arthur (2006) found reduced stem density of red maple following three low-intensity surface burns in a five-year period, but the proportion of clonal sprouts for surviving red maple stems had increased. Similarly, red maple clonal sprouting in the current study was much greater in the highly-managed north region than the south region, indicating that both fire and cutting stimulated clonal sprouting (Table 8). Blankenship and Arthur (2006) concluded that low-intensity burns during any part of the season resulted in strictly mixed-mesophytic dominance.

With appropriate initial conditions prior to management such as a lack of oak competitors, a variety of burn regimes can have positive effects upon oak regeneration. Other authors have expressed this sentiment as Franklin et al. (2003) concluded that each ecosystem responds with species extant at the time of treatment. In other words, the initial condition of the ecosystem prior to disturbance largely determines the outcome of post-treatment succession. In several sites of the current study where red maple was not abundant prior to treatment, prescribed burns, wildfires, and cut and burn activities successfully stimulated oak regeneration. Almost pure stands of black oak and white oak formed after severe wildfires swept through A11-5B(s) and A11-5B(n) on the Allegan lake plain (Table 40a). Good oak regeneration was also observed at MAN1B (Table 48a) on northern outwash, where a single prescribed burn occurred, and at HUR3C (Table 50a) on northern lake plain, where removal of jack pine and prescribed burns were conducted to convert a pine-dominated forest into an oak-dominated forest. In all preceding examples, burns were intense enough to stimulate oak sprouting, and, because of the lack of mesophytic competition, the future overstory will likely remain dominated by oak species. Blankenship and Arthur (2006) found that in the Appalachian oak ridges of Kentucky, medium-high intensity burns during the spring or winter resulted in dominance by oaks and mesophytic species in equal proportions. In the Piedmont of Virginia, a single high-intensity spring fire conducted 2 to 4 years after a 50% basal area reduction shelterwood cut was sufficient to regenerate oak to 75% dominance (Brose et al. 1999). Alternatively, a medium-high intensity summer burn after the same cutting treatment had similar results.

Where understory control of non-oak species is needed, other possible management options include application of herbicides, girdling, and mechanical removal. Johnson et al. (1989) showed promising results when herbicide was applied to competing vegetation prior to cutting, and Bundy et al. (1991) simultaneously removed competing vegetation while exposing the mineral seedbed for oak germination by scarifying the soil. A similar treatment involves mechanical uprooting of larger-stemmed competitors (Jacobs and Wray 1992). Following understory control, artificial planting of acorns may be done to increase oak seedling abundance. These methods, though somewhat effective, can be economically feasible only on a small scale. Chemicals used in herbicides are costly, and targeted species-specific spraying is laborious. In addition, compaction and disintegration of soil structure often are indirect effects when attempting mechanical removal.

Many studies have included predictive models to forecast likely success of oak regeneration when certain management practices are instituted (Weigel and Peng 2002, Götmark 2007, Steiner et al. 2008). Though the logistic regression model of the current study does allude to some general principles that may be universally followed for oak management (e.g., reducing overstory and understory basal area, encouraging oak seedling abundance), guidelines applicable throughout all oak-dominated forests of Michigan are difficult to specify due to the diversity of ecosystems. However, it may be more practical to highlight ecosystem-wide considerations rather than focusing on an objective of oak regeneration alone. In most situations, activities that benefit the ecosystem also encourage oak regeneration. For example, in the southern lake plain and all landforms of the north region, today's oak-dominated forests often have a large component of eastern white pine in the understory. Because eastern white pine was formerly a dominant species prior to the logging era, managing for an oak-pine overstory mix in these places may be appropriate.

A diversified overstory is beneficial because pests, such as gypsy moths, cause less mortality to oaks in mixed pine-oak stands than purely oak-dominated stands (McManus et al. 1989). Additionally, spread of oak wilt is slower in diversified stands since intraspecific fungal transmission via root grafting is not as prevalent when more than one species is present (O'Brien 2000, Courteau et al. 2006). The presence of pine species can also aid oak regeneration by serving as nurse tree cover and may make soil conditions more favorable for oaks by decreasing soil moisture and nutrient availability. Hartman et al. (2005) found greater incidence of oak regeneration and lower incidence of red maple regeneration under an overstory of pine compared to oak. A 5-6 cm litter layer composed of pine needles was believed to impede mineral soil penetration by radicles of red maple samaras; in contrast, the radicles of heavy-seeded acorns with ample stored reserves were better able to penetrate the needle substrate and reach mineral soil. Consequently, encouraging pine in the understory can inhibit the spread of undesirable mesophytic and early-successional species, many of which disperse light seeds. It is then feasible to sustain a cyclical pine-oak succession in which the overstory of one species serves to cultivate the understory of the other until replacement occurs and the process then alternates. Prescribed burns timed to coincide with oak and pine seed production may further aid this mutualism. Similar principles may be extended to the oak-hickory mutualism in the south region, and management prescriptions that benefit one species will likely also benefit the other.

Other aspects of oak ecosystem management include deer browse, frost damage, and restoration of open oak ecosystems and biodiversity. Deer browse increased with categorical levels of deer abundance (Figures 17a-c), but the relationship between oak regeneration and categorical levels of deer abundance was more ambiguous (Table 25). In the south region, oak regeneration was negatively related to deer abundance (Table 26), but this finding was not consistent among most oak species in the north region (Table 27) because of confounding factors related to geographic location and landform occurrence of sites categorized as having "high" deer abundance. These sites exhibited high deer abundance levels because they were located in the southern half of the north region in Iosco, Montcalm, and Newaygo counties where snowfall is less pronounced than counties farther north or those near the interior High Plains sub-subsection VII.2.2 (Albert 1995). Furthermore, 5 of 10 "high" sites occurred on sandy outwash or lake plain landforms that exhibited abundant oak regeneration and appeared unaffected by deer browse. The scale mismatch of using county-level deer abundance estimates for site-specific evaluation likely added additional uncertainty and inaccuracy.

The impact of deer browsing can exacerbate existing conditions that impede oak regeneration and recruitment into the overstory. For example, in both regions, red maple regeneration did not appear to be affected by any categorical level of deer abundance, indicating its potential competitive advantage over oak species in locations with high deer densities. Other species may similarly outcompete oaks when there is high incidence of deer herbivory. Busby et al. (2008) found that American beech in coastal New England mixed forests (i.e., oak-beech-hickory-pine) quickly established in the understory during an era of fire suppression and intermittent, low- to moderate-intensity hurricane disturbances. These events in conjunction with cessation of active logging and a high deer population favored American beech persistence. Like red maple, American beech foliage is less palatable to deer compared to oaks, and both red maple and American beech saplings are able to regenerate under their own canopies. Conversely, low understory tolerance, slow sapling growth, and frequent browsing of terminal shoots drastically reduce the probability of sustaining oak regeneration. Stewart et al. (2008) also found that autumnal deer herbivory can cause substantial losses of nitrogen and phosphorous stored in oak seedling stems and tissues. This finding is imminently applicable to the current study as sites with low soil phosphorous concentration and high deer abundance may be prone to poor oak regeneration.

Reducing deer density to levels that would no longer exacerbate the problem of oak regeneration is difficult for managers to propose to the hunting public, but it is vitally important from an ecological context (MacDougall 2008). An alternative to deer culling is to exclude deer from areas that have abundant oak advanced regeneration with exclosures or by purposely placing logging slash to serve as a physical barrier. This would be especially useful on ice-contact or moraine landforms that inherently exhibit poor oak regeneration.

In the north region, oak regeneration can be severely inhibited by frost damage if silvicultural practices contribute to the formation of frost pockets on the landscape. This possibility is most relevant for the northern ice-contact landform with surrounding outwash plains (Kalkaska, Crawford, Oscoda, Missaukee, Roscommon, and Ogemaw Counties). According to the Michigan DNR (Botti and Mech 2000), proper air drainage and mixing is crucial for the prevention of frost pockets. Additionally, cutting of forest patches greater than 0.81 ha promotes escape of warm air at the ground level while simultaneously pulling in cold air to replace it. Pine species provide the most effective thermal blanket, since their canopy is retained throughout the year. Again, where oak regeneration is a primary management concern, it may be prudent for managers to emphasize an oak-pine species mix and limit the size of clearcuts on landscapes prone to frost pocket formation.

As a final consideration, restoration to more open oak ecosystems (e.g., oak barrens, oak opening, and oak-pine barrens) through the conversion of closed-canopy oak ecosystems is a viable option in some cases. Evidence of groundcover prairie or barrens species may warrant this restoration objective. In the current study, however, groundcover composition at many sites was often dominated entirely by Pennsylvania sedge, bracken fern, or ericaceous shrubs. Beyond the purpose of stimulating oak regeneration, there are benefits to reducing overstory density (Courteau et al. 2006). Closely spaced trees are known to experience root grafting and can transmit resources among one another in mutualistic fashion. This is likely facilitated by mycorrhizal fungi (Dickie et al. 2002), but pathogenic outbreaks may also be spread more easily by this same mechanism (e.g., oak wilt mentioned previously). If species diversity can be increased by increasing light irradiance at the forest floor, this may also alleviate deer browse on oaks, since browse pressure would be distributed among a greater forage selection.

Future studies should be directed at experimental designs that elucidate the causative factors of oak regeneration in specific ecosystems (e.g., landform types) under specific management regimes. A complete history of study sites is necessary to control for past anthropogenic manipulations and disturbances. In addition, more variables need to be tested and modeled (e.g., direct inter-specific interactions, effects of combined management treatments, and effects of shading at multiple vegetation strata), and the effects on each oak species needs to be differentiated. The evolution and coexistence of oaks and hickories in the south region and oaks and pines in both south and north regions require better understanding so that management prescriptions benefit mutualistic species groups rather than any single species. Future studies should also carefully account for variations in herbivory, both by deer and other mammals (e.g., use of exclosures for control plots). More precise estimations of site-level deer abundance would have greatly improved some of the findings of the current study and reduced scale-related error. The consequences from a decision of non-management compared to the cost and uncertainty of active management need to be predicted more accurately before the onset of activities. Therefore, long-term studies that monitor results from paired control and treatment plots replicated across the landscape are recommended to evaluate management effectiveness. A sufficiently long monitoring period is recommended as most ecosystem responses occur on decadal or longer time scales.

CONCLUSIONS

The current overstory of many upland forests of Lower Michigan is dominated by oak species. However, a conspicuous lack of oak regeneration accompanied by increases in overstory and understory red maple abundance in many forested oak ecosystems prompted investigation of the problem as related to ecological factors and management and disturbance histories. Oak regeneration was found to vary between broad regional ecosystems (i.e., south and north regions of the Lower Peninsula) and among finer-scale landforms within each region (i.e., ice-contact terrain, moraine, outwash, and lake plain). At the regional level, oak regeneration was greater in the north region than south region, presumably because of its generally lower soil moisture and nutrient concentrations, which limit the growth of many oak competitors, and higher management intensity. However, red maple regeneration in both regions was equal to or greater than that of oak regeneration, suggesting the need for understory control and overstory removal of red maple. At the landform level, oak regeneration was generally greatest on outwash and sand lake plain landforms. The competitive advantage of red maple, in the absence of fire, on ice-contact and moraine landforms was not as pronounced or realized on the drier outwash and lake plain landforms. Therefore, there are landform-mediated factors that dictate the probability of successful oak regeneration.

Oak regeneration appears to be negatively related to deer abundance in the south region but did not show a consistent pattern among oak species in the north region. Red maple regeneration did not appear to be affected by any level of deer abundance in either region, which may provide it with a competitive advantage over oak where deer numbers are high.

Different management activities, ranging from various cutting regimes, prescribed burns, and combinations of cutting and burning resulted in different vegetation responses. More intensive activities, such as clearcuts and shelterwood cuts with or without prescribed burns positively increased oak regeneration compared to sites that received no recent management. However, controlling aggressive red maple sprouting following treatment is necessary to promote future oak recruitment. Conditions that corresponded to successful oak regeneration in the current study include: 1) low soil exchangeable cation concentration (i.e., low soil nutrient availability), 2) low overstory basal area, 3) low understory basal area, especially red maple, 4) low groundcover coverage, 5) low shrub abundance, 6) high oak seedling abundance, 7) occurrence on outwash or lake plain landforms, and 8) presence of sandy subsurface soil horizons (i.e., somewhat excessively-drained to excessively-drained soil). Consequently, managers seeking to promote oak regeneration must first take account of the ecological conditions of the site and initial conditions of the vegetation (i.e., existing species) prior to active management. Upon this evaluation, activities that will help ensure successful oak regeneration include reducing overstory basal area, increasing light availability in the understory, and limiting competition, especially from red maple, black cherry, and sassafras. In some situations, promoting a pine overstory to serve as future nurse tree cover for oak saplings may be warranted, especially in the north region. The current study has shown that great variation exists among forested oak ecosystems of Lower Michigan, and management for oak regeneration will benefit from a firm understanding of these differences at the regional and site level.

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TABLES AND FIGURES

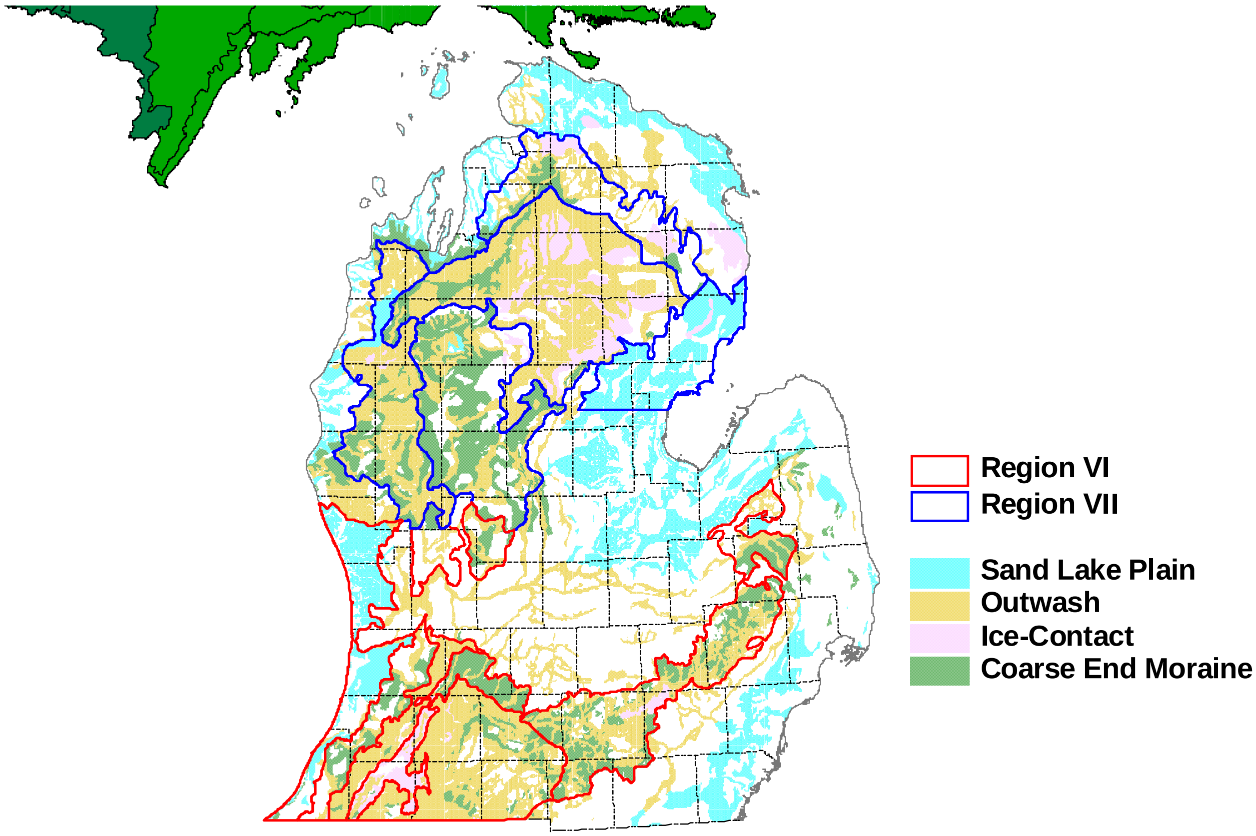


Figure 1. Map showing selected sub-subsections (Albert 1995) in both southern (Region VI) and northern (Region VII) regions where dry and dry-mesic oak forests are most abundant today. Also shown are the four most prominent landforms in which these oak forests occur (Farrand and Bell 1982). *Note*: some sub-subsection boundaries and landforms have been omitted for ease of viewing.

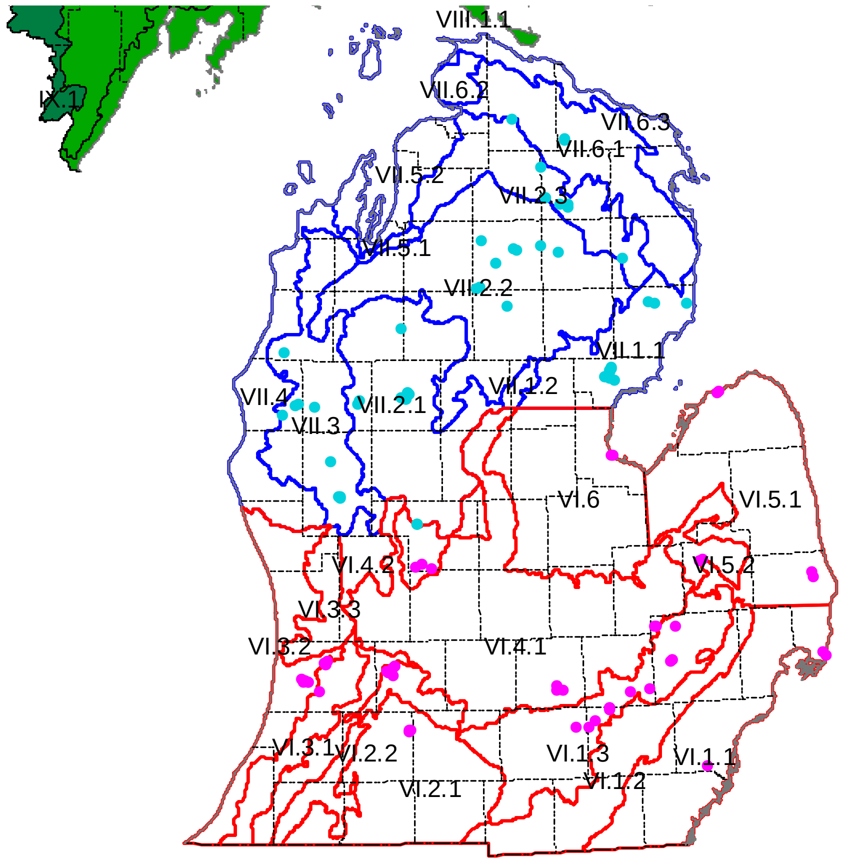


Figure 2. Sampled sites with sub-subsection boundaries shown for Region VI and Region VII. Pink dots depict sampled sites in Region VI bounded by red outline. Turquoise dots depict sampled sites in Region VII bounded by blue outline.

Table 1a. Summary of sampled sites organized by regional landscape ecosystems (Albert 1995) and landforms (Farrand and Bell 1982).

Region	Sub-Subsection	Landform[1]	# of Sites
South	VI.1.1	lake plain	3
	VI.1.3	ice-contact	7
		moraine	3
		outwash	2
	VI.2.1	outwash	4
	VI.2.2	moraine	6
		outwash	1
	VI.3.1	lake plain	2
		moraine	2
	VI.3.2	lake plain	7
	VI.4.1	ice-contact	1
		moraine	1
		outwash	3
	VI.4.2	moraine	1
		outwash	2
	VI.5.1	lake plain	4
	VI.5.2	moraine	2
	VI.6	lake plain	2
Region Total	11 sub-subsections	4 landforms	53
North	VII.1.1	lake plain	9
		outwash	2
	VII.2.1	ice-contact	1
		moraine	12
	VII.2.2	ice-contact	9
	VII.2.3	ice-contact	1
		moraine	5
		outwash	2
	VII.3	moraine	3
		outwash	6
	VII.6.1	moraine	2
Region Total	6 sub-subsections	4 landforms	52
Total	**17 sub-subsections**	**4 landforms**	**105**

[1] Lake plain designation includes sand lake plain, clay lake plain, sand-over-clay lake plain, and sand dune features. Moraine designation includes both ground and end moraines of varying soil textures.

Table 1b. Summary of sampled sites organized by landforms (Farrand and Bell 1982).

Region	Landform[(1)]	# of Sites
South	ice-contact	8
	moraine	15
	outwash	12
	lake plain	18
Region Total	4 landforms	53
North	ice-contact	11
	moraine	22
	outwash	10
	lake plain	9
Region Total	4 landforms	52
Total	**4 landforms**	**105**

[1] Lake plain designation includes sand lake plain, clay lake plain, sand-over-clay lake plain, and sand dune features. Moraine designation includes both ground and end moraines of varying soil textures.

Table 1c. Summary of sampled sites organized by Management Areas.

Region	Management Area[1]	# of Sites
South	Algonac SP	2
	Allegan SGA	11
	Barry SGA	5
	Bay City SRA	2
	Brighton SRA	1
	Dansville SGA	3
	Flat River SGA	3
	Fort Custer SRA	4
	Highland SRA	3
	Holly SRA	1
	Island Lake SRA	1
	Lapeer SGA	2
	Oakwoods MP	1
	Pinckney SRA	3
	Port Huron SGA	2
	Rush Lake SGA	2
	Seven Lakes SP	2
	Waterloo SRA	3
	Yankee Springs SRA	2
Region Total	19 areas	53
North	Atlanta FMU	7
	Cadillac FMU	10
	Gaylord FMU	1
	Gladwin FMU	8
	Grayling FMU	8
	Huron-Manistee NF (Huron)	4
	Huron-Manistee NF (Manistee)	9
	Langston SGA	3
	Pigeon River Country FMU	1
	Roscommon FMU	1
Region Total	10 areas	52
Total	**29 areas**	**105**

[1] MP – Metropark, NF – national forest, FMU – state forest management unit, SGA – state game area, SP – state park, SRA – state recreation area

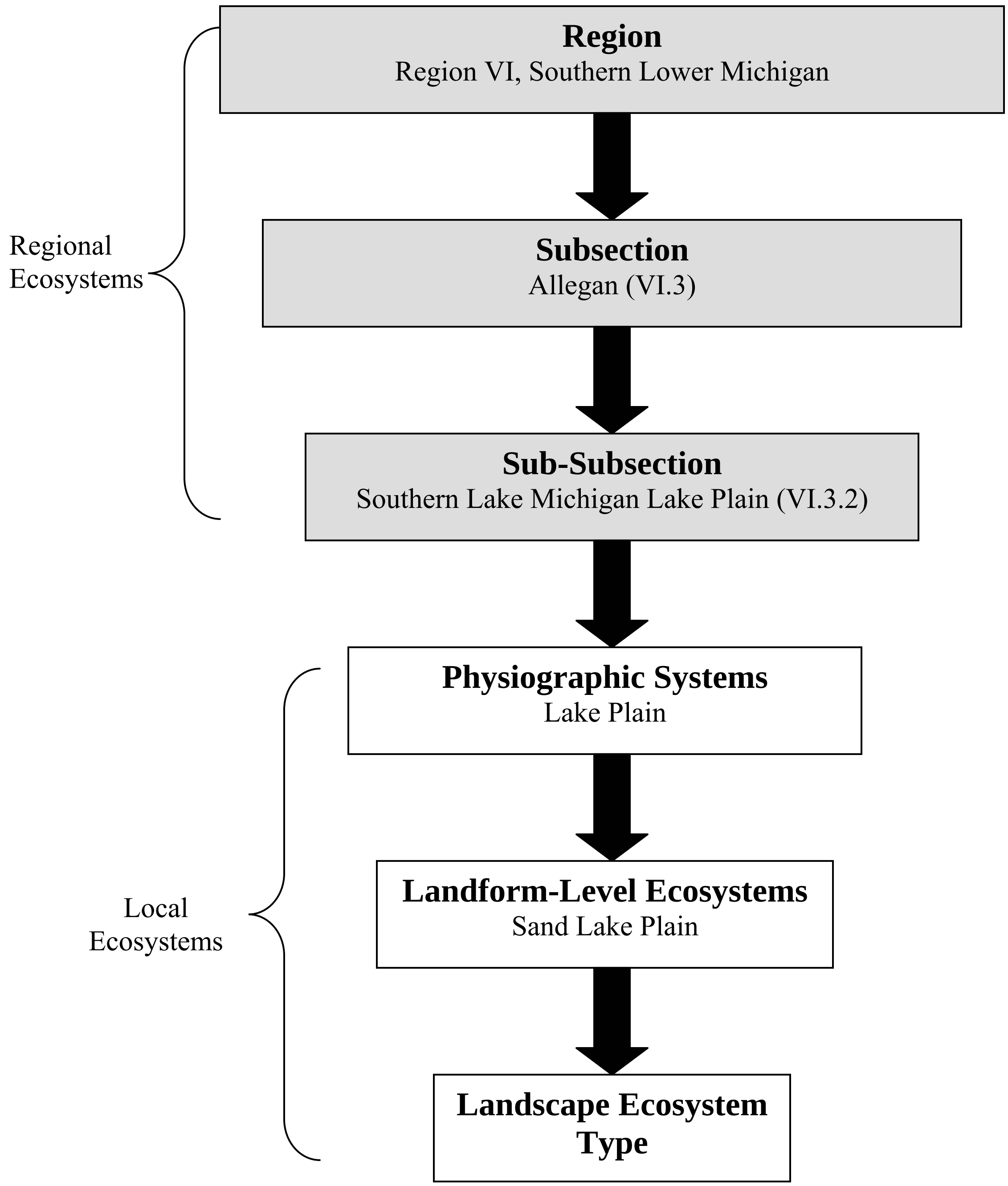


Figure 3. Example of the hierarchical organization of landscape ecosystems at successively smaller scales for oak-dominated forested ecosystems in Michigan. Adapted from Albert (1995).

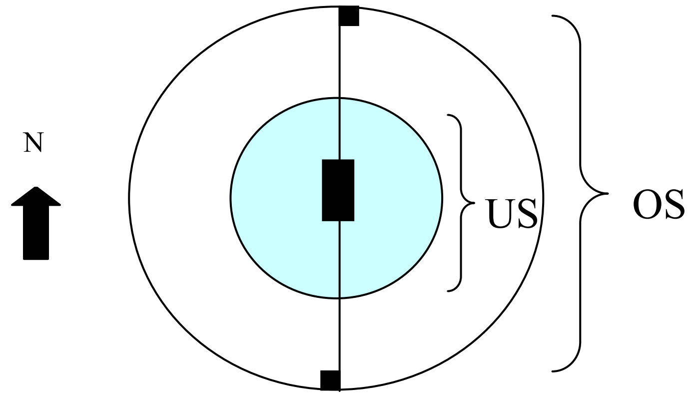


Figure 4. Conceptual diagram of a sampling plot. OS – overstory plot, US – understory plot. Also shown are the 4 m^2 strip transect plot and the two 1 m^2 groundcover plots.

Table 2. Definition of species groups for age class distributions.

Species Group	Scientific Name	Common Name
Early-Successional	*Betula papyrifera*	paper birch
	Populus grandidentata	bigtooth aspen
	Populus tremuloides	trembling aspen
	Prunus serotina	black cherry
	Sassafras albidum	sassafras
Mid-Successional	*Acer rubrum*	red maple
	Fraxinus americana	white ash
	Ulmus americana	American elm
Late-Successional	*Acer saccharum*	sugar maple
	Carya cordiformis	bitternut hickory
	Carya glabra	pignut hickory
	Carya ovata	shagbark hickory
	Fagus grandifolia	American beech
	Tilia americana	basswood
Oaks	*Quercus alba*	white oak
	Quercus ellipsoidalis	northern pin oak
	Quercus rubra	northern red oak
	Quercus velutina	black oak
Pines	*Pinus banksiana*	jack pine
	Pinus resinosa	red pine
	Pinus strobus	eastern white pine

Table 3. Variables included in discriminant analysis of landforms within the southern and northern regional ecosystems of Lower Michigan as selected by logistic regression and by an automated, backward elimination procedure of additional variables with a probability of 0.15 to remove.

	Chosen for South Region	Chosen for North Region
Variables From Logistic Regression		
Total Cation Concentration (P, K, Ca, Mg) - $\mu g\ g^{-1}$	X	X
Overstory Basal Area - $m^2\ ha^{-1}$	X	X
Understory Basal Area (w/o oaks) - $m^2\ ha^{-1}$	X	X
Percent Groundcover Coverage	X	X
Shrubs - # per 4 m^2 plot	X	X
All Oak Species Seedlings - # per 4 m^2 plot	X	X
Additional Variables		
Overstory Species Richness	X	X
Understory Species Richness		X
Groundcover Species Richness		
Soil pH	X	X
Percent Slope		X
Percent Canopy Closure		X
Tree Seedlings - # per 4 m^2 plot	X	X
Tree Saplings - # per 4 m^2 plot		
Percent Overstory Stems as Sprouts - All Species		
Percent Understory Stems as Sprouts - All Species		
Total	**9**	**12**

Table 4. Comparison of overstory tree species between the southern and northern regional ecosystems of Lower Michigan[1, 2].

	Overstory (dbh ≥ 9.1)				
	mean dbh (cm)	stem density (stems ha^{-1})	relative density (%)	basal area (m^2 ha^{-1})	relative dominance (%)
South					
Quercus velutina	37.0 (1.7)	131.4 (16.6)	28.0	12.3 (1.2)	46.0
Quercus alba	31.0 (1.7)	75.0 (12.3)	16.0	5.2 (0.7)	19.4
Acer rubrum	16.6 (0.7)	106.7 (16.2)	22.8	3.2 (0.6)	11.9
Quercus rubra	31.0 (3.3)	16.0 (3.7)	3.4	1.7 (0.5)	6.4
Prunus serotina	18.3 (1.0)	34.5 (5.9)	7.4	1.1 (0.2)	3.9
Carya glabra	23.8 (2.1)	16.8 (4.7)	3.6	0.9 (0.2)	3.2
Populus grandidentata	20.8 (1.3)	22.5 (16.5)	4.8	0.5 (0.3)	1.9
Sassafras albidum	15.1 (0.8)	20.8 (5.6)	4.4	0.5 (0.1)	1.7
Fraxinus americana	22.6 (3.5)	3.5 (1.6)	0.7	0.2 (0.1)	0.7
Populus tremuloides	27.3 (4.1)	2.6 (1.4)	0.6	0.2 (0.1)	0.7
Juglans nigra	34.4 (10.7)	1.6 (1.1)	0.3	0.2 (0.1)	0.6
Pinus strobus	18.2 (1.3)	4.2 (1.8)	0.9	0.1 (0.1)	0.5
Acer saccharum	17.0 (1.1)	4.3 (2.3)	0.9	0.1 (0.1)	0.5
Carya ovata	21.1 (2.9)	2.7 (1.0)	0.6	0.1 (0.1)	0.4
Carya cordiformis	35.5 (10.2)	1.0 (0.7)	0.2	0.1 (0.1)	0.3
Others (22 species)		24.9	5.3	0.5	1.9
Total		468.6 (25.7)	100.00	26.8 (1.0)†	100.00
North					
Quercus rubra	31.2 (1.5)	119.5 (19.6)	30.7	8.9 (1.3)	47.6
Quercus alba	26.1 (1.4)	63.3 (12.3)	16.3	2.7 (0.5)	14.4
Quercus velutina	30.2 (2.2)	45.3 (13.9)	11.6	2.5 (0.7)	13.6
Acer rubrum	14.1 (0.6)	76.0 (18.8)	19.5	1.7 (0.4)	9.0
Pinus resinosa	21.0 (2.7)	21.0 (13.7)	5.4	0.9 (0.6)	4.9
Populus grandidentata	19.8 (1.7)	24.4 (9.5)	6.3	0.8 (0.2)	4.2
Quercus ellipsoidalis	21.9 (3.1)	15.6 (7.9)	4.0	0.6 (0.3)	3.3
Pinus strobus	18.4 (1.8)	14.1 (5.1)	3.6	0.4 (0.1)	1.9
Pinus banksiana	15.1 (1.1)	2.4 (1.3)	0.6	0.1 (0.0)	0.3
Acer saccharum	13.8 (1.3)	3.9 (2.9)	1.0	0.1 (0.0)	0.3
Fagus grandifolia	14.6 (5.1)	0.6 (0.3)	0.2	0.0 (0.0)	0.1
Prunus serotina	18.0 (4.8)	0.5 (0.2)	0.1	0.0 (0.0)	0.1
Amelanchier arborea	10.5 (0.6)	1.3 (0.5)	0.3	0.0 (0.0)	0.1
Sassafras albidum	10.9 (0.8)	1.0 (0.4)	0.3	0.0 (0.0)	0.1
Fraxinus americana	16.4 (3.2)	0.4 (0.2)	0.1	0.0 (0.0)	0.0
Others (3 species)		0.4	0.1	0.0	0.0
Total		389.6 (37.1)	100.00	18.7 (1.4)†	100.00

[1] For each species, means are shown outside of parentheses, one standard error inside of parentheses. Listed are 15 species with the highest relative dominance in each region.
[2] Stem density and basal area [South (n = 53), North (n = 51)]. Mean dbh sample sizes vary by species.
† Indicates significant difference between regions at α = 0.05, two-sample independent t-test.

Table 5. Comparison of canopy closure, overstory richness, understory richness, and groundcover richness and coverage between the southern and northern regional ecosystems of Lower Michigan(1).

	Regional Ecosystem	
	South	North
Variable(2)		
Percent Canopy Closure†	92.19 (1.02)	75.36 (3.20)
Overstory Species Richness†	3.06 (0.12)	2.01 (0.12)
Understory Species Richness†	2.15 (0.15)	1.62 (0.16)
Groundcover Species Richness	6.34 (0.34)	5.75 (0.27)
Percent Groundcover Coverage†	15.61 (1.38)	31.69 (2.45)

1 For each variable, means are shown outside of parentheses, one standard error inside of parentheses.
2 For all variables except Overstory Species Richness: [South (n = 53), North (n = 52)]. Overstory Species Richness [South (n = 53), North (n = 51)].
† Indicates significant difference at α = 0.05, two-sample independent t-test. Significance for Percent Canopy Closure applies to arcsine-transformation of original values (i.e. arcsin √(x) = x').

Table 6. Comparison of overstory stem sprouting between the southern and northern regional ecosystems of Lower Michigan(1).

	Regional Ecosystem	
	South	North
Percent Stems as Sprouts (2)		
All Species†	15.85 (1.58)	29.59 (2.76)
All Oak Species†	14.01 (1.67)	31.75 (2.85)
Red Maple‡	19.68 (3.54)	40.91 (6.09)

1 For each variable, means are shown outside of parentheses, one standard error inside of parentheses.
2 Percent Stems as Sprouts: All Species [South (n = 53), North (n = 51)]; All Oak Species [South (n = 53), North (n = 49]; Red Maple [South (n = 40), North (n = 34)].
† Indicates significant difference at α = 0.05, two-sample independent t-test. Original values of all variables were log-transformed (i.e. Log_{10} (x + 1) = x') before significance tests.
‡ Indicates significant difference at α = 0.05, two-sample independent Mann-Whitney U-Test.

Table 7. Comparison of understory tree species between the southern and northern regional ecosystems of Lower Michigan[1, 2].

	Understory (1.5 ≥ dbh < 9.1)				
	mean dbh (cm)	stem density (stems ha^{-1})	relative density (%)	basal area (m^2 ha^{-1})	relative dominance (%)
South					
Acer rubrum	4.3 (0.2)	342.6 (68.5)	25.9	0.565 (0.109)	29.8
Quercus alba	4.8 (0.4)	199.6 (82.1)	15.1	0.276 (0.109)	14.6
Prunus serotina	4.1 (0.3)	92.8 (14.6)	7.0	0.139 (0.026)	7.4
Cornus florida	4.3 (0.4)	79.2 (23.1)	6.0	0.130 (0.044)	6.9
Amelanchier arborea	3.5 (0.3)	80.4 (17.9)	6.1	0.115 (0.038)	6.1
Quercus velutina	4.3 (0.5)	84.5 (26.9)	6.4	0.114 (0.034)	6.0
Sassafras albidum	4.7 (0.3)	57.7 (13.0)	4.4	0.102 (0.022)	5.4
Hamamelis virginiana	2.7 (0.1)	131.3 (37.5)	9.9	0.099 (0.031)	5.2
Ostrya virginiana	3.8 (0.3)	47.5 (17.2)	3.6	0.065 (0.025)	3.4
Ulmus americana	4.1 (0.4)	35.5 (15.7)	2.7	0.052 (0.021)	2.7
Carya glabra	3.8 (0.4)	28.7 (7.6)	2.2	0.045 (0.015)	2.4
Quercus rubra	5.5 (1.0)	8.3 (3.7)	0.6	0.028 (0.014)	1.5
Acer saccharum	4.6 (0.7)	15.5 (10.3)	1.2	0.025 (0.014)	1.3
Populus grandidentata	4.8 (1.0)	7.5 (4.6)	0.6	0.020 (0.016)	1.1
Carya cordiformis	3.0 (1.3)	10.2 (9.8)	0.8	0.016 (0.016)	0.9
Others (29 species)		99.2	7.5	0.102	5.4
Total		1320.8 (137.0)†	100.00	1.893 (0.191)	100.00
North					
Acer rubrum	3.4 (0.2)	640.3 (104.1)	34.1	0.601 (0.114)	32.4
Quercus alba	3.8 (0.4)	187.7 (76.6)	10.0	0.275 (0.147)	14.8
Hamamelis virginiana	2.4 (0.1)	318.1 (99.8)	17.0	0.189 (0.056)	10.2
Quercus rubra	3.6 (0.5)	126.8 (73.1)	6.8	0.166 (0.097)	8.9
Populus grandidentata	3.7 (0.5)	198.8 (61.5)	10.6	0.160 (0.046)	8.6
Pinus strobus	4.5 (0.4)	75.4 (37.1)	4.0	0.127 (0.065)	6.8
Quercus velutina	4.0 (0.5)	99.6 (29.9)	5.3	0.111 (0.034)	6.0
Amelanchier arborea	2.5 (0.2)	73.7 (23.6)	3.9	0.055 (0.019)	3.0
Sassafras albidum	3.4 (0.4)	34.2 (13.3)	1.8	0.043 (0.020)	2.3
Prunus serotina	2.8 (0.2)	44.2 (16.1)	2.4	0.032 (0.012)	1.7
Pinus banksiana	3.4 (0.4)	15.1 (6.5)	0.8	0.023 (0.013)	1.2
Pinus resinosa	4.5 (0.8)	8.8 (4.7)	0.5	0.018 (0.010)	0.9
Quercus ellipsoidalis	3.6 (0.7)	9.6 (6.6)	0.5	0.014 (0.010)	0.8
Acer saccharum	4.5 (1.1)	11.2 (10.4)	0.6	0.013 (0.011)	0.7
Fagus grandifolia	3.9 (0.5)	9.2 (4.7)	0.5	0.012 (0.007)	0.7
Others (7 species)		22.4	1.2	0.019	1.0
Total		1875.2 (237.8)†	100.00	1.857 (0.273)	100.00

[1] For each species, means are shown outside of parentheses, one standard error inside of parentheses. Listed are 15 species with the highest relative dominance in each region.
[2] Stem density and basal area [South (n = 53), North (n = 52)]. Mean dbh sample sizes vary by species.
† Indicates significant difference between regions at α = 0.05, two-sample independent t-test.

Table 8. Comparison of understory stem sprouting between the southern and northern regional ecosystems of Lower Michigan[(1)].

	Regional Ecosystem	
	South	North
Percent Stems as Sprouts[(2)]		
All Species†	26.23 (2.83)	53.05 (3.82)
All Oak Species‡	19.60 (4.85)	40.21 (6.41)
Red Maple‡	19.63 (4.13)	58.77 (6.15)

[1] For each variable, means are shown outside of parentheses, one standard error inside of parentheses.
[2] Percent Stems as Sprouts: All Species [South (n = 53), North (n = 52)]; All Oak Species [South (n = 30), North (n = 35]; Red Maple [South (n = 44), North (n = 40)].
† Indicates significant difference at $\alpha = 0.05$, two-sample independent t-test. Original values of all variables were log-transformed (i.e. $Log_{10}(x + 1) = x'$) before significance tests.
‡ Indicates significant difference at $\alpha = 0.05$, two-sample independent Mann-Whitney U-Test.

Table 9a. Comparison of oak and red maple regeneration (understory stem density) between the southern and northern regional ecosystems of Lower Michigan[1, 2].

	Regional Ecosystem	
	South	North
Understory Stem Density (stems ha^{-1})		
All Oak Species†	292.83 (103.81)	423.76 (115.34)
White Oak	199.62 (82.07)	187.69 (76.59)
Black Oak-Northern Pin Oak[3]	84.91 (27.03)	109.23 (30.00)
Northern Red Oak‡	8.30 (3.75)	126.84 (73.08)
Red Maple†	342.64 (68.51)	640.30 (104.14)

1 For each variable, means are shown outside of parentheses, one standard error inside of parentheses.
2 For all variables: South (n = 53), North (n = 52).
3 Stems of black oak and northern pin oak are aggregated due to difficulties with field identification between these closely related species.
† Indicates significant difference at $\alpha = 0.10$, two-sample independent Mann-Whitney U-Test.
‡ Indicates significant difference at $\alpha = 0.05$, two-sample independent Mann-Whitney U-Test.

Table 9b. Comparison of difference in oak and red maple regeneration (understory stem density) between the southern and northern regional ecosystems of Lower Michigan[1].

	Regional Ecosystem	
	South	North
Difference in Understory Stem Density (stems ha^{-1})[2]		
All Oak Species and Red Maple Difference	-49.81 (134.88)	-216.54 (162.70)

1 Means are shown outside of parentheses, one standard error inside of parentheses.
2 Positive number indicates greater oak than red maple abundance; negative number indicates converse. South (n = 53), North (n = 52).

Table 10a. Comparison of groundcover vegetation between the southern and northern regional ecosystems of Lower Michigan listed by highest coverage[1, 2].

	Ground Cover (dbh < 1.5 cm)		
	frequency (# of subplot occurrences)	mean coverage (% of 1 m^2 plot)	relative coverage (%)
South			
Pteridium aquilinum	173	1.97	12.7
Sassafras albidum	297	1.24	7.9
Carex pensylvanica	437	0.97	6.2
Prunus serotina	351	0.89	5.7
Gaylussacia baccata	103	0.89	5.7
Quercus alba	200	0.74	4.7
Rubus allegheniensis	45	0.63	4.0
Quercus velutina	301	0.57	3.7
Acer rubrum	418	0.54	3.5
Hamamelis virginiana	85	0.44	2.9
Parthenocissus quinquefolia	157	0.43	2.8
Rubus flagellaris	182	0.42	2.7
Cornus foemina	65	0.41	2.6
Viburnum acerifolium	58	0.39	2.5
Vaccinium angustifolium	168	0.38	2.4
Others (227 species)	3677	4.69	30.1
Total	6717	15.61	100.00
North			
Pteridium aquilinum	553	10.66	33.6
Carex pensylvanica	672	6.08	19.2
Vaccinium angustifolium	559	2.20	6.9
Quercus alba	251	1.67	5.3
Acer rubrum	553	1.67	5.3
Quercus velutina	201	1.30	4.1
Gaylussacia baccata	122	0.78	2.5
Quercus rubra	252	0.64	2.0
Prunus serotina	203	0.58	1.8
Gaultheria procumbens	254	0.58	1.8
Rubus allegheniensis	56	0.51	1.6
Amelanchier arborea	287	0.47	1.5
Populus grandidentata	46	0.45	1.4
Hamamelis virginiana	114	0.40	1.3
Aster macrophyllus	73	0.37	1.2
Others (141 species)	1756	3.33	10.5
Total	5952	31.69	100.00

[1] Listed are 15 species with the highest relative coverage in each region.
[2] Number of subplots for South and North are 1060 and 1038, respectively.

Table 10b. Comparison of groundcover vegetation between the southern and northern regional ecosystems of Lower Michigan listed by highest frequency[1,2].

Ground Cover (dbh < 1.5 cm)			
	frequency (# of subplot occurrences)	mean coverage (% of 1 m^2 plot)	relative coverage (%)
South			
Carex pensylvanica	437	0.97	6.2
Acer rubrum	418	0.54	3.5
Prunus serotina	351	0.89	5.7
Quercus velutina	301	0.57	3.7
Sassafras albidum	297	1.24	7.9
Desmodium glutinosum	264	0.37	2.4
Quercus alba	200	0.74	4.7
Rubus flagellaris	182	0.42	2.7
Fraxinus americana	180	0.28	1.8
Pteridium aquilinum	173	1.97	12.7
Vaccinium angustifolium	168	0.38	2.4
Parthenocissus quinquefolia	157	0.43	2.8
Osmorhiza claytonii	157	0.09	0.6
Desmodium nudiflorum	129	0.23	1.5
Circaea lutetiana	127	0.12	0.8
Others (227 species)	3176	6.35	40.7
Total	6717	15.61	100.00
North			
Carex pensylvanica	672	6.08	19.2
Vaccinium angustifolium	559	2.20	6.9
Pteridium aquilinum	553	10.66	33.6
Acer rubrum	553	1.67	5.3
Amelanchier arborea	287	0.47	1.5
Gaultheria procumbens	254	0.58	1.8
Quercus rubra	252	0.64	2.0
Quercus alba	251	1.67	5.3
Prunus serotina	203	0.58	1.8
Quercus velutina	201	1.30	4.1
Oryzopsis asperifolia	176	0.27	0.9
Trientalis borealis	150	0.10	0.3
Maianthemum canadense	124	0.07	0.2
Gaylussacia baccata	122	0.78	2.5
Hamamelis virginiana	114	0.40	1.3
Others (141 species)	1481	4.22	13.3
Total	5952	31.69	100.00

[1] Listed are 15 species with the highest frequency in each region.
[2] Number of subplots for South and North are 1060 and 1038, respectively.

Table 11. Comparison of seedling, sapling, and shrub abundance between the southern and northern regional ecosystems of Lower Michigan[1].

	Regional Ecosystem	
	South	North
Variable[2]		
All Oak Species Seedling†	3.95 (0.47)	7.96 (0.98)
All Oak Species Saplings	0.24 (0.06)	0.33 (0.07)
Red Maple Seedlings†	3.70 (0.75)	12.89 (2.39)
Red Maple Saplings	0.27 (0.06)	0.56 (0.13)
Tree Seedlings	14.91 (1.49)	18.98 (2.73)
Tree Saplings	0.72 (0.10)	1.04 (0.18)
Shrubs†	18.12 (2.87)	60.46 (10.02)

[1] For each variable, means are shown outside of parentheses, one standard error inside of parentheses.
[2] Seedlings = 1-150 cm tall, Saplings = 151-300+ cm tall. For all variables: South (n = 53), North (n = 52). Units are numbers per 4 m^2 plot.
† Indicates significant difference at $\alpha = 0.05$, two-sample independent t-test. Original values of all variables were log-transformed (i.e. $Log_{10}(x + 1) = x'$) before significance tests.

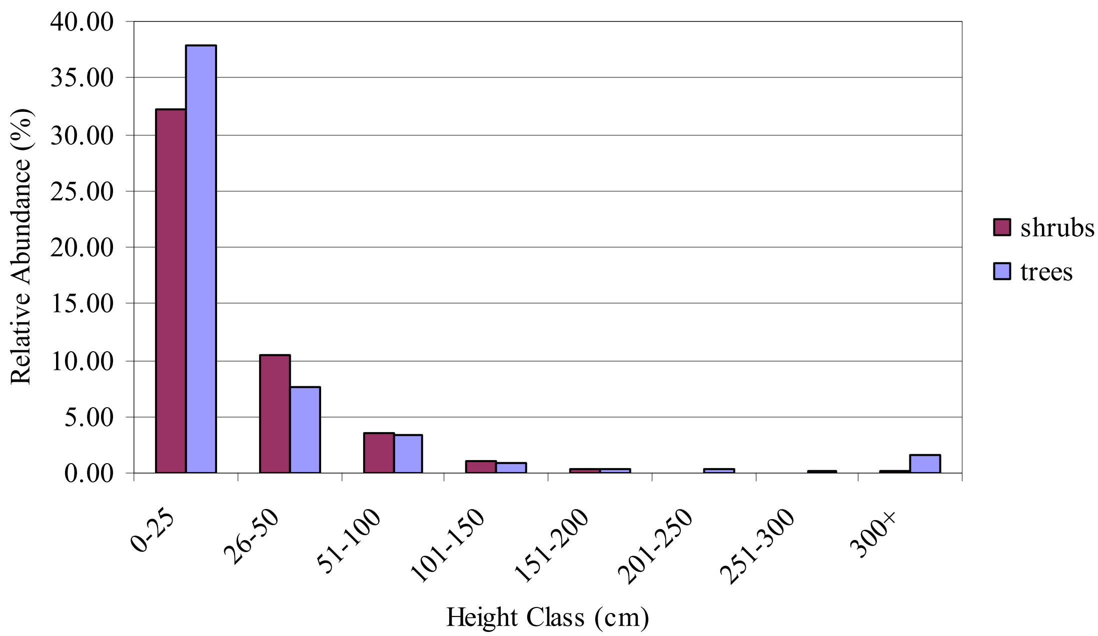


Figure 5. Height class distribution of tree and shrub seedlings and saplings in the **southern** regional ecosystem of Lower Michigan. Relative abundance of each physiognomic group shown as a percentage of total stems among all height classes.

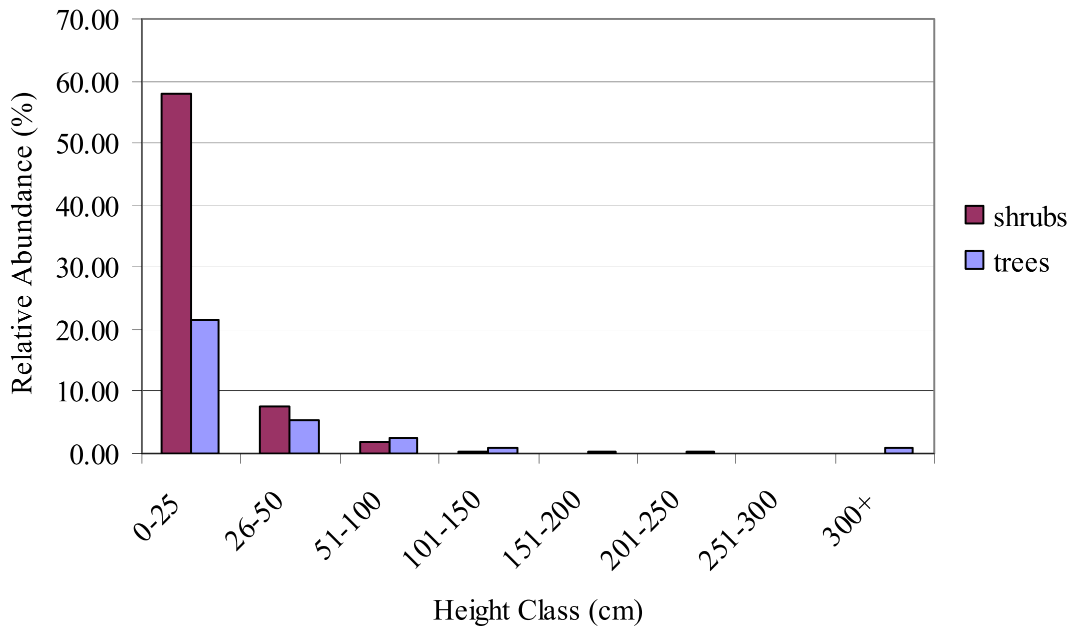


Figure 6. Height class distribution of tree and shrub seedlings and saplings in the **northern** regional ecosystem of Lower Michigan. Relative abundance of each physiognomic group shown as a percentage of total stems among all height classes.

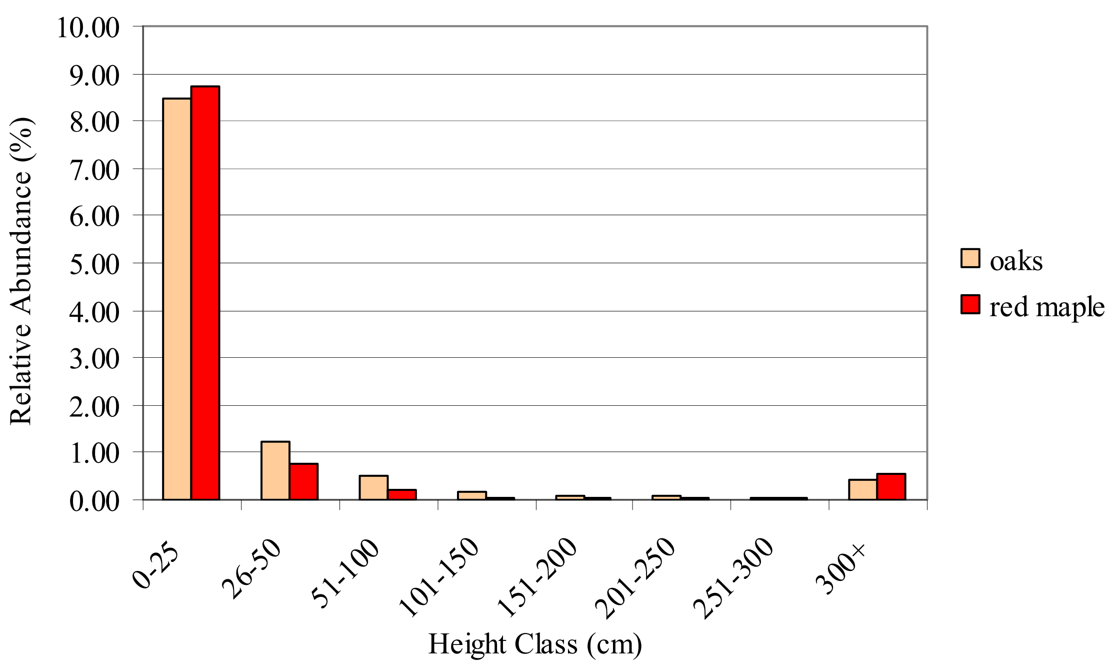


Figure 7. Height class distribution of all collective oak species and red maple seedlings and saplings in the **southern** regional ecosystem of Lower Michigan. Relative abundance of each species group shown as a percentage of total stems among all height classes.

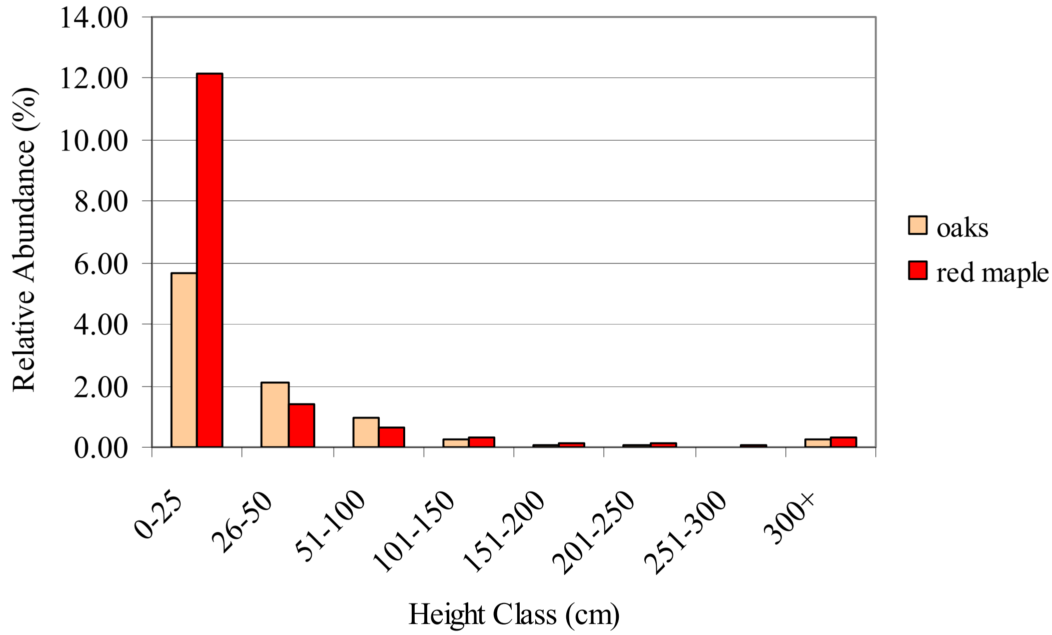


Figure 8. Height class distribution of all collective oak species and red maple seedlings and saplings in the **northern** regional ecosystem of Lower Michigan. Relative abundance of each species group shown as a percentage of total stems among all height classes.

Table 12. Comparison of deer browsing pressure between the southern and northern regional ecosystems of Lower Michigan(1).

	Regional Ecosystem	
	South	North
Percent Browsed Stems(2)		
All Species†	13.58 (1.65)	1.09 (0.34)
All Oak Species†	12.93 (2.22)	0.20 (0.11)
Red Maple†	14.57 (3.19)	0.89 (0.47)

1 For each variable, means are shown outside of parentheses, one standard error inside of parentheses.
2 Percent Browsed Stems: All Species [South (n = 53), North (n = 52)]; All Oak Species [South (n = 52), North (n = 52)]; Red Maple [South (n = 51), North (n = 46)].
† Indicates significant difference at $\alpha = 0.05$, two-sample independent Mann-Whitney U-Test.

Table 13. Comparison of soil pH, exchangeable cations, and physiographic features between the southern and northern regional ecosystems of Lower Michigan[1].

	Regional Ecosystem	
	South	North
Variable[2]		
pH†	4.89 (0.07)	4.50 (0.03)
P†	47.50 (3.63)	27.15 (2.68)
K†	49.12 (2.42)	24.20 (0.85)
Ca†	376.11 (44.10)	128.04 (11.34)
Mg†	58.94 (6.33)	24.43 (1.54)
Transformed Aspect	1.01 (0.05)	1.07 (0.05)
Percent Slope	-8.39 (1.11)	-6.76 (0.65)

1 For each variable, means are shown outside of parentheses, one standard error inside of parentheses.

2 P = phosphorus (µg g^{-1}), K = potassium (µg g^{-1}), Ca = calcium (µg g^{-1}), Mg = magnesium (µg g^{-1}). For all variables: South (n = 53), North (n = 52).

† Indicates significant difference at $\alpha = 0.05$, two-sample independent t-test. Significance for P, K, Ca, and Mg applies to log-transformation of original values (i.e. Log_{10} (x) = x’).

Table 14. Comparison of overstory tree species among landforms within the southern and northern regional ecosystems of Lower Michigan[1, 2].

	Overstory (dbh ≥ 9.1)				
	mean dbh (cm)	stem density (stems ha^{-1})	relative density (%)	basal area (m^2 ha^{-1})	relative dominance (%)
			South		
Ice-Contact					
Quercus velutina	39.4 (3.0)	98.8 (35.0)	24.9	10.1 (2.6)	37.5
Quercus alba	38.4 (4.2)	36.9 (8.9)	9.3	5.3 (1.7)	19.5
Quercus rubra	34.4 (9.4)	27.5 (13.5)	6.9	3.8 (1.8)	14.0
Carya glabra	29.2 (2.2)	45.6 (19.1)	11.5	3.3 (1.2)	12.2
Acer rubrum	16.6 (1.6)	67.5 (19.9)	17.0	1.9 (0.5)	6.9
Others (17 species)		120.6	30.4	2.7	9.9
Total		396.9 (19.7)	100.00	26.9 (2.2)	100.00
Moraine					
Quercus velutina	37.7 (4.0)	128.3 (33.2)	23.8	12.2 (2.8)	43.7
Quercus alba	31.3 (3.4)	66.0 (10.0)	12.2	5.2 (1.1)	18.7
Acer rubrum	16.9 (1.4)	135.7 (24.7)	25.2	3.5 (0.7)	12.4
Quercus rubra	30.7 (6.6)	20.0 (7.2)	3.7	2.2 (1.1)	7.7
Populus grandidentata	18.0 (2.5)	64.7 (57.6)	12.0	1.1 (0.8)	3.8
Others (21 species)		124.7	23.1	3.8	13.6
Total		539.3 (68.1)	100.0	28.0 (1.9)	100.0
Outwash					
Quercus velutina	32.4 (3.1)	167.9 (37.8)	32.3	13.5 (2.6)	47.6
Acer rubrum	17.3 (1.3)	135.0 (33.8)	25.9	4.3 (1.4)	15.1
Quercus alba	29.5 (3.4)	47.5 (13.3)	9.1	3.8 (1.2)	13.4
Prunus serotina	23.5 (2.1)	66.7 (14.3)	12.8	2.8 (0.7)	10.0
Carya glabra	16.0 (1.1)	29.6 (13.4)	5.7	0.7 (0.3)	2.6
Others (20 species)		73.8	14.2	3.2	11.2
Total		520.4 (28.1)	100.0	28.4 (2.3)	100.0
Lake Plain					
Quercus velutina	38.6 (2.9)	124.2 (28.4)	30.5	12.7 (2.1)	50.9
Quercus alba	28.9 (2.8)	117.8 (32.0)	28.9	6.1 (1.3)	24.7
Acer rubrum	15.5 (1.3)	81.1 (34.9)	19.9	2.8 (1.4)	11.4
Quercus rubra	26.4 (5.0)	14.2 (6.8)	3.5	1.1 (0.6)	4.6
Prunus serotina	17.5 (2.0)	20.3 (9.2)	5.0	0.5 (0.2)	1.9
Others (19 species)		49.4	12.2	1.6	6.6
Total		406.9 (40.8)	100.0	24.8 (1.5)	100.0

Table 14. (continued).

	Overstory (dbh ≥ 9.1)				
	mean dbh (cm)	stem density (stems ha^{-1})	relative density (%)	basal area (m^2 ha^{-1})	relative dominance (%)
			North		
Ice-Contact					
Quercus rubra	30.0 (1.4)	155.0 (26.1)	41.2	11.1 (1.8)	59.1
Quercus alba	27.0 (1.8)	59.5 (23.2)	15.8	2.9 (1.0)	15.5
Acer rubrum	12.4 (0.7)	66.8 (45.1)	17.8	1.4 (1.1)	7.3
Pinus strobus	20.7 (3.1)	44.5 (20.2)	11.8	1.1 (0.4)	5.7
Pinus resinosa	19.0 (3.1)	20.5 (9.9)	5.4	1.0 (0.6)	5.2
Others (5 species)		30.0	8.0	1.3	7.1
Total		376.4 (71.0)	100.00	18.8 (2.6)	100.00
Moraine					
Quercus rubra	31.3 (2.4)	165.0 (28.1)	41.2	13.3 (2.2)	61.7
Acer rubrum	14.7 (0.9)	120.5 (34.3)	30.1	2.8 (0.8)	13.1
Quercus alba	29.2 (3.4)	36.6 (11.5)	9.1	2.0 (0.6)	9.3
Quercus velutina	33.4 (4.2)	20.0 (9.6)	5.0	1.9 (0.9)	8.7
Populus grandidentata	20.6 (3.3)	38.0 (20.8)	9.5	1.2 (0.5)	5.4
Others (10 species)		20.7	5.2	0.4	1.8
Total		400.7 (57.8)	100.0	21.6 (2.0)	100.0
Outwash					
Quercus velutina	23.9 (3.8)	138.3 (62.0)	30.8	5.5 (2.7)	35.6
Pinus resinosa	32.3 (4.9)	81.7 (76.2)	18.2	3.8 (3.2)	24.5
Quercus alba	20.9 (2.8)	115.6 (49.1)	25.7	3.0 (1.3)	19.8
Quercus rubra	19.9 (-)	69.4 (69.4)	15.5	2.3 (2.3)	14.8
Acer rubrum	14.8 (2.2)	29.4 (24.0)	6.6	0.4 (0.3)	2.6
Others (4 species)		15.0	3.3	0.4	2.6
Total		449.4 (128.6)	100.0	15.4 (4.5)	100.0
Lake Plain					
Quercus alba	24.0 (1.6)	81.1 (26.1)	25.4	3.8 (1.2)	25.4
Quercus velutina	28.9 (1.7)	59.4 (28.7)	18.6	3.6 (1.6)	24.5
Quercus ellipsoidalis	21.9 (3.1)	88.3 (37.5)	27.7	3.5 (1.6)	24.1
Quercus rubra	39.3 (2.8)	15.0 (11.5)	4.7	2.0 (1.5)	13.4
Populus grandidentata	17.6 (2.3)	20.0 (10.2)	6.3	0.7 (0.5)	4.9
Others (6 species)		55.0	17.2	1.1	7.7
Total		318.9 (44.2)	100.0	14.7 (2.5)	100.0

[1] For each species, means are shown outside of parentheses, one standard error inside of parentheses. Listed are five species with the highest relative dominance in each Region's landforms.

[2] Stem density and basal area for South: Ice-Contact (n = 8), Moraine (n = 15), Outwash (n = 12), Lake Plain (n = 18). Stem density and basal area for North: Ice-Contact (n = 11), Moraine (n = 22), Outwash (n = 9), Lake Plain (n = 9). Mean dbh sample sizes vary by species.

Table 15. Comparison of overstory richness, understory richness, and groundcover richness and coverage among landforms within the southern and northern regional ecosystems of Lower Michigan[1].

	Landform			
	Ice-Contact	Moraine	Outwash	Lake Plain
		South		
Variable[2]				
Percent Canopy Closure	93.23 (3.00)	94.84 (1.04)	92.39 (1.88)	89.38 (2.14)
Overstory Species Richness†	3.65 (0.36)[a]	3.39 (0.15)[a]	3.28 (0.24)[a]	2.36 (0.17)[b]
Understory Species Richness	2.09 (0.30)	2.44 (0.27)	2.22 (0.35)	1.88 (0.25)
Groundcover Species Richness	6.91 (1.11)	5.57 (0.50)	7.44 (0.89)	5.99 (0.45)
Percent Groundcover Coverage†	16.47 (3.68)[ab]	10.94 (1.81)[a]	13.40 (2.71)[ab]	20.59 (2.55)[b]
		North		
Percent Canopy Closure†	76.31 (4.49)[ab]	85.29 (3.80)[a]	62.76 (9.76)[b]	63.92 (8.08)[b]
Overstory Species Richness	2.36 (0.28)	1.94 (0.17)	1.72 (0.31)	2.01 (0.25)
Understory Species Richness	1.27 (0.18)	2.10 (0.31)	1.41 (0.24)	1.12 (0.11)
Groundcover Species Richness	6.23 (0.31)	5.88 (0.33)	5.60 (1.07)	5.00 (0.63)
Percent Groundcover Coverage	34.39 (4.10)	28.11 (3.96)	33.28 (5.81)	35.39 (6.72)

[1] For each variable, means are shown outside of parentheses, one standard error inside of parentheses.

[2] For all variables for South: Ice-Contact (n = 8), Moraine (n = 15), Outwash (n = 12), Lake Plain (n = 18). Percent Canopy Closure, Understory Species Richness, Groundcover Species Richness, and Percent Groundcover Coverage for North: Ice-Contact (n = 11), Moraine (n = 22), Outwash (n = 10), Lake Plain (n = 9). Overstory Species Richness for North: Ice-Contact (n = 11), Moraine (n = 22), Outwash (n = 9), Lake Plain (n = 9).

† Indicates significant difference at $\alpha = 0.05$, ANOVA. Significance for Percent Canopy Closure applies to arcsine-transformation of original values (i.e. arcsin $\sqrt{(x)} = x'$). Comparisons with the same letter are not significantly different at $\alpha = 0.05$ when applying Tukey's HSD test.

Table 16. Comparison of overstory stem sprouting among landforms within the southern and northern regional ecosystems of Lower Michigan[1].

	Landform			
	Ice-Contact	Moraine	Outwash	Lake Plain
		South		
Percent Stems as Sprouts				
All Species†	6.51 (2.37)[a]	19.38 (3.65)[b]	17.34 (2.60)[b]	16.06 (2.54)[ab]
All Oak Species	7.56 (2.47)	17.35 (4.27)	12.28 (2.77)	15.25 (2.53)
Red Maple	6.57 (3.69)	26.30 (7.05)	18.79 (5.57)	19.73 (7.87)
		North		
All Species	27.99 (3.54)	33.25 (4.82)	22.06 (6.88)	30.11 (6.47)
All Oak Species	33.98 (2.38)	30.58 (5.18)	28.27 (8.15)	35.39 (6.07)
Red Maple	46.23 (15.28)	45.88 (8.41)	22.96 (14.45)	32.52 (14.93)

[1] For each variable, means are shown outside of parentheses, one standard error inside of parentheses.

† Indicates significant difference at $\alpha = 0.10$, ANOVA. Original values were log-transformed (i.e. $\text{Log}_{10}(x + 1) = x'$) before significance test. Comparisons with the same letter are not significantly different at $\alpha = 0.10$ when applying Tukey's HSD test.

SAMPLE SIZES FOR TABLE 16

	Landform			
	Ice-Contact	Moraine	Outwash	Lake Plain
		South		
Percent Stems as Sprouts				
All Species	8	15	12	18
All Oak Species	8	15	12	18
Red Maple	7	15	9	9
		North		
All Species	11	22	9	9
All Oak Species	11	22	8	8
Red Maple	8	16	4	6

Table 17. Comparison of understory tree species among landforms within the southern and northern regional ecosystems of Lower Michigan[1, 2].

	Understory (1.5 ≥ dbh < 9.1)				
	mean dbh (cm)	stem density (stems ha^{-1})	relative density (%)	basal area (m^2 ha^{-1})	relative dominance (%)
			South		
Ice-Contact					
Acer rubrum	4.2 (0.6)	252.5 (86.3)	24.6	0.47 (0.17)	30.2
Ostrya virginiana	4.9 (0.7)	112.5 (71.5)	11.0	0.20 (0.14)	13.0
Prunus serotina	4.5 (0.9)	95.0 (45.3)	9.3	0.18 (0.11)	11.1
Amelanchier arborea	3.5 (0.6)	115.0 (49.2)	11.2	0.15 (0.07)	9.8
Hamamelis virginiana	2.8 (0.2)	187.5 (104.8)	18.3	0.13 (0.08)	8.4
Others (21 species)		262.5	25.6	0.43	27.5
Total		1025.0 (141.7)	100.00	1.57 (0.22)	100.00
Moraine					
Acer rubrum	4.3 (0.2)	629.3 (204.1)	41.2	1.00 (0.32)	42.0
Cornus florida	4.3 (0.6)	142.7 (64.8)	9.3	0.24 (0.12)	10.0
Sassafras albidum	4.5 (0.5)	93.3 (29.6)	6.1	0.19 (0.06)	7.8
Hamamelis virginiana	3.1 (0.2)	206.7 (106.3)	13.5	0.18 (0.09)	7.6
Prunus serotina	4.0 (0.4)	112.0 (33.3)	7.3	0.15 (0.04)	6.4
Others (25 species)		342.7	22.4	0.62	26.1
Total		1526.7 (282.3)	100.0	2.38 (0.46)	100.0
Outwash					
Acer rubrum	4.5 (0.4)	273.3 (72.2)	24.7	0.45 (0.11)	29.2
Quercus velutina	5.2 (1.0)	95.0 (50.7)	8.6	0.16 (0.08)	10.4
Quercus alba	4.6 (0.5)	78.3 (49.4)	7.1	0.15 (0.10)	10.0
Prunus serotina	4.3 (0.7)	81.7 (21.9)	7.4	0.15 (0.06)	9.9
Carya glabra	4.6 (0.7)	55.0 (22.0)	5.0	0.11 (0.06)	7.4
Others (24 species)		525.0	47.4	0.51	33.0
Total		1108.3 (216.6)	100.0	1.54 (0.20)	100.0
Lake Plain					
Quercus alba	4.1 (0.7)	495.6 (226.4)	34.8	0.59 (0.30)	31.6
Acer rubrum	4.1 (0.4)	190.0 (65.4)	13.4	0.32 (0.12)	17.2
Amelanchier arborea	3.5 (0.5)	87.8 (38.3)	6.2	0.17 (0.10)	9.1
Cornus florida	4.1 (0.6)	90.0 (37.8)	6.3	0.16 (0.08)	8.3
Quercus velutina	3.5 (0.7)	147.8 (66.7)	10.4	0.15 (0.08)	8.2
Others (25 species)		411.1	28.9	0.48	25.6
Total		1422.2 (289.4)	100.0	1.87 (0.37)	100.0

Table 17. (continued).

	Understory (1.5 ≥ dbh < 9.1)				
	mean dbh (cm)	stem density (stems ha^{-1})	relative density (%)	basal area (m^2 ha^{-1})	relative dominance (%)
			North		
Ice-Contact					
Pinus strobus	4.6 (0.8)	232.7 (160.4)	17.1	0.42 (0.29)	36.1
Acer rubrum	2.6 (0.3)	478.2 (100.7)	35.2	0.34 (0.08)	29.2
Populus grandidentata	4.4 (1.1)	401.8 (208.0)	29.5	0.22 (0.10)	19.4
Quercus alba	3.4 (1.1)	116.4 (68.5)	8.6	0.07 (0.05)	6.4
Pinus resinosa	5.4 (0.0)	21.8 (18.2)	1.6	0.06 (0.05)	4.7
Others (6 species)		109.1	8.0	0.05	4.2
Total		1360.0 (318.7)[†ab]	100.00	1.15 (0.38)	100.00
Moraine					
Acer rubrum	3.3 (0.3)	1058.2 (185.8)	40.7	0.94 (0.18)	39.5
Hamamelis virginiana	2.6 (0.1)	678.2 (213.4)	26.1	0.41 (0.12)	17.3
Quercus rubra	4.3 (0.7)	160.9 (121.4)	6.2	0.27 (0.20)	11.4
Populus grandidentata	3.5 (0.6)	235.5 (92.5)	9.0	0.25 (0.09)	10.4
Sassafras albidum	3.4 (0.4)	80.0 (28.9)	3.1	0.10 (0.05)	4.3
Others (14 species)		389.1	15.0	0.41	17.1
Total		2601.8 (410.2)[†a]	100.0	2.37 (0.44)	100.0
Outwash					
Quercus alba	4.3 (0.6)	732.0 (352.7)	37.4	1.13 (0.72)	45.8
Acer rubrum	4.6 (1.2)	379.6 (210.2)	19.4	0.54 (0.38)	22.0
Quercus velutina	4.0 (0.7)	320.0 (103.0)	16.4	0.38 (0.13)	15.2
Quercus rubra	3.2 (-)	275.6 (275.6)	14.1	0.25 (0.25)	10.2
Amelanchier arborea	2.3 (0.5)	79.1 (67.7)	4.0	0.06 (0.06)	2.5
Others (7 species)		170.9	8.7	0.11	4.3
Total		1957.1 (587.3)[†ab]	100.0	2.47 (0.84)	100.0
Lake Plain					
Acer rubrum	4.5 (0.4)	106.7 (69.4)	16.7	0.16 (0.10)	21.1
Pinus banksiana	4.0 (0.6)	62.2 (31.3)	9.8	0.11 (0.07)	14.2
Quercus velutina	3.8 (1.4)	102.2 (85.5)	16.0	0.09 (0.07)	11.1
Quercus ellipsoidalis	3.6 (0.7)	55.6 (35.6)	8.7	0.08 (0.06)	10.5
Amelanchier arborea	2.8 (0.6)	53.3 (20.3)	8.4	0.07 (0.05)	9.3
Others (8 species)		257.8	40.4	0.26	33.8
Total		637.8 (151.0)[†b]	100.0	0.77 (0.16)	100.0

[1] For each species, means are shown outside of parentheses, one standard error inside of parentheses. Listed are five species with the highest relative dominance in each Region's landforms.

[2] Stem density and basal area for South: Ice-Contact (n = 8), Moraine (n = 15), Outwash (n = 12), Lake Plain (n = 18). Stem density and basal area for North: Ice-Contact (n = 11), Moraine (n = 22), Outwash (n = 10), Lake Plain (n = 9). Mean dbh sample sizes vary by species.

[†] Indicates significant difference among landforms within each region at α = 0.05, ANOVA Comparisons with the same letter are not significantly different at α = 0.05 when applying Tukey's HSD test.

Table 18. Comparison of understory stem sprouting among landforms within the southern and northern regional ecosystems of Lower Michigan[1].

	Landform			
	Ice-Contact	Moraine	Outwash	Lake Plain
		South		
Percent Stems as Sprouts				
All Species	20.41 (6.64)	24.93 (5.37)	17.96 (3.15)	35.40 (5.63)
All Oak Species	7.02 (7.02)	13.84 (10.29)	14.01 (8.70)	27.57 (7.99)
Red Maple	17.72 (13.94)	19.80 (7.32)	13.98 (3.57)	24.06 (8.39)
		North		
All Species	47.33 (7.25)	56.54 (4.93)	59.67 (12.42)	44.12 (9.10)
All Oak Species	26.33 (14.64)	39.33 (9.59)	59.90 (13.40)	30.30 (14.87)
Red Maple[†]	85.86 (6.31)[a]	55.11 (7.95)[a]	69.75 (23.68)[a]	5.00 (5.00)[b]

[1] For each variable, means are shown outside of parentheses, one standard error inside of parentheses.
[†] Indicates significant difference at α = 0.05, ANOVA. Original values were log-transformed (i.e. Log_{10} (x + 1) = x') before significance test. Comparisons with the same letter are not significantly different at α = 0.05 when applying Tukey's HSD test.

SAMPLE SIZES FOR TABLE 18

	Landform			
	Ice-Contact	Moraine	Outwash	Lake Plain
		South		
Percent Stems as Sprouts				
All Species	8	15	12	18
All Oak Species	3	7	6	14
Red Maple	7	14	9	14
		North		
All Species	11	22	10	9
All Oak Species	7	12	9	7
Red Maple	11	20	4	5

Table 19a. Comparison of oak and red maple regeneration (understory stem density) among landforms within the southern and northern regional ecosystems of Lower Michigan[1, 2].

	Landform			
	Ice-Contact	Moraine	Outwash	Lake Plain
		South		
Understory Stem Density (stems ha^{-1})				
All Oak Species	60.00 (46.75)	81.33 (43.62)	176.67 (92.83)	650.00 (282.84)
White Oak	7.50 (5.26)	44.00 (26.27)	78.33 (49.39)	495.56 (226.38)
Black Oak-Northern Pin Oak[3]	47.50 (47.50)	20.00 (11.21)	96.67 (51.69)	147.78 (66.69)
Northern Red Oak	5.00 (5.00)	17.33 (10.12)	1.67 (1.67)	6.67 (6.67)
Red Maple	252.50 (86.35)	629.33 (204.08)	273.33 (72.17)	190.00 (65.41)
		North		
All Oak Species‡	145.46 (72.77)[ab]	242.73 (122.59)[a]	1327.56 (434.99)[b]	202.22 (86.82)[ab]
White Oak	116.36 (68.48)	34.55 (14.84)	732.00 (352.74)	44.44 (17.57)
Black Oak-Northern Pin Oak[3]‡	1.82 (1.82)[a]	47.27 (22.55)[a]	320.00 (103.02)[b]	157.78 (84.88)[ab]
Northern Red Oak†	27.27 (11.84)	160.91 (121.43)	275.56 (275.56)	0.00 (0.00)
Red Maple‡	478.18 (100.71)[ab]	1058.18 (185.79)[a]	379.56 (210.16)[b]	106.67 (69.44)[b]

1 For each variable, means are shown outside of parentheses, one standard error inside of parentheses.

2 For all variables for South: Ice-Contact (n = 8), Moraine (n = 15), Outwash (n = 12), Lake Plain (n = 18). For all variables for North: Ice-Contact (n = 11), Moraine (n = 22), Outwash (n = 10), Lake Plain (n = 9).

3 Stems of black oak and northern pin oak are aggregated due to difficulties with field identification between these closely related species.

† Indicates significance at $\alpha = 0.10$, Kruskal-Wallis. Comparisons with the same letter are not significantly different at $\alpha = 0.10$ when applying non-parametric Tukey-type multiple comparison Nemenyi test. However, pairwise significant differences may not have been detected with this test for certain variables.

‡ Indicates significance at $\alpha = 0.05$, Kruskal-Wallis. Comparisons with the same letter are not significantly different at $\alpha = 0.05$ when applying non-parametric Tukey-type multiple comparison Nemenyi test.

Table 19b. Comparison of difference in oak and red maple regeneration (understory stem density) among landforms within the southern and northern regional ecosystems of Lower Michigan[(1)].

	Landform			
	Ice-Contact	Moraine	Outwash	Lake Plain
	South			
Difference in Understory Stem Density (stems ha^{-1})[(2)]				
All Oak Species and Red Maple Difference†	-192.50[ab]	-548.00[** a]	-96.67[ab]	460.00[b]
	(114.33)	(200.91)	(135.53)	(312.65)
	North			
All Oak Species and Red Maple Difference†	-332.73[** a]	-815.46[** a]	948.00[* b]	95.56[ab]
	(132.29)	(232.83)	(465.39)	(132.11)

1 For each variable, means are shown outside of parentheses, one standard error inside of parentheses.
2 Positive number indicates greater oak than red maple abundance; negative number indicates converse. South: Ice-Contact (n = 8), Moraine (n = 15), Outwash (n = 12), Lake Plain (n = 18). North: Ice-Contact (n = 11), Moraine (n = 22), Outwash (n = 10), Lake Plain (n = 9).
* Difference between All Oak Species and Red Maple understory stem density within each region and landform is significantly different from zero at $\alpha = 0.10$, paired t-test.
** Difference between All Oak Species and Red Maple understory stem density within each region and landform is significantly different from zero at $\alpha = 0.05$, paired t-test.
† Difference among landforms within each region is significantly different at $\alpha = 0.05$, ANOVA. Comparisons with the same letter are not significantly different at $\alpha = 0.05$ when applying Tukey's HSD test.

Table 20a. Comparison of groundcover vegetation among landforms within the southern and northern regional ecosystems of Lower Michigan listed by highest coverage[1, 2].

	Ground Cover (dbh < 1.5 cm)		
	frequency (# of subplot occurrences)	mean coverage (% of 1 m^2 plot)	relative coverage (%)
		South	
Ice-Contact			
Viburnum acerifolium	21	1.83	11.1
Cornus foemina	19	1.82	11.0
Parthenocissus quinquefolia	60	1.54	9.4
Quercus velutina	33	1.21	7.3
Carex pensylvanica	50	1.21	7.3
Others (108 species)	923	8.86	53.8
Total	1106	16.47	100.00
Moraine			
Pteridium aquilinum	44	1.70	15.6
Prunus serotina	87	1.00	9.2
Sassafras albidum	97	0.94	8.6
Hamamelis virginiana	33	0.88	8.1
Acer rubrum	140	0.80	7.3
Others (133 species)	1269	5.61	51.3
Total	1670	10.94	100.0
Outwash			
Sassafras albidum	78	1.24	9.3
Acer rubrum	125	0.89	6.6
Prunus serotina	115	0.86	6.4
Ostrya virginiana	11	0.82	6.1
Desmodium glutinosum	85	0.71	5.3
Others (155 species)	1372	8.88	66.3
Total	1786	13.40	100.0
Lake Plain			
Pteridium aquilinum	121	4.29	20.9
Gaylussacia baccata	95	2.52	12.3
Sassafras albidum	99	1.82	8.9
Quercus alba	100	1.80	8.7
Carex pensylvanica	203	1.65	8.0
Others (146 species)	1537	8.50	41.3
Total	2155	20.59	100.0

Table 20a. (continued).

	Ground Cover (dbh < 1.5 cm)		
	frequency (# of subplot occurrences)	mean coverage (% of 1 m^2 plot)	relative coverage (%)
		North	
Ice-Contact			
Pteridium aquilinum	166	14.97	43.5
Carex pensylvanica	163	4.27	12.4
Quercus alba	87	3.72	10.8
Vaccinium angustifolium	139	2.26	6.6
Acer rubrum	148	2.09	6.1
Others (54 species)	667	7.09	20.6
Total	1370	34.39	100.00
Moraine			
Pteridium aquilinum	259	11.21	39.9
Carex pensylvanica	211	3.43	12.2
Acer rubrum	300	2.78	9.9
Vaccinium angustifolium	175	1.24	4.4
Prunus serotina	133	1.15	4.1
Others (103 species)	1511	8.30	29.5
Total	2589	28.12	100.0
Outwash			
Carex pensylvanica	152	11.16	33.6
Pteridium aquilinum	62	3.97	12.0
Quercus velutina	82	3.21	9.7
Vaccinium angustifolium	118	3.10	9.3
Quercus alba	57	2.55	7.7
Others (87 species)	622	9.23	27.8
Total	1093	33.23	100.0
Lake Plain			
Pteridium aquilinum	66	11.39	32.2
Carex pensylvanica	146	9.15	25.9
Vaccinium angustifolium	127	3.46	9.8
Quercus velutina	45	2.57	7.3
Quercus alba	50	1.76	5.0
Others (58 species)	466	7.06	20.0
Total	900	35.40	100.0

[1] Listed are five species with the highest relative coverage in each Region's landforms.
[2] Number of subplots for South: Ice-Contact (n = 160), Moraine (n = 300), Outwash (n = 240), Lake Plain (n = 360). Number of subplots for North: Ice-Contact (n = 220), Moraine (n = 440), Outwash (n = 198), Lake Plain (n = 180).

Table 20b. Comparison of groundcover vegetation among landforms within the southern and northern regional ecosystems of Lower Michigan listed by highest frequency[1, 2].

Ground Cover (dbh < 1.5 cm)			
	frequency (# of subplot occurrences)	mean coverage (% of 1 m^2 plot)	relative coverage (%)
		South	
Ice-Contact			
Acer rubrum	68	0.33	2.0
Parthenocissus quinquefolia	60	1.54	9.4
Carex pensylvanica	50	1.21	7.3
Desmodium glutinosum	44	0.19	1.2
Circaea lutetiana	40	0.22	1.3
Others (108 species)	844	12.98	78.8
Total	1106	16.47	100.00
Moraine			
Acer rubrum	140	0.80	7.3
Carex pensylvanica	110	0.31	2.8
Sassafras albidum	97	0.94	8.6
Desmodium glutinosum	97	0.44	4.1
Prunus serotina	87	1.00	9.2
Others (133 species)	1139	7.44	68.1
Total	1670	10.94	100.0
Outwash			
Acer rubrum	125	0.89	6.6
Prunus serotina	115	0.86	6.4
Desmodium glutinosum	85	0.71	5.3
Quercus velutina	80	0.37	2.8
Sassafras albidum	78	1.24	9.3
Others (155 species)	1303	9.33	69.7
Total	1786	13.40	100.0
Lake Plain			
Carex pensylvanica	203	1.65	8.0
Vaccinium angustifolium	142	1.04	5.1
Quercus velutina	125	0.77	3.7
Pteridium aquilinum	121	4.29	20.9
Prunus serotina	114	0.86	4.2
Others (146 species)	1450	11.97	58.1
Total	2155	20.59	100.0

Table 20b. (continued).

	Ground Cover (dbh < 1.5 cm)		
	frequency (# of subplot occurrences)	mean coverage (% of 1 m^2 plot)	relative coverage (%)
		North	
Ice-Contact			
Pteridium aquilinum	166	14.97	43.5
Carex pensylvanica	163	4.27	12.4
Acer rubrum	148	2.09	6.1
Vaccinium angustifolium	139	2.26	6.6
Quercus rubra	97	1.07	3.1
Others (54 species)	657	9.74	28.3
Total	1370	34.39	100.00
Moraine			
Acer rubrum	300	2.78	9.9
Pteridium aquilinum	259	11.21	39.9
Carex pensylvanica	211	3.43	12.2
Vaccinium angustifolium	175	1.24	4.4
Amelanchier arborea	146	0.68	2.4
Others (103 species)	1498	8.77	31.2
Total	2589	28.12	100.0
Outwash			
Carex pensylvanica	152	11.16	33.6
Vaccinium angustifolium	118	3.10	9.3
Quercus velutina	82	3.21	9.7
Pteridium aquilinum	62	3.97	12.0
Quercus alba	57	2.55	7.7
Others (87 species)	622	9.23	27.8
Total	1093	33.23	100.0
Lake Plain			
Carex pensylvanica	146	9.15	25.9
Vaccinium angustifolium	127	3.46	9.8
Pteridium aquilinum	66	11.39	32.2
Gaultheria procumbens	56	1.56	4.4
Acer rubrum	52	0.13	0.4
Others (58 species)	453	9.71	27.4
Total	900	35.40	100.0

[1] Listed are five species with the highest frequency in each Region's landforms.
[2] Number of subplots for South: Ice-Contact (n = 160), Moraine (n = 300), Outwash (n = 240), Lake Plain (n = 360). Number of subplots for North: Ice-Contact (n = 220), Moraine (n = 440), Outwash (n = 198), Lake Plain (n = 180).

Table 21. Comparison of seedling, sapling, and shrub abundance among landforms within the southern and northern regional ecosystems of Lower Michigan[(1)].

	Landform			
	Ice-Contact	Moraine	Outwash	Lake Plain
			South	
Variable[(2)]				
All Oak Species Seedling	2.50 (0.84)	2.37 (0.37)	5.79 (1.41)	4.68 (0.74)
All Oak Species Saplings	0.08 (0.04)	0.13 (0.03)	0.16 (0.06)	0.47 (0.16)
Red Maple Seedlings	2.38 (0.76)	4.45 (1.35)	5.63 (1.94)	2.37 (1.31)
Red Maple Saplings	0.14 (0.06)	0.51 (0.17)	0.22 (0.09)	0.16 (0.07)
Tree Seedlings	13.06 (5.32)	15.47 (2.59)	19.07 (3.39)	12.49 (2.02)
Tree Saplings	0.60 (0.16)	0.93 (0.20)	0.56 (0.14)	0.70 (0.21)
Shrubs†	18.44 (4.54)[ab]	6.89 (1.69)[a]	14.41 (2.89)[ab]	29.81 (7.08)[b]
			North	
All Oak Species Seedling†	11.01 (2.25)[a]	4.77 (0.90)[b]	8.90 (2.54)[ab]	10.97 (2.96)[a]
All Oak Species Saplings	0.26 (0.11)	0.20 (0.04)	0.83 (0.30)	0.19 (0.05)
Red Maple Seedlings† *	19.42 (6.93)[ac]	18.39 (3.75)[a]	2.31 (1.20)[b]	3.21 (1.53)[bc]
Red Maple Saplings‡	0.56 (0.31)[ab]	1.02 (0.23)[a]	0.03 (0.02)[b]	0.01 (0.01)[b]
Tree Seedlings†	24.36 (7.73)[a]	27.23 (4.08)[a]	5.52 (1.79)[b]	7.21 (2.06)[b]
Tree Saplings†	1.04 (0.36)[ab]	1.68 (0.32)[a]	0.44 (0.22)[b]	0.14 (0.04)[b]
Shrubs†	66.24 (15.99)[ab]	30.94 (6.44)[a]	52.35 (9.16)[ab]	134.60 (44.39)[b]

[1] For each variable, means are shown outside of parentheses, one standard error inside of parentheses.

[2] Seedlings = 1-150 cm tall, Saplings = 151-300+ cm tall. For all variables for South: Ice-Contact (n = 8), Moraine (n = 15), Outwash (n = 12), Lake Plain (n = 18). For all variables for North: Ice-Contact (n = 11), Moraine (n = 22), Outwash (n = 10), Lake Plain (n = 9). Units are numbers per 4 m^2 plot.

† Indicates significant difference at α = 0.05, ANOVA. Original values were log-transformed (i.e. $\log_{10}(x + 1) = x'$) before significance tests. Comparisons with the same letter are not significantly different at α = 0.05 when applying Tukey's HSD test.

‡ Indicates significance at α = 0.05, Kruskal-Wallis. Comparisons with the same letter are not significantly different at α = 0.05 when applying non-parametric Tukey-type multiple comparison Nemenyi test.

* Significant pairwise differences at α = 0.10.

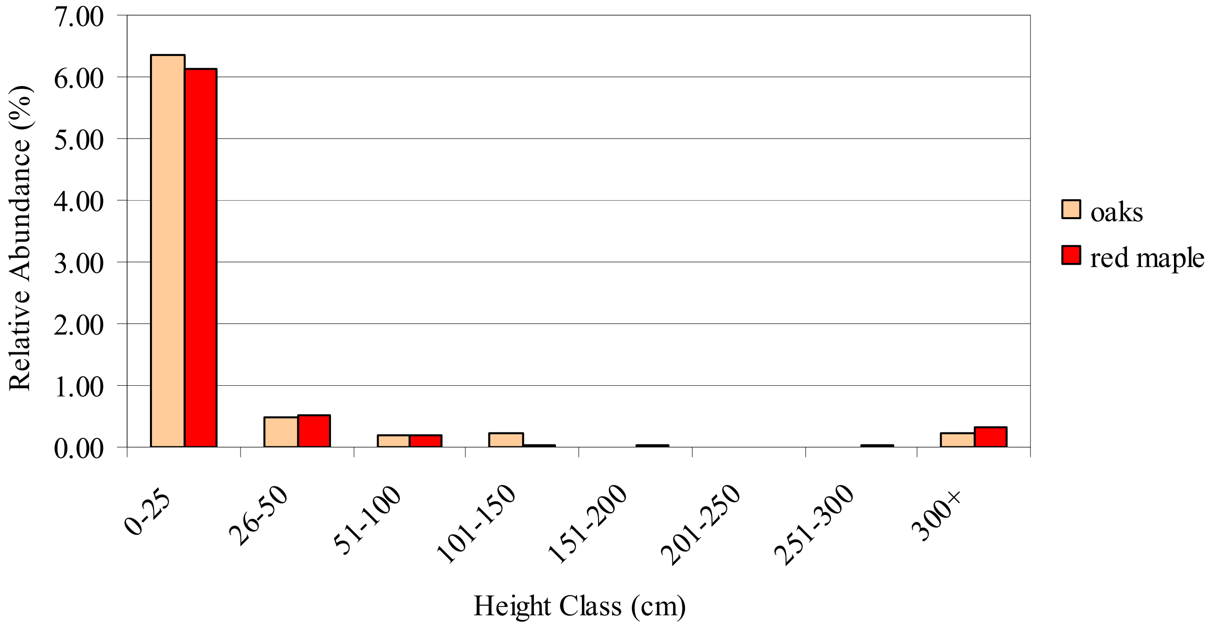


Figure 9. Height class distribution of all collective oak species and red maple seedlings and saplings on **ice-contact terrain** in the **southern** regional ecosystem of Lower Michigan. Relative abundance of each species group shown as a percentage of total stems among all height classes.

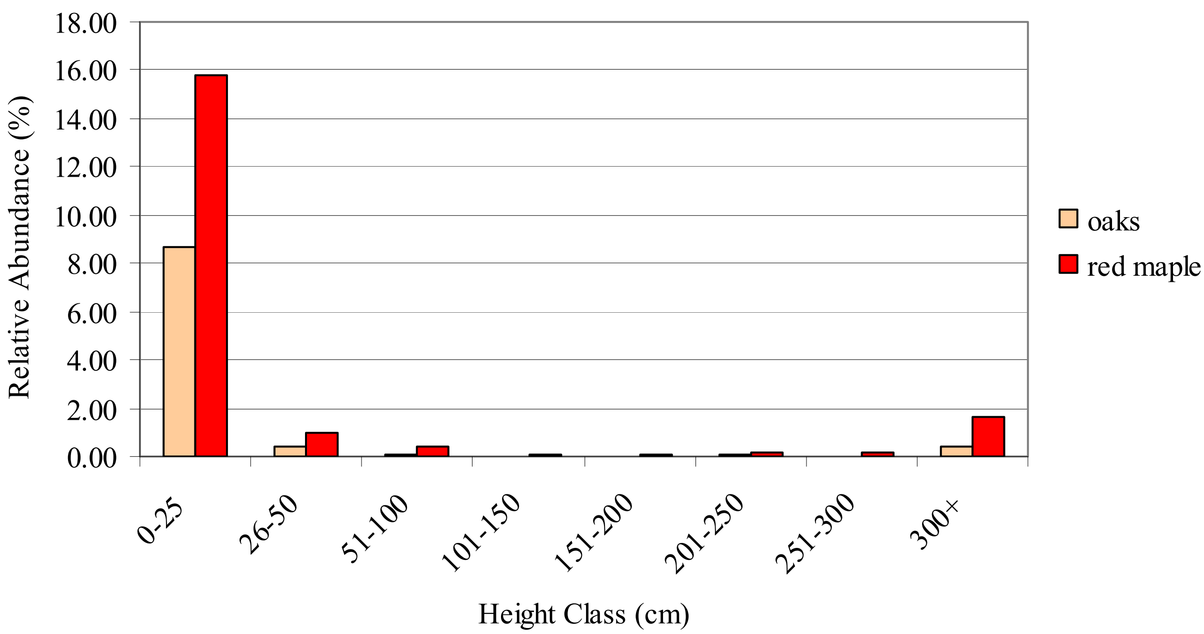


Figure 10. Height class distribution of all collective oak species and red maple seedlings and saplings on **moraine** in the **southern** regional ecosystem of Lower Michigan. Relative abundance of each species group shown as a percentage of total stems among all height classes.

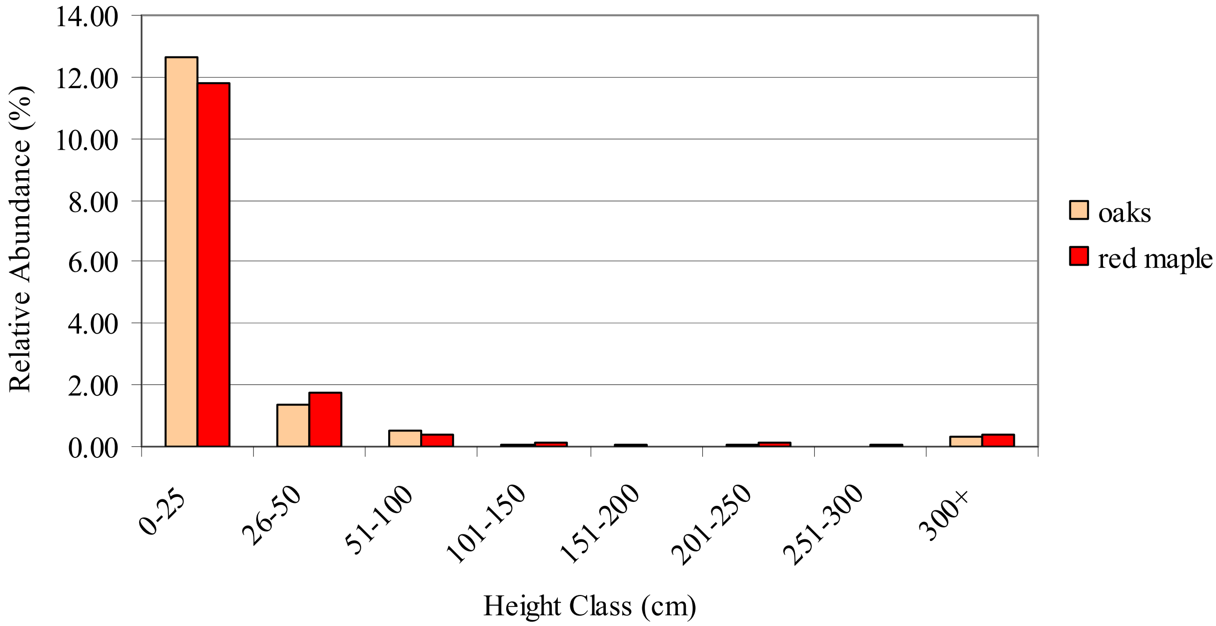


Figure 11. Height class distribution of all collective oak species and red maple seedlings and saplings on **outwash** in the **southern** regional ecosystem of Lower Michigan. Relative abundance of each species group shown as a percentage of total stems among all height classes.

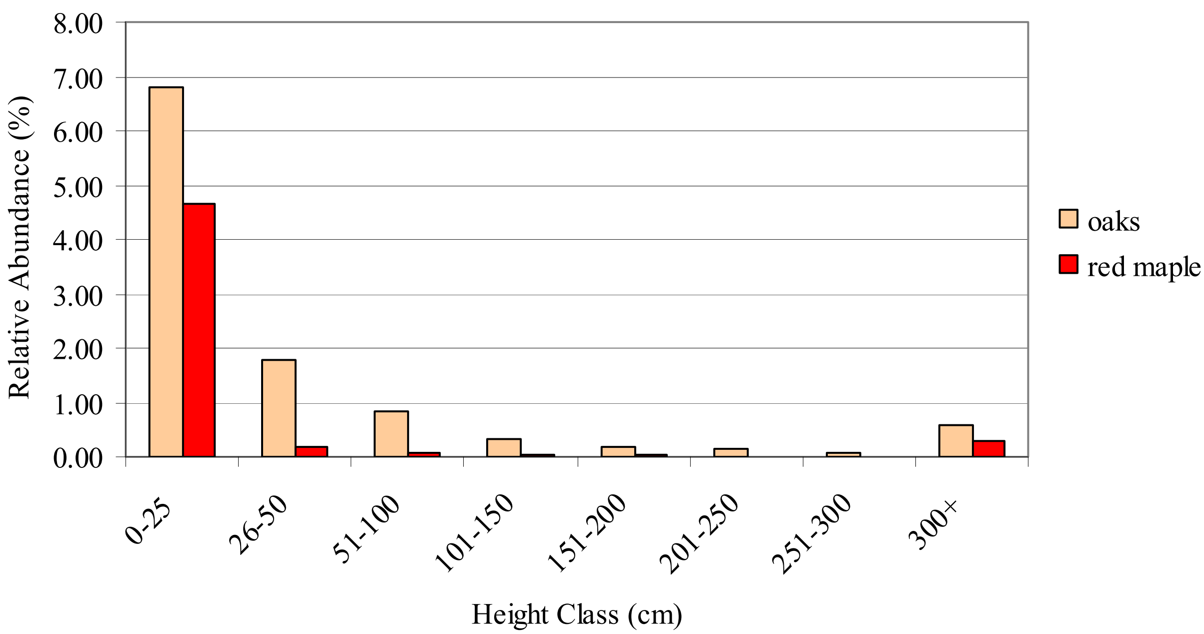


Figure 12. Height class distribution of all collective oak species and red maple seedlings and saplings on **lake plain** in the **southern** regional ecosystem of Lower Michigan. Relative abundance of each species group shown as a percentage of total stems among all height classes.

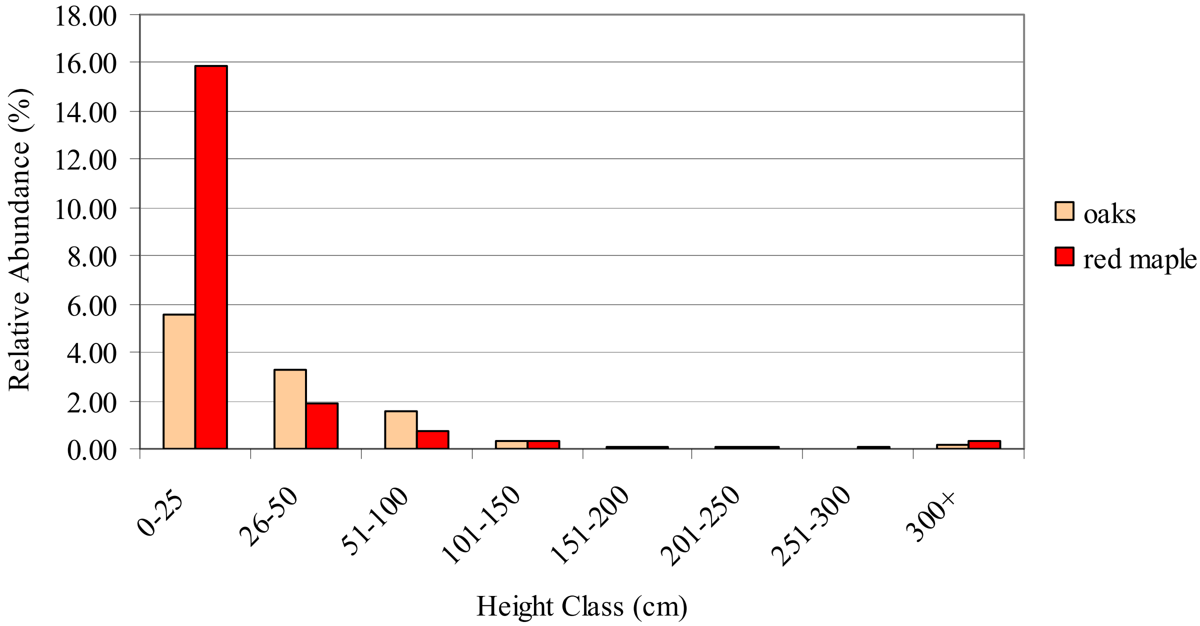


Figure 13. Height class distribution of all collective oak species and red maple seedlings and saplings on **ice-contact terrain** in the **northern** regional ecosystem of Lower Michigan. Relative abundance of each species group shown as a percentage of total stems among all height classes.

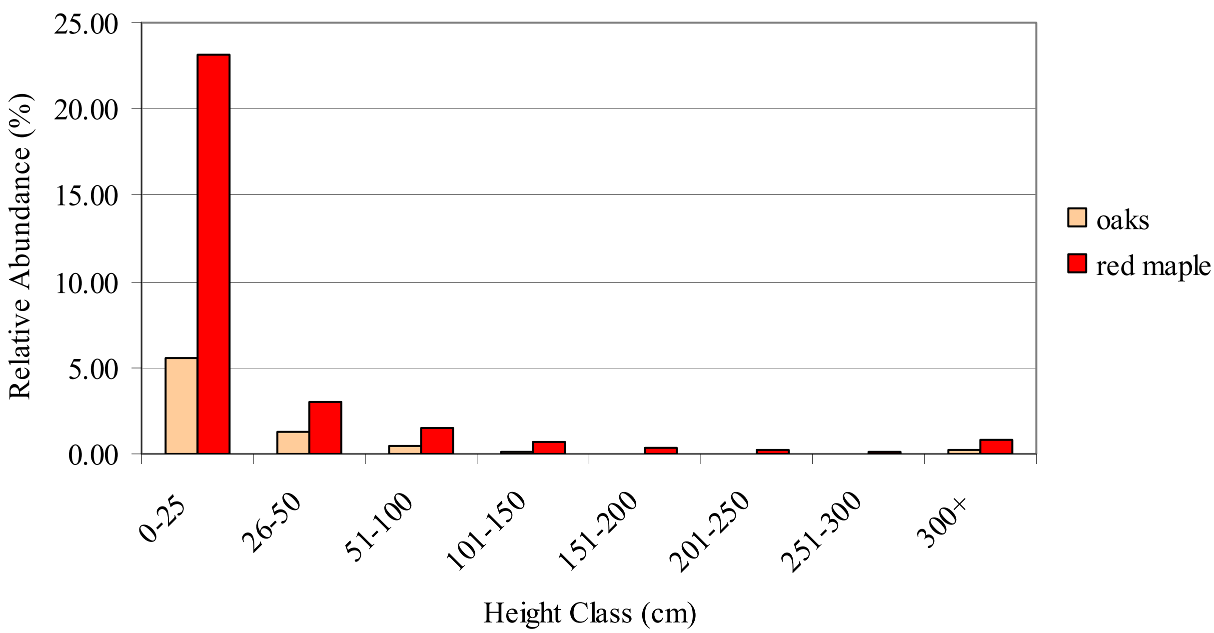


Figure 14. Height class distribution of all collective oak species and red maple seedlings and saplings on **moraine** in the **northern** regional ecosystem of Lower Michigan. Relative abundance of each species group shown as a percentage of total stems among all height classes.

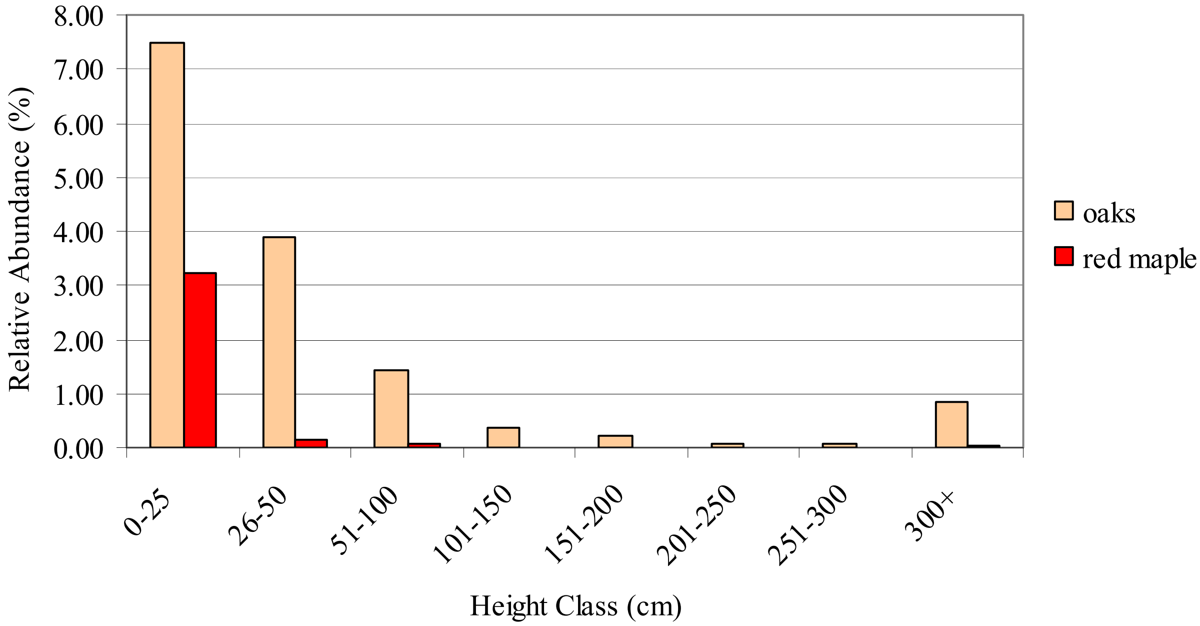


Figure 15. Height class distribution of all collective oak species and red maple seedlings and saplings on **outwash** in the **northern** regional ecosystem of Lower Michigan. Relative abundance of each species group shown as a percentage of total stems among all height classes.

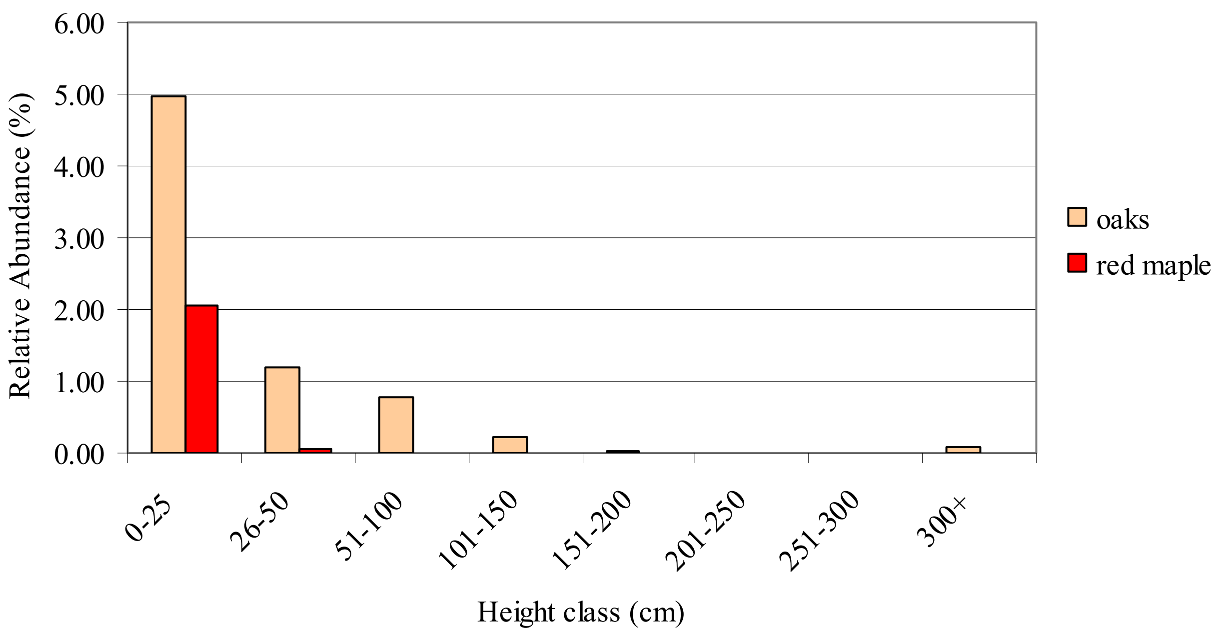


Figure 16. Height class distribution of all collective oak species and red maple seedlings and saplings on **lake plain** in the **northern** regional ecosystem of Lower Michigan. Relative abundance of each species group shown as a percentage of total stems among all height classes.

Table 22. Comparison of deer browsing pressure among landforms within the southern and northern regional ecosystems of Lower Michigan[1].

	Landform			
	Ice-Contact	Moraine	Outwash	Lake Plain
		South		
Percent Browsed Stems				
All Species	12.25 (4.22)	15.81 (3.83)	11.08 (2.77)	13.97 (2.69)
All Oak Species	9.14 (5.49)	13.36 (4.36)	14.15 (4.41)	13.48 (4.16)
Red Maple	9.65 (3.24)	14.47 (4.52)	6.66 (2.00)	23.05 (8.78)
		North		
All Species	0.38 (0.18)	1.84 (0.74)	0.19 (0.14)	1.12 (0.61)
All Oak Species	0.35 (0.29)	0.26 (0.22)	0.12 (0.12)	0.00 (0.00)
Red Maple	0.19 (0.19)	1.77 (0.96)	0.00 (0.00)	0.00 (0.00)

[1] For each variable, means are shown outside of parentheses, one standard error inside of parentheses.

SAMPLE SIZES FOR TABLE 22

	Landform			
	Ice-Contact	Moraine	Outwash	Lake Plain
		South		
Percent Browsed Stems				
All Species	8	15	12	18
All Oak Species	8	15	12	17
Red Maple	8	15	12	16
		North		
All Species	11	22	10	9
All Oak Species	11	22	10	9
Red Maple	11	22	6	7

Table 23. Comparison of soil pH, exchangeable cations, and physiographic features among landforms within the southern and northern regional ecosystems of Lower Michigan(1).

	Landform			
	Ice-Contact	Moraine	Outwash	Lake Plain
		South		
Variable(2)				
pH†	5.60 (0.17)[a]	4.88 (0.12)[b]	4.85 (0.11)[b]	4.60 (0.08)[b]
P	46.55 (14.33)	52.17 (6.12)	52.88 (4.93)	40.45 (6.32)
K†	65.05 (8.04)[a]	50.77 (4.16)[ab]	45.50 (4.02)[ab]	43.08 (3.54)[b]
Ca†	742.83 (147.47)[a]	370.91 (65.65)[ab]	334.21 (65.82)[ab]	245.39 (64.20)[b]
Mg†	107.58 (18.59)[a]	60.23 (10.42)[ab]	52.59 (9.38)[ab]	40.47 (10.09)[b]
Transformed Aspect	1.03 (0.16)	0.88 (0.12)	1.09 (0.09)	1.06 (0.08)
Percent Slope†	-17.11 (5.27)[a]	-9.38 (1.07)[ab]	-8.40 (1.82)[b]	-3.67 (0.70)[b]
		North		
pH	4.42 (0.04)	4.56 (0.03)	4.56 (0.06)	4.39 (0.09)
P†	17.81 (2.26)[ac]	39.68 (4.87)[b]	23.02 (2.86)[ab]	12.55 (2.04)[c]
K† *	21.86 (0.99)[ab]	26.38 (1.42)[a]	24.87 (2.29)[ab]	20.97 (1.45)[b]
Ca	107.12 (9.81)	136.30 (13.08)	153.84 (48.01)	104.73 (19.12)
Mg	22.28 (1.90)	26.57 (1.50)	26.24 (6.82)	19.84 (1.89)
Transformed Aspect	1.14 (0.13)	1.01 (0.07)	1.05 (0.13)	1.18 (0.10)
Percent Slope†	-7.57 (0.75)[a]	-10.21 (0.90)[a]	-2.11 (0.38)[b]	-2.52 (0.35)[b]

1 For each variable, means are shown outside of parentheses, one standard error inside of parentheses.

2 P = phosphorus ($\mu g\ g^{-1}$), K = potassium ($\mu g\ g^{-1}$), Ca = calcium ($\mu g\ g^{-1}$), Mg = magnesium ($\mu g\ g^{-1}$). For all variables for South: Ice-Contact (n = 8), Moraine (n = 15), Outwash (n = 12), Lake Plain (n = 18). For all variables for North: Ice-Contact (n = 11), Moraine (n = 22), Outwash (n = 10), Lake Plain (n = 9).

† Indicates significance at $\alpha = 0.05$, ANOVA. Significance for P, K, Ca, and Mg applies to log-transformation of original values (i.e. $Log_{10}(x) = x'$). Comparisons with the same letter are not significantly different at $\alpha = 0.05$ when applying Tukey's HSD test.

* Pair-wise K comparison between moraine and lake plain in the northern regional ecosystem, p = 0.53.

Table 24. Relationship between deer browsing pressure and categorical levels of deer abundance of Lower Michigan[(1)].

	Level of Deer Abundance		
	Low	Medium	High
Percent Browsed Stems			
All Species[†]	0.64 (0.23)[a]	7.16 (1.60)[b]	10.69 (1.81)[c]
All Oak Species[†]	0.20 (0.17)[a]	6.85 (2.06)[ab]	9.22 (2.24)[b]
Red Maple[†]	0.57 (0.41)[a]	10.12 (3.95)[a]	9.70 (2.10)[b]

[1] For each variable, means are shown outside of parentheses, one standard error inside of parentheses.
[†] Indicates significance at $\alpha = 0.05$, Kruskal-Wallis. Comparisons with the same letter are not significantly different at $\alpha = 0.05$ when applying non-parametric Tukey-type multiple comparison Nemenyi test.

SAMPLE SIZES FOR TABLE 24

	Level of Deer Abundance		
	Low	Medium	High
Percent Browsed Stems			
All Species	19	44	42
All Oak Species	19	44	41
Red Maple	19	39	39

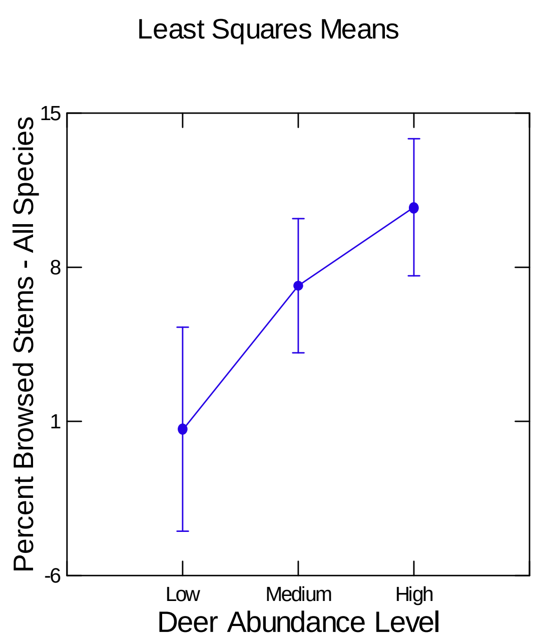


Figure 17a. Relationship between percentage of **all** stems browsed and categorical levels of deer abundance of Lower Michigan. Means are shown with error bars.

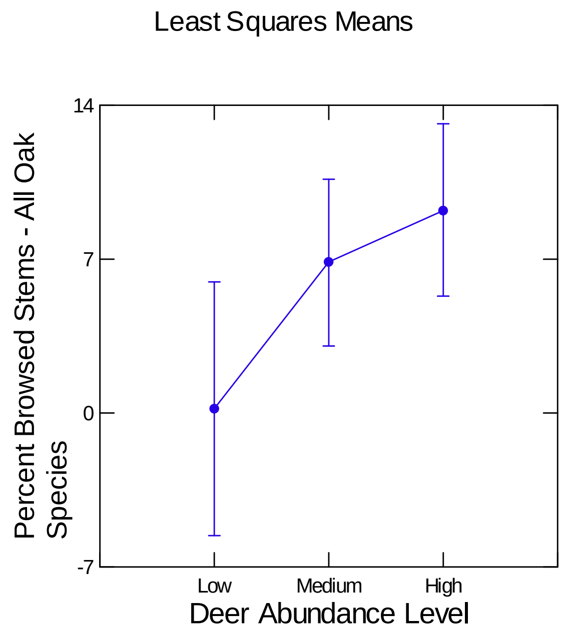


Figure 17b. Relationship between percentage of all **oak** stems browsed and categorical levels of deer abundance of Lower Michigan. Means are shown with error bars.

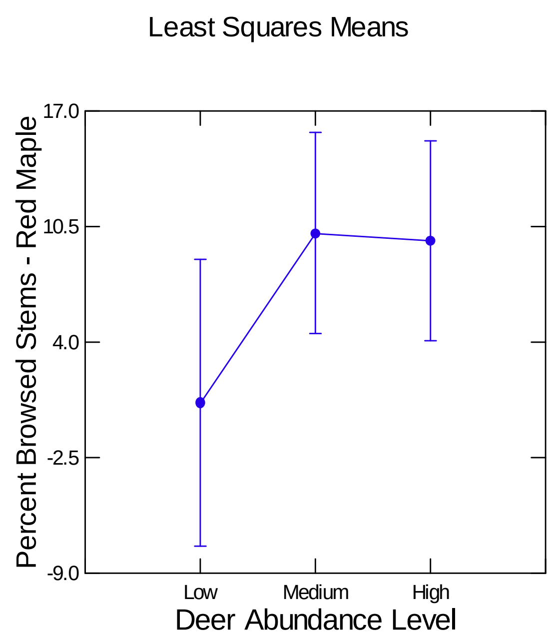


Figure 17c. Relationship between percentage of **red maple** stems browsed and categorical levels of deer abundance of Lower Michigan. Means are shown with error bars.

Table 25. Comparison of oak and red maple regeneration (understory stem density) and seedling and sapling abundance among categorical levels of deer abundance of Lower Michigan[1, 2].

	Level of Deer Abundance		
	Low	Medium	High
Understory Stem Density (stems ha^{-1})			
All Oak Species	392.40 (193.27)	459.09 (138.21)	235.71 (94.62)
White Oak†	67.37 (41.13)[a]	312.27 (106.35)[b]	126.67 (80.05)[ab]
Black Oak-Northern Pin Oak[(3)†]	1.05 (1.05)[a]	138.64 (40.33)[b]	96.67 (25.11)[b]
Northern Red Oak†	323.98 (194.32)[a]	8.18 (4.03)[b]	12.38 (7.34)[b]
Red Maple†	653.45 (107.53)[a]	453.18 (106.59)[b]	454.76 (102.09)[b]
Seedling and Sapling Abundance[(4)]			
All Oak Species Seedlings†	8.10(1.62)	6.64 (1.00)	4.21(0.57)
All Oak Species Saplings	0.28 (0.07)	0.39 (0.10)	0.18(0.04)
Red Maple Seedlings†	20.48 (4.50)[a]	7.20 (1.96)[b]	3.82 (0.77)[b]
Red Maple Saplings	0.65 (0.21)	0.38 (0.12)	0.34 (0.09)

[1] For each variable, means are shown outside of parentheses, one standard error inside of parentheses.
[2] For all variables: Low (n = 19), Medium (n = 44), High (n = 42).
[3] Stems of black oak and northern pin oak are aggregated due to difficulties with field identification between these closely related species.
[4] Units are numbers per 4 m^2 plot for All Oak Species and Red Maple Seedlings/Saplings.
† Indicates significance at α = 0.05, Kruskal-Wallis. Comparisons with the same letter are not significantly different at α = 0.05 when applying non-parametric Tukey-type multiple comparison Nemenyi test. However, pairwise significant differences may not have been detected with this test for certain variables.

Table 26. Comparison of oak and red maple regeneration (understory stem density) and seedling and sapling abundance among categorical levels of deer abundance in the **southern** regional ecosystem of Lower Michigan[1, 2].

	Level of Deer Abundance	
	Medium	High
Understory Stem Density (stems ha^{-1})		
All Oak Species†	598.10 (244.44)	92.50 (37.12)
White Oak†	443.81 (195.85)	39.38 (19.52)
Black Oak-Northern Pin Oak[3]	139.05 (59.35)	49.38 (20.87)
Northern Red Oak	15.24 (8.04)	3.75 (3.17)
Red Maple	270.48 (79.24)	390.00 (100.99)
Seedling and Sapling Abundance[4]		
All Oak Species Seedlings	4.41 (0.67)	3.65 (0.64)
All Oak Species Saplings†	0.42 (0.14)	0.12 (0.03)
Red Maple Seedlings†	2.54 (1.14)	4.46 (0.97)
Red Maple Saplings	0.23 (0.09)	0.29 (0.08)

1 For each variable, means are shown outside of parentheses, one standard error inside of parentheses.
2 For all variables: Medium (n = 21), High (n = 32).
3 Stems of black oak and northern pin oak are aggregated due to difficulties with field identification between these closely related species.
4 Units are numbers per 4 m^2 plot for All Oak Species and Red Maple Seedlings/Saplings.
† Indicates significance at $\alpha = 0.05$, two-sample independent Mann-Whitney U-Test.

Table 27. Comparison of oak and red maple regeneration (understory stem density) and seedling and sapling abundance among categorical levels of deer abundance in the **northern** regional ecosystem of Lower Michigan[1, 2].

	Level of Deer Abundance		
	Low	Medium	High
Understory Stem Density (stems ha^{-1})			
All Oak Species†	392.40 (193.27)	332.17 (142.47)	694.00 (354.24)
White Oak† *	67.37 (41.13)	192.17 (95.28)	406.00 (327.17)
Black Oak-Northern Pin Oak[3]†	1.05 (1.05)[a]	138.26 (56.20)[a]	248.00 (62.62)[b]
Northern Red Oak†	323.98 (194.32)[a]	1.74 (1.74)[b]	40.00 (28.44)[ab]
Red Maple	653.45 (107.53)	620.00 (186.07)	662.00 (284.18)
Seedling and Sapling Abundance[4]			
All Oak Species Seedlings	8.10 (1.62)	8.69 (1.73)	6.01 (1.08)
All Oak Species Saplings	0.28 (0.07)	0.36 (0.14)	0.38 (0.16)
Red Maple Seedlings†	20.48 (4.50)[a]	11.45 (3.40)[ab]	1.78 (0.63)[b]
Red Maple Saplings	0.65 (0.21)	0.51 (0.21)	0.49 (0.26)

[1] For each variable, means are shown outside of parentheses, one standard error inside of parentheses.
[2] For all variables: Low (n = 19), Medium (n = 23), High (n = 10).
[3] Stems of black oak and northern pin oak are aggregated due to difficulties with field identification between these closely related species.
[4] Units are numbers per 4 m^2 plot for All Oak Species and Red Maple Seedlings/Saplings.
† Indicates significance at $\alpha = 0.05$, Kruskal-Wallis. Comparisons with the same letter are not significantly different at $\alpha = 0.05$ when applying non-parametric Tukey-type multiple comparison Nemenyi test. However, pairwise significant differences may not have been detected with this test for certain variables.
* Among-group Kruskal-Wallis comparison for White Oak, p = 0.051.

Table 28. Comparison of various vegetation measures among management prescriptions of Lower Michigan[(1)].

	Management Prescription			
Variable	Unmanaged	Cut	Burned	Cut and Burned
Percent Canopy Closure‡	92.96[a]	74.50[b]	86.41[ab]	59.37[b]
	(0.78)	(4.11)	(3.26)	(14.47)
Overstory Species Richness‡	2.94[a]	1.87[b]	2.74[ab]	1.65[ab]
	(0.12)	(0.17)	(0.30)	(0.70)
Overstory Stem Density - stems ha^{-1}‡	524.73[a]	292.24[b]	417.73[ab]	292.50[ab]
	(24.43)	(51.63)	(45.97)	(128.82)
Overstory Basal Area - m^2 ha^{-1}‡	27.81[a]	15.35[b]	23.34[ab]	11.60[b]
	(0.88)	(1.61)	(1.59)	(4.82)
Understory Species Richness†	1.82	2.19	1.22	1.23
	(0.13)	(0.25)	(0.18)	(0.50)
Understory Stem Density - stems ha^{-1}‡	1073.51[a]	2831.04[b]	869.09[a]	1040.00[ab]
	(94.34)	(340.48)	(272.86)	(612.10)
Understory Basal Area - m^2 ha^{-1}†	1.62	2.82	1.25	0.88
	(0.15)	(0.46)	(0.33)	(0.36)
Percent Understory Stems as Sprouts - All Species‡	27.08[a]	61.72[b]	30.84[a]	70.73[ab]
	(3.44)	(3.99)	(7.60)	(21.24)
Percent Understory Stems as Sprouts - All Oak Species‡	8.43[a]	50.25[b]	27.25[ab]	61.28[ab]
	(3.16)	(7.97)	(8.54)	(30.74)
Percent Understory Stems as Sprouts - Red Maple‡	18.79[a]	65.31[b]	27.65[ab]	53.85[ab]
	(5.37)	(7.07)	(12.39)	(46.15)
Tree Saplings - # per 4 m^2 plot‡	0.60[ab]	1.49[a]	0.33[b]	0.30[ab]
	(0.10)	(0.27)	(0.11)	(0.18)
Percent Browsed Stems - All Species‡	8.21[a]	5.48[b]	10.71[ab]	5.20[ab]
	(1.62)	(1.95)	(4.23)	(5.20)

[1] For each variable, means are shown outside of parentheses, one standard error inside of parentheses. For management prescriptions, "Cut" includes clearcut, selection, shelterwood, and thinning; "Cut and Burned" includes clearcut, removal, shelterwood, and thinning in conjunction with prescribed burn(s).

† Indicates significance at α = 0.10, Kruskal-Wallis. Comparisons with the same letter are not significantly different at α = 0.10 when applying non-parametric Tukey-type multiple comparison Nemenyi test. However, pairwise significant differences may not have been detected with this test for certain variables.

‡ Indicates significance at α = 0.05, Kruskal-Wallis. Comparisons with the same letter are not significantly different at α = 0.05 when applying non-parametric Tukey-type multiple comparison Nemenyi test.

SAMPLE SIZES FOR TABLE 28

	Management Prescription			
	Unmanaged	Cut	Burned	Cut and Burned
Variable				
Percent Canopy Closure	37	30	11	4
Overstory Species Richness	37	29	11	4
Overstory Stem Density	37	29	11	4
Overstory Basal Area	37	29	11	4
Understory Species Richness	37	30	11	4
Understory Stem Density	37	30	11	4
Understory Basal Area	37	30	11	4
Percent Understory Stems as Sprouts - All Species	37	30	11	4
Percent Understory Stems as Sprouts - All Oak Species	20	22	9	3
Percent Understory Stems as Sprouts - Red Maple	32	25	6	2
Tree Saplings	37	30	11	4
Percent Browsed Stems - All Species	37	30	11	4

Table 29. Comparison of oak and red maple regeneration (understory stem density) and seedling and sapling abundance among management prescriptions of Lower Michigan[1, 2].

	Management Prescription			
	Unmanaged	Cut	Burned	Cut and Burned
Understory Stem Density (stems ha^{-1})				
All Oak Species‡	88.65[a]	758.52[b]	463.64[ab]	820.00[ab]
	(30.77)	(213.33)	(291.51)	(636.97)
White Oak	48.11	400.00	347.27	480.00
	(17.49)	(161.85)	(220.04)	(428.33)
Black Oak-Northern Pin Oak[(3)†]	32.97	155.33	116.36	340.00
	(14.40)	(44.56)	(82.23)	(217.56)
Northern Red Oak†	7.57	203.19	0.00	0.00
	(3.66)	(125.25)	(0.00)	(0.00)
Red Maple‡	334.05[ab]	995.85[a]	96.36[b]	85.00[ab]
	(59.86)	(171.30)	(59.93)	(61.31)
Seedling and Sapling Abundance[(4)]				
All Oak Species Seedlings	4.62	7.12	7.76	5.33
	(0.65)	(1.19)	(2.50)	(1.74)
All Oak Species Saplings	0.18	0.43	0.33	0.78
	(0.03)	(0.11)	(0.16)	(0.74)
Red Maple Seedlings	7.32	8.66	2.68	2.55
	(1.68)	(2.55)	(0.96)	(1.53)
Red Maple Saplings‡	0.26	0.85	0.07	0.03
	(0.08)	(0.21)	(0.05)	(0.03)

[1] For each variable, means are shown outside of parentheses, one standard error inside of parentheses. For management prescriptions, "Cut" includes clearcut, selection, shelterwood, and thinning; "Cut and Burned" includes clearcut, removal, shelterwood, and thinning in conjunction with prescribed burn(s).

[2] For all variables: Unmanaged (n = 37), Cut (n = 30), Burned (n = 11), Cut and Burned (n = 4).

[3] Stems of black oak and northern pin oak are aggregated due to difficulties with field identification between these closely related species.

[4] Units are numbers per 4 m^2 plot for All Oak Species and Red Maple Seedlings/Saplings.

† Indicates significance at $\alpha = 0.10$, Kruskal-Wallis. Comparisons with the same letter are not significantly different at $\alpha = 0.10$ when applying non-parametric Tukey-type multiple comparison Nemenyi test. However, pairwise significant differences may not have been detected with this test for certain variables.

‡ Indicates significance at $\alpha = 0.05$, Kruskal-Wallis. Comparisons with the same letter are not significantly different at $\alpha = 0.05$ when applying non-parametric Tukey-type multiple comparison Nemenyi test. However, pairwise significant differences may not have been detected with this test for certain variables.

Table 30. Comparison of difference in oak and red maple regeneration (understory stem density) among management prescriptions of Lower Michigan[1].

	Management Prescription			
	Unmanaged	Cut	Burned	Cut and Burned
Difference in Understory Stem Density (stems ha^{-1})[2]				
All Oak Species and Red Maple Difference†	-245.41*	-237.33	367.27	735.00
	(76.35)	(316.95)	(311.67)	(667.50)

[1] For each variable, means are shown outside of parentheses, one standard error inside of parentheses. For management prescriptions, "Cut" includes clearcut, selection, shelterwood, and thinning; "Cut and Burned" includes clearcut, removal, shelterwood, and thinning in conjunction with prescribed burn(s).

[2] Positive number indicates greater oak than red maple abundance; negative number indicates converse. Unmanaged (n = 37), Cut (n = 30), Burned (n = 11), Cut and Burned (n = 4).

* Difference between All Oak Species and Red Maple understory stem density within each prescription is significantly different from zero at $\alpha = 0.05$, paired t-test.

† Difference among prescriptions is significantly different at $\alpha = 0.10$, Kruskal-Wallis. However, pairwise significant differences were not detected when applying non-parametric Tukey-type multiple comparison Nemenyi test.

Table 31. Case study profiles of sites among management prescriptions on ice-contact terrain in the southern regional ecosystem of Lower Michigan.

	Ice-Contact Site		
	P-PICK	P-BURN	P-EO-E
Descriptor			
Sub-Subsection[(1)]	VI.1.3	VI.1.3	VI.1.3
Pre-Settlement Vegetation Type[(2)]	mixed oak forest	mixed oak forest	mixed oak forest
Management Prescription	prescribed burn 2001	prescribed burn 2001	unmanaged
Predominant Soil Texture B-horizon	loamy sand	loamy sand	sandy loam / sandy clay loam
Categorical Deer Abundance	medium	medium	medium
Variable[(3)]			
Percent Canopy Closure†	72.34 (7.27)[a]	96.57 (0.56)[b]	95.89 (0.90)[b]
Overstory Density - stems ha^{-1}	330.00 (52.28)	455.00 (63.44)	410.00 (33.17)
Overstory Basal Area - m^2 ha^{-1}†	14.58 (3.40)[a]	30.00 (3.22)[b]	27.11 (2.67)[b]
Understory Density - stems ha^{-1}† *	400.00 (136.63)[a]	1600.00 (416.33)[b]	1340.00 (157.90)[b]
Understory Basal Area - m^2 ha^{-1}†	0.59 (0.34)[a]	1.90 (0.44)[b]	1.34 (0.25)[ab]
Groundcover Species Richness†	2.90 (0.46)[a]	6.80 (0.51)[b]	12.55 (0.72)[c]
Percent Groundcover Coverage‡	9.57 (4.08)[a]	23.75 (9.61)[ab]	35.11 (3.33)[b]
Shrubs - # per 4 m^2 plot ‡	0.00 (0.00)[a]	32.40 (15.40)[b]	38.90 (7.48)[b]
pH†	4.88 (0.09)[a]	4.97 (0.04)[a]	5.91 (0.10)[b]
P†	132.20 (8.08)[a]	82.10 (7.94)[b]	12.80 (1.34)[c]
K†	31.90 (2.21)[a]	42.00 (2.84)[b]	72.20 (3.78)[c]
Ca†	145.30 (15.25)[a]	184.20 (21.97)[a]	872.10 (40.71)[b]
Mg†	20.50 (1.49)[a]	38.20 (2.97)[b]	122.50 (5.28)[c]
Percent Slope†	-4.80 (0.99)[a]	-3.40 (1.46)[a]	-12.80 (2.11)[b]

[1] Albert, D.A. 1995. Regional landscape ecosystems of Michigan, Minnesota, and Wisconsin: A working map and classification. General Technical Report NC-178, North Central Forest Experiment Station, Forest Service, U.S. Dept. of Agriculture, St. Paul, MN.

[2] Comer, P.J., D.A. Albert, H.A. Wells, B.L. Hart, J.B. Raab, D.L. Price, D.M. Kashian, R.A. Corner, and D.W. Schuen. 1995. Michigan's presettlement vegetation, as interpreted from the General Land Office Surveys 1816-1856. Michigan Natural Features Inventory, Lansing, MI. Digital Map.

[3] For each variable, means are shown outside of parentheses, one standard error inside of parentheses. P = phosphorus (μg g^{-1}), K = potassium (μg g^{-1}), Ca = calcium (μg g^{-1}), Mg = magnesium (μg g^{-1}). For all variables and sites: n = 10.

† Indicates significant difference at $\alpha = 0.05$, ANOVA. Significance for Percent Canopy Closure applies to arcsine-transformation of original values (i.e. arcsin $\sqrt{(x)}$ = x'). Significance for P, K, Ca, and Mg applies to log-transformation of original values (i.e. Log_{10} (x) = x'). Comparisons with the same letter are not significantly different at $\alpha = 0.05$ when applying Tukey's HSD test.

‡ Indicates significance at $\alpha = 0.05$, Kruskal-Wallis. Comparisons with the same letter are not significantly different at $\alpha = 0.05$ when applying non-parametric Tukey-type multiple comparison Nemenyi test.

* Pairwise comparison for Understory Density between P-PICK and P-EO-E, p = 0.051.

Table 32a. Case study site comparison of oak and red maple regeneration (understory stem density) and seedling and sapling abundance among management prescriptions on ice-contact terrain in the southern regional ecosystem of Lower Michigan[1, 2].

	Ice-Contact Site		
	P-PICK *Burned*	P-BURN *Burned*	P-EO-E *Unmanaged*
Understory Stem Density (stems ha^{-1})			
All Oak Species†	380.00 (141.26)[a]	0.00 (0.00)[b]	80.00 (32.66)[ab]
White Oak	0.00 (0.00)	0.00 (0.00)	40.00 (26.67)
Black Oak-Northern Pin Oak[3]†	380.00 (141.26)[a]	0.00 (0.00)[b]	0.00 (0.00)[b]
Northern Red Oak	0.00 (0.00)	0.00 (0.00)	40.00 (26.67)
Red Maple†	20.00 (20.00)[a]	680.00 (219.49)[b]	220.00 (46.67)[ab]
Seedling and Sapling Abundance[4]			
All Oak Species Seedlings†	5.80 (1.64)[a]	1.00 (0.33)[b]	2.00 (1.22)[b]
All Oak Species Saplings	0.10 (0.10)	0.10 (0.10)	0.30 (0.15)
Red Maple Seedlings†	0.80 (0.42)[a]	7.00 (2.70)[b]	0.40 (0.22)[a]
Red Maple Saplings	0.00 (0.00)	0.50 (0.31)	0.10 (0.10)

1 For each variable, means are shown outside of parentheses, one standard error inside of parentheses.
2 For all variables and sites: n = 10.
3 Stems of black oak and northern pin oak are aggregated due to difficulties with field identification between these closely related species.
4 Units are numbers per 4 m^2 plot for All Oak Species and Red Maple Seedlings/Saplings.
† Indicates significance at α = 0.05, Kruskal-Wallis. Comparisons with the same letter are not significantly different at α = 0.05 when applying non-parametric Tukey-type multiple comparison Nemenyi test.

Table 32b. Case study site comparison of difference in oak and red maple regeneration (understory stem density) among management prescriptions on ice-contact terrain in the southern regional ecosystem of Lower Michigan[1].

	Ice-Contact Site		
	P-PICK *Burned*	P-BURN *Burned*	P-EO-E *Unmanaged*
Difference in Understory Stem Density (stems ha^{-1})[2]			
All Oak Species and Red Maple Difference†	360.00[* a] (148.47)	-680.00[* b] (219.49)	-140.00[* c] (42.69)

1 For each variable, means are shown outside of parentheses, one standard error inside of parentheses.
2 Positive number indicates greater oak than red maple abundance; negative number indicates converse. For all sites: n = 10.
* Difference between All Oak Species and Red Maple understory stem density within each site is significantly different from zero at α = 0.05, paired t-test.
† Difference among sites is significantly different at α = 0.05, ANOVA. Comparisons with the same letter are not significantly different at α = 0.10 when applying Tukey's HSD test.

Table 33. Case study profiles of sites between management prescriptions on sandy clay loam moraine in the southern regional ecosystem of Lower Michigan.

	Sandy Clay Loam Moraine Site	
	S1-CUT	7L-3S
Descriptor		
Sub-Subsection[(1)]	VI.2.2	VI.4.1
Pre-Settlement Vegetation Type[(2)]	mixed oak forest	oak-hickory forest
Management Prescription	partial shelterwood 1989	unmanaged
Predominant Soil Texture B-horizon	sandy clay loam	sandy loam / sandy clay loam
Categorical Deer Abundance	high	high
Variable[(3)]		
Percent Canopy Closure†	98.80 (0.22)	97.45 (0.28)
Overstory Density - stems ha^{-1}	280.00 (51.75)	330.00 (42.95)
Overstory Basal Area - m^2 ha^{-1}†	14.30 (2.58)	30.01 (4.63)
Understory Density - stems ha^{-1}†	4220.00 (707.08)	1580.00 (191.95)
Understory Basal Area - m^2 ha^{-1}†	6.68 (1.09)	1.95 (0.47)
Groundcover Species Richness†	9.65 (1.23)	4.15 (0.46)
Percent Groundcover Coverage	11.07 (2.00)	15.78 (4.90)
Shrubs - # per 4 m^2 plot	4.60 (1.56)	5.20 (2.87)
pH†	4.42 (0.08)	5.52 (0.15)
P†	79.00 (10.80)	27.00 (3.60)
K† *	66.80 (4.28)	55.70 (3.34)
Ca†	334.40 (35.54)	841.70 (156.34)
Mg†	53.60 (2.75)	148.00 (26.04)
Percent Slope†	-15.70 (3.04)	-2.65 (0.42)

[1] Albert, D.A. 1995. Regional landscape ecosystems of Michigan, Minnesota, and Wisconsin: A working map and classification. General Technical Report NC-178, North Central Forest Experiment Station, Forest Service, U.S. Dept. of Agriculture, St. Paul, MN.

[2] Comer, P.J., D.A. Albert, H.A. Wells, B.L. Hart, J.B. Raab, D.L. Price, D.M. Kashian, R.A. Corner, and D.W. Schuen. 1995. Michigan's presettlement vegetation, as interpreted from the General Land Office Surveys 1816-1856. Michigan Natural Features Inventory, Lansing, MI. Digital Map.

[3] For each variable, means are shown outside of parentheses, one standard error inside of parentheses. P = phosphorus ($\mu g\ g^{-1}$), K = potassium ($\mu g\ g^{-1}$), Ca = calcium ($\mu g\ g^{-1}$), Mg = magnesium ($\mu g\ g^{-1}$). For all variables and sites: n = 10.

† Indicates significant difference at $\alpha = 0.05$, two-sample independent t-test. Significance for Percent Canopy Closure applies to arcsine-transformation of original values (i.e. arcsin $\sqrt{(x)} = x'$). Significance for P, K, Ca, and Mg applies to log-transformation of original values (i.e. $Log_{10}(x) = x'$).

* Comparison for K, p = 0.06.

Table 34a. Case study site comparison of oak and red maple regeneration (understory stem density) and seedling and sapling abundance between management prescriptions on sandy clay loam moraine in the southern regional ecosystem of Lower Michigan[1, 2].

	Sandy Clay Loam Moraine Site	
	S1-CUT	7L-3S
	Partial Shelterwood	*Unmanaged*
Understory Stem Density (stems ha^{-1})		
All Oak Species	0.00 (0.00)	0.00 (0.00)
White Oak	0.00 (0.00)	0.00 (0.00)
Black Oak-Northern Pin Oak[3]	0.00 (0.00)	0.00 (0.00)
Northern Red Oak	0.00 (0.00)	0.00 (0.00)
Red Maple†	2960.00 (775.63)	300.00 (158.47)
Seedling and Sapling Abundance[4]		
All Oak Species Seedlings†	2.60 (0.75)	0.70 (0.52)
All Oak Species Saplings	0.00 (0.00)	0.00 (0.00)
Red Maple Seedlings	0.90 (0.35)	0.50 (0.31)
Red Maple Saplings†	2.00 (0.82)	0.30 (0.30)

1 For each variable, means are shown outside of parentheses, one standard error inside of parentheses.
2 For all variables and sites: n = 10.
3 Stems of black oak and northern pin oak are aggregated due to difficulties with field identification between these closely related species.
4 Units are numbers per 4 m^2 plot for All Oak Species and Red Maple Seedlings/Saplings.
† Indicates significance at α = 0.05, two-sample independent Mann-Whitney U-Test.

Table 34b. Case study site comparison of difference in oak and red maple regeneration (understory stem density) between management prescriptions on sandy clay loam moraine in the southern regional ecosystem of Lower Michigan[1].

	Sandy Clay Loam Moraine Site	
	S1-CUT	7L-3S
	Partial Shelterwood	*Unmanaged*
Difference in Understory Stem Density (stems ha^{-1})[2]		
All Oak Species and Red Maple Difference†	-2960.00 (775.63)*	-300.00 (158.47)

1 For each variable, means are shown outside of parentheses, one standard error inside of parentheses.
2 Positive number indicates greater oak than red maple abundance; negative number indicates converse. For all sites: n = 10.
* Difference between All Oak Species and Red Maple understory stem density within each site is significantly different from zero at α = 0.05, paired t-test.
† Difference between sites is significantly different at α = 0.05, two-sample independent t-test.

Table 35. Case study profiles of sites between management prescriptions on loamy sand moraine in the southern regional ecosystem of Lower Michigan.

	Loamy Sand Moraine Site	
	S24CC1	S19-1
Descriptor		
Sub-Subsection(1)	VI.2.2	VI.2.2
Pre-Settlement Vegetation Type(2)	black oak barren	black oak barren
Management Prescription	1) clearcut with reserves 1960s-1970s 2) arson fire late 1970s, early 1980s 3) salvage cut 1982	unmanaged
Predominant Soil Texture B-horizon	medium sand	loamy sand
Categorical Deer Abundance	High	High
Variable(3)		
Percent Canopy Closure†	91.22 (1.69)	96.01 (1.10)
Overstory Density - stems ha^{-1}‡	645.00 (60.76)	340.00 (43.97)
Overstory Basal Area - m^2 ha^{-1}	20.52 (2.06)	25.87 (3.14)
Understory Density - stems ha^{-1}	920.00 (219.49)	860.00 (236.74)
Understory Basal Area - m^2 ha^{-1}	1.61 (0.38)	1.19 (0.36)
Groundcover Species Richness	5.10 (0.58)	3.95 (0.64)
Percent Groundcover Coverage	9.22 (2.11)	8.73 (2.83)
Shrubs - # per 4 m^2 plot‡	0.00 (0.00)	3.40 (1.88)
pH	4.63 (0.06)	4.54 (0.04)
P†	70.00 (8.33)	108.60 (9.58)
K	43.70 (2.01)	45.20 (2.13)
Ca	267.60 (17.79)	229.90 (20.36)
Mg†	38.70 (2.01)	31.60 (1.59)
Percent Slope†	-13.90 (1.05)	-9.60 (0.97)

1 Albert, D.A. 1995. Regional landscape ecosystems of Michigan, Minnesota, and Wisconsin: A working map and classification. General Technical Report NC-178, North Central Forest Experiment Station, Forest Service, U.S. Dept. of Agriculture, St. Paul, MN.

2 Comer, P.J., D.A. Albert, H.A. Wells, B.L. Hart, J.B. Raab, D.L. Price, D.M. Kashian, R.A. Corner, and D.W. Schuen. 1995. Michigan's presettlement vegetation, as interpreted from the General Land Office Surveys 1816-1856. Michigan Natural Features Inventory, Lansing, MI. Digital Map.

3 For each variable, means are shown outside of parentheses, one standard error inside of parentheses. P = phosphorus (µg g^{-1}), K = potassium (µg g^{-1}), Ca = calcium (µg g^{-1}), Mg = magnesium (µg g^{-1}). For all variables except Percent Canopy Closure: S24CC1 (n = 10), S19-1 (n = 10). For Percent Canopy Closure: S24CC1 (n = 9), S19-1 (n = 9).

† Indicates significant difference at $\alpha = 0.05$, two-sample independent t-test. Significance for Percent Canopy Closure applies to arcsine-transformation of original values (i.e. arcsin $\sqrt{(x)} = x'$). Significance for P and Mg applies to log-transformation of original values (i.e. $Log_{10}(x) = x'$).

‡ Indicates significance at $\alpha = 0.05$, two-sample independent Mann-Whitney U-Test.

Table 36a. Case study site comparison of oak and red maple regeneration (understory stem density) and seedling and sapling abundance between management prescriptions on loamy sand moraine in the southern regional ecosystem of Lower Michigan[1, 2].

	Loamy Sand Moraine Site	
	S24CC1 *Clearcut and Burned*	S19-1 *Unmanaged*
Understory Stem Density (stems ha^{-1})		
All Oak Species†	240.00 (139.20)	0.00 (0.00)
White Oak† *	160.00 (118.51)	0.00 (0.00)
Black Oak-Northern Pin Oak(3)†	80.00 (32.66)	0.00 (0.00)
Northern Red Oak	0.00 (0.00)	0.00 (0.00)
Red Maple†	260.00 (181.48)	700.00 (253.42)
Seedling and Sapling Abundance(4)		
All Oak Species Seedlings	2.10 (0.50)	2.10 (0.64)
All Oak Species Saplings	0.00 (0.00)	0.00 (0.00)
Red Maple Seedlings	6.10 (2.39)	20.10 (15.05)
Red Maple Saplings	0.10 (0.10)	0.70 (0.40)

1 For each variable, means are shown outside of parentheses, one standard error inside of parentheses.
2 For all variables and sites: n = 10.
3 Stems of black oak and northern pin oak are aggregated due to difficulties with field identification between these closely related species.
4 Units are numbers per 4 m^2 plot for All Oak Species and Red Maple Seedlings/Saplings.
† Indicates significance at $\alpha = 0.05$, two-sample independent Mann-Whitney U-Test.
* Comparison for White Oak, $p = 0.068$.

Table 36b. Case study site comparison of difference in oak and red maple regeneration (understory stem density) between management prescriptions on loamy sand moraine in the southern regional ecosystem of Lower Michigan[1].

	Loamy Sand Moraine Site	
	S24CC1 *Clearcut and Burned*	S19-1 *Unmanaged*
Difference in Understory Stem Density (stems ha^{-1})(2)		
All Oak Species and Red Maple Difference†	-20.00 (257.20)	-700.00 (253.42)*

1 For each variable, means are shown outside of parentheses, one standard error inside of parentheses.
2 Positive number indicates greater oak than red maple abundance; negative number indicates converse. For all sites: n = 10.
* Difference between All Oak Species and Red Maple understory stem density within each site is significantly different from zero at $\alpha = 0.05$, paired t-test.
† Difference between sites is significantly different at $\alpha = 0.10$, two-sample independent t-test.

Table 37. Case study profiles of sites between management prescriptions on outwash in the southern regional ecosystem of Lower Michigan.

	Outwash Site	
	FC-BRN1	FC-WAY2
Descriptor		
Sub-Subsection(1)	VI.2.1	VI.2.1
Pre-Settlement Vegetation Type(2)	oak-hickory forest	oak-hickory forest
Management Prescription	prescribed burn 1999, 2002, 2004	unmanaged
Predominant Soil Texture B-horizon	loamy sand	loamy sand
Categorical Deer Abundance	high	high
Variable(3)		
Percent Canopy Closure†	75.25 (5.30)	91.52 (1.96)
Overstory Density - stems ha^{-1}†	435.00 (65.85)	635.00 (48.33)
Overstory Basal Area - m^2 ha^{-1}	19.83 (2.36)	24.78 (2.75)
Understory Density - stems ha^{-1}†	20.00 (20.00)	1280.00 (296.95)
Understory Basal Area - m^2 ha^{-1}†	0.03 (0.03)	2.35 (0.57)
Groundcover Species Richness†	11.25 (0.75)	4.50 (0.57)
Percent Groundcover Coverage†	16.03 (2.06)	5.71 (1.34)
Shrubs - # 4 m^2 per plot‡	37.50 (12.74)	7.20 (6.44)
pH†	5.45 (0.20)	4.80 (0.05)
P	59.90 (6.16)	72.60 (4.51)
K	42.20 (5.27)	31.50 (2.74)
Ca†	473.20 (110.76)	130.90 (25.62)
Mg†	62.00 (13.90)	25.50 (2.73)
Percent Slope†	-5.40 (0.60)	-3.17 (0.68)

1 Albert, D.A. 1995. Regional landscape ecosystems of Michigan, Minnesota, and Wisconsin: A working map and classification. General Technical Report NC-178, North Central Forest Experiment Station, Forest Service, U.S. Dept. of Agriculture, St. Paul, MN.

2 Comer, P.J., D.A. Albert, H.A. Wells, B.L. Hart, J.B. Raab, D.L. Price, D.M. Kashian, R.A. Corner, and D.W. Schuen. 1995. Michigan's presettlement vegetation, as interpreted from the General Land Office Surveys 1816-1856. Michigan Natural Features Inventory, Lansing, MI. Digital Map.

3 For each variable, means are shown outside of parentheses, one standard error inside of parentheses. P = phosphorus (µg g^{-1}), K = potassium (µg g^{-1}), Ca = calcium (µg g^{-1}), Mg = magnesium (µg g^{-1}). For all variables except Percent Slope: FC-BRN1 (n = 10), FC-WAY2 (n = 10). For Percent Slope: FC-BRN1 (n = 10), FC-WAY2 (n = 9).

† Indicates significant difference at $\alpha = 0.05$, two-sample independent t-test. Significance for Percent Canopy Closure applies to arcsine-transformation of original values (i.e. arcsin $\sqrt{(x)} = x'$). Significance for Ca and Mg applies to log-transformation of original values (i.e. $Log_{10}(x) = x'$).

‡ Indicates significance at $\alpha = 0.05$, two-sample independent Mann-Whitney U-Test.

Table 38a. Case study site comparison of oak and red maple regeneration (understory stem density) and seedling and sapling abundance between management prescriptions on outwash in the southern regional ecosystem of Lower Michigan[1, 2].

	Outwash Site	
	FC-BRN1 *Burned*	FC-WAY2 *Unmanaged*
Understory Stem Density (stems ha^{-1})		
All Oak Species†	0.00 (0.00)	980.00 (317.56)
White Oak†	0.00 (0.00)	500.00 (229.49)
Black Oak-Northern Pin Oak[3]†	0.00 (0.00)	480.00 (169.18)
Northern Red Oak	0.00 (0.00)	0.00 (0.00)
Red Maple	0.00 (0.00)	0.00 (0.00)
Seedling and Sapling Abundance[4]		
All Oak Species Seedlings	8.00 (1.92)	6.80 (2.26)
All Oak Species Saplings	0.10 (0.10)	0.50 (0.22)
Red Maple Seedlings†	0.10 (0.10)	1.80 (1.26)
Red Maple Saplings	0.00 (0.00)	0.00 (0.00)

1 For each variable, means are shown outside of parentheses, one standard error inside of parentheses.
2 For all variables and sites: n = 10.
3 Stems of black oak and northern pin oak are aggregated due to difficulties with field identification between these closely related species.
4 Units are numbers per 4 m^2 plot for All Oak Species and Red Maple Seedlings/Saplings.
† Indicates significance at $\alpha = 0.05$, two-sample independent Mann-Whitney U-Test.

Table 38b. Case study site comparison of difference in oak and red maple regeneration (understory stem density) between management prescriptions on outwash in the southern regional ecosystem of Lower Michigan[1].

	Outwash Site	
	FC-BRN1 *Burned*	FC-WAY2 *Unmanaged*
Difference in Understory Stem Density (stems ha^{-1})[2]		
All Oak Species and Red Maple Difference†	0.00 (0.00)	980.00 (317.56)*

1 For each variable, means are shown outside of parentheses, one standard error inside of parentheses.
2 Positive number indicates greater oak than red maple abundance; negative number indicates converse. For all sites: n = 10.
* Difference between All Oak Species and Red Maple understory stem density within each site is significantly different from zero at $\alpha = 0.05$, paired t-test.
† Difference between sites is significantly different at $\alpha = 0.05$, two-sample independent Mann-Whitney U-Test.

Table 39. Case study profiles of sites among management prescriptions on sand lake plain in the southern regional ecosystem of Lower Michigan.

	Sand Lake Plain Site			
	A11-5B(s)	A11-5B(n)	A18-N	A18-S
Descriptor				
Sub-Subsection[(1)]	VI.3.2	VI.3.2	VI.3.2	VI.3.2
Pre-Settlement Vegetation Type[(2)]	oak-pine barren	oak-pine barren	white pine-white oak forest	white pine-white oak forest
Management Prescription	arson fire 5/8/88	1) arson fire 5/8/88 2) wildfire 9/3/96	shelterwood 1996	unmanaged
Predominant Soil Texture B-horizon	loamy sand	loamy sand	loamy sand	loamy sand
Categorical Deer Abundance	medium	medium	medium	medium
Variable[(3)]				
Percent Canopy Closure	85.28 (3.56)	78.58 (5.80)	79.72 (5.67)	93.66 (0.75)
Overstory Density - stems ha^{-1}†	245.00 (39.76)[a]	245.00 (39.05)[a]	50.00 (16.67)[b]	490.00 (42.03)[c]
Overstory Basal Area - m^2 ha^{-1}†	14.85 (1.95)[a]	18.51 (2.81)[a]	10.77 (3.55)[a]	32.20 (3.23)[b]
Understory Density - stems ha^{-1}†	3020.00 (596.62)[ac]	1760.00 (347.44)[ab]	3640.00 (584.09)[c]	740.00 (140.00)[b]
Understory Basal Area - m^2 ha^{-1}†	3.71 (0.96)[a]	0.82 (0.23)[b]	2.44 (0.46)[ab]	1.47 (0.32)[b]
Groundcover Species Richness†	3.95 (0.40)[a]	4.55 (0.55)[a]	9.00 (0.72)[b]	5.35 (0.40)[a]
Percent Groundcover Coverage	22.66 (6.20)	30.02 (4.94)	30.33 (7.00)	16.76 (4.41)
Shrubs - # 4 m^2 per plot	19.70 (6.20)	23.80 (6.50)	23.40 (6.37)	16.20 (7.79)
pH†	4.50 (0.05)[a]	4.50 (0.04)[a]	4.78 (0.03)[b]	4.58 (0.03)[a]
P	58.00 (10.69)	64.20 (8.71)	98.70 (19.09)	73.40 (9.31)
K†	38.40 (1.74)[a]	41.10 (3.47)[a]	64.70 (7.69)[b]	44.4 (2.33)[a]
Ca†	56.60 (8.04)[a]	106.50 (10.90)[b]	169.00 (32.25)[b]	105.80 (10.04)[b]
Mg†	17.30 (1.84)[a]	20.00 (2.06)[ab]	28.00 (2.58)[b]	22.90 (1.43)[ab]
Percent Slope	-3.30 (0.86)	-1.90 (0.50)	-1.70 (0.63)	-1.80 (0.47)

[1] Albert, D.A. 1995. Regional landscape ecosystems of Michigan, Minnesota, and Wisconsin: A working map and classification. General Technical Report NC-178, North Central Forest Experiment Station, Forest Service, U.S. Dept. of Agriculture, St. Paul, MN.

[2] Comer, P.J., D.A. Albert, H.A. Wells, B.L. Hart, J.B. Raab, D.L. Price, D.M. Kashian, R.A. Corner, and D.W. Schuen. 1995. Michigan's presettlement vegetation, as interpreted from the General Land Office Surveys 1816-1856. Michigan Natural Features Inventory, Lansing, MI. Digital Map.

[3] For each variable, means are shown outside of parentheses, one standard error inside of parentheses. P = phosphorus (µg g^{-1}), K = potassium (µg g^{-1}), Ca = calcium (µg g^{-1}), Mg = magnesium (µg g^{-1}). For all variables and sites: n = 10.

† Indicates significant difference at $\alpha = 0.05$, ANOVA. Significance for K, Ca, and Mg applies to log-transformation of original values (i.e. $Log_{10}(x) = x'$). Comparisons with the same letter are not significantly different at $\alpha = 0.05$ when applying Tukey's HSD test.

Table 40a. Case study site comparison of oak and red maple regeneration (understory stem density) and seedling and sapling abundance among management prescriptions on sand lake plain in the southern regional ecosystem of Lower Michigan[1, 2].

	Sand Lake Plain Site			
	A11-5B(s) *Burned Once*	A11-5B(n) *Burned Twice*	A18-N *Shelterwood*	A18-S *Unmanaged*
Understory Stem Density (stems ha^{-1})				
All Oak Species†	2940.00[a]	1740.00[a]	2220.00[a]	160.00[b]
	(625.42)	(345.19)	(488.49)	(118.51)
White Oak†	2020.00[a]	1600.00[a]	1500.00[a]	160.00[b]
	(412.53)	(309.84)	(411.23)	(118.51)
Black Oak-Northern Pin Oak[(3)†]	920.00[a]	140.00[b]	720.00[ab]	0.00[b]
	(305.80)	(73.33)	(365.39)	(0.00)
Northern Red Oak	0.00	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)
Red Maple	0.00	0.00	0.00	20.00
	(0.00)	(0.00)	(0.00)	(20.00)
Seedling and Sapling Abundance[(4)]				
All Oak Species Seedlings	7.20	4.60	5.50	7.20
	(1.67)	(0.89)	(0.81)	(1.78)
All Oak Species Saplings	1.40	1.40	1.10	0.20
	(0.40)	(0.40)	(0.61)	(0.13)
Red Maple Seedlings	0.00	0.00	0.10	0.30
	(0.00)	(0.00)	(0.10)	(0.21)
Red Maple Saplings	0.00	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)

1 For each variable, means are shown outside of parentheses, one standard error inside of parentheses.
2 For all variables and sites: n = 10.
3 Stems of black oak and northern pin oak are aggregated due to difficulties with field identification between these closely related species.
4 Units are numbers per 4 m^2 plot for All Oak Species and Red Maple Seedlings/Saplings.
† Indicates significance at α = 0.05, Kruskal-Wallis. Comparisons with the same letter are not significantly different at α = 0.05 when applying non-parametric Tukey-type multiple comparison Nemenyi test.

Table 40b. Case study site comparison of difference in oak and red maple regeneration (understory stem density) among management prescriptions on sand lake plain in the southern regional ecosystem of Lower Michigan[1].

	Sand Lake Plain Site			
	A11-5B(s) *Burned Once*	A11-5B(n) *Burned Twice*	A18-N *Shelterwood*	A18-S *Unmanaged*
Difference in Understory Density (stems ha^{-1})[2]				
All Oak Species and Red Maple Difference†	2940.00* a (625.42)	1740.00* a (345.19)	2200.00* a (488.49)	140.00b (123.11)

1 For each variable, means are shown outside of parentheses, one standard error inside of parentheses.

2 Positive number indicates greater oak than red maple abundance; negative number indicates converse. For all sites: n = 10.

* Difference between All Oak Species and Red Maple understory stem density within each site is significantly different from zero at α = 0.05, paired t-test.

† Difference among sites is significantly different at α = 0.05, ANOVA. Comparisons with the same letter are not significantly different at α = 0.05 when applying Tukey's HSD test. Pairwise comparison between A11-5B(n) and A18-S, p = 0.063.

Table 41. Case study profiles of sites among management prescriptions on ice-contact terrain (PArVHa / PArVVb Kotar Habitat Type) in the northern regional ecosystem of Lower Michigan.

	Ice-Contact Site (PArVHa / PArVVb)			
	GRAY12	GRAY15	ROSC1	GAYL2
Descriptor				
Sub-Subsection[(1)]	VII.2.2	VII.2.2	VII.2.2	VII.2.3
Pre-Settlement Vegetation Type[(2)]	mixed pine-oak forest	mixed pine-oak forest	white pine-red pine forest	jack pine-red pine forest
Management Prescription	5-spot changed to shelterwood 11/21/02 with 40% closure	thinning 2/13/01	1) aspen and maple removal, ~1996 2) burned ~2003 3) thinned and burned ~2004	unmanaged
Kotar Habitat Type[(3)]	PArVHa / PArVVb	PArVHa / PArVVb	PArVHa / PArVVb	PArVHa
Predominant Soil Texture B-horizon	loamy sand/ coarse sand	coarse sand	loamy sand over clay loam	medium sand
Categorical Deer Abundance	low	low	low	low
Variable[(4)]				
Percent Canopy Closure[†,*]	75.30 (4.79)^{a}	81.70 (4.31)^{ab}	76.29 (3.74)^{a}	89.29 (2.22)^{b}
Overstory Density - stems ha^{-1}[†]	190.00 (42.03)^{a}	415.00 (34.20)^{b}	200.00 (32.49)^{a}	710.00 (50.44)^{c}
Overstory Basal Area - m^{2} ha^{-1}[†]	9.18 (2.82)^{a}	27.19 (1.85)^{bc}	19.34 (2.65)^{b}	28.57 (1.59)^{c}
Understory Density - stems ha^{-1}[†]	3400.00 (845.38)^{a}	740.00 (249.53)^{b}	80.00 (53.33)^{b}	1060.00 (238.61)^{b}
Understory Basal Area - m^{2} ha^{-1}[†]	2.10 (0.73)^{a}	0.46 (0.16)^{ab}	0.02 (0.01)^{b}	1.79 (0.45)^{a}
Groundcover Species Richness	5.55 (0.51)	6.15 (0.33)	5.40 (0.38)	6.05 (0.20)
Percent Groundcover Coverage[†]	44.37 (7.02)^{a}	34.53 (4.51)^{ab}	22.72 (4.92)^{b}	20.26 (3.48)^{b}
Shrubs - # per 4 m^{2} plot[†]	31.40 (9.71)^{a}	32.80 (8.09)^{ab}	8.30 (2.63)^{a}	71.50 (15.89)^{b}
pH[†]	4.47 (0.07)^{ac}	4.29 (0.06)^{ab}	4.57 (0.03)^{c}	4.26 (0.05)^{b}
P[†]	17.10 (1.48)^{a}	22.90 (6.09)^{a}	24.30 (3.00)^{a}	8.60 (1.83)^{b}
K[†]	21.00 (1.56)^{a}	22.10 (2.64)^{a}	21.00 (0.84)^{a}	15.00 (0.92)^{b}
Ca[†]	119.10 (6.57)^{a}	100.10 (14.03)^{a}	146.30 (17.14)^{a}	55.40 (9.06)^{b}
Mg[†]	24.20 (1.25)^{a}	16.20 (2.41)^{bc}	29.00 (1.88)^{a}	12.00 (1.22)^{c}
Percent Slope[†]	-8.60 (1.13)^{a}	-4.60 (0.67)^{b}	-6.70 (0.58)^{ab}	-9.35 (1.30)^{a}

1 Albert, D.A. 1995. Regional landscape ecosystems of Michigan, Minnesota, and Wisconsin: A working map and classification. General Technical Report NC-178, North Central Forest Experiment Station, Forest Service, U.S. Dept. of Agriculture, St. Paul, MN.

2 Comer, P.J., D.A. Albert, H.A. Wells, B.L. Hart, J.B. Raab, D.L. Price, D.M. Kashian, R.A. Corner, and D.W. Schuen. 1995. Michigan's presettlement vegetation, as interpreted from the General Land Office Surveys 1816-1856. Michigan Natural Features Inventory, Lansing, MI. Digital Map.

3 http://www.mcgi.state.mi.us/forestHabitatTypes/

4 For each variable, means are shown outside of parentheses, one standard error inside of parentheses. P = phosphorus (µg g^{-1}), K = potassium (µg g^{-1}), Ca = calcium (µg g^{-1}), Mg = magnesium (µg g^{-1}). For all variables and sites: n = 10.

† Indicates significant difference at $\alpha = 0.05$, ANOVA. Significance for Percent Canopy Closure applies to arcsine-transformation of original values (i.e. arcsin $\sqrt{(x)} = x'$). Significance for P, K, Ca, and Mg applies to log-transformation of original values (i.e. $\text{Log}_{10}(x) = x'$). Comparisons with the same letter are not significantly different at $\alpha = 0.05$ when applying Tukey's HSD test.

* Pair-wise significance for Percent Canopy Closure is at $\alpha = 0.10$.

Table 42a. Case study site comparison of oak and red maple regeneration (understory stem density) and seedling and sapling abundance among management prescriptions on ice-contact terrain (PArVHa / PArVVb Kotar Habitat Type) in the northern regional ecosystem of Lower Michigan[1, 2].

	Ice-Contact Site (PArVHa / PArVVb)			
	GRAY12 *Shelterwood*	GRAY15 *Thinning*	ROSC1 *Thinned and Burned*	GAYL2 *Unmanaged*
Understory Stem Density (stems ha^{-1})				
All Oak Species	20.00	20.00	0.00	0.00
	(20.00)	(20.00)	(0.00)	(0.00)
White Oak	20.00	0.00	0.00	0.00
	(20.00)	(0.00)	(0.00)	(0.00)
Black Oak-Northern Pin Oak[3]	0.00	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)
Northern Red Oak	0.00	20.00	0.00	0.00
	(0.00)	(20.00)	(0.00)	(0.00)
Red Maple	920.00	680.00	80.00	280.00
	(430.19)	(227.45)	(53.33)	(143.60)
Seedling and Sapling Abundance[4]				
All Oak Species Seedlings†	9.10[ab]	20.60[a]	2.80[b]	10.70[ab]
	(2.19)	(2.43)	(1.16)	(2.53)
All Oak Species Saplings	0.20	0.20	0.10	0.40
	(0.20)	(0.13)	(0.10)	(0.22)
Red Maple Seedlings†	5.10[a]	26.80[b]	4.10[a]	11.90[ab]
	(1.36)	(3.44)	(1.16)	(3.38)
Red Maple Saplings†	0.00[a]	1.20[b]	0.00[a]	0.20[ab]
	(0.00)	(0.53)	(0.00)	(0.20)

1 For each variable, means are shown outside of parentheses, one standard error inside of parentheses.
2 For all variables and sites: n = 10.
3 Stems of black oak and northern pin oak are aggregated due to difficulties with field identification between these closely related species.
4 Units are numbers per 4 m^2 plot for All Oak Species and Red Maple Seedlings/Saplings.
† Indicates significance at α = 0.05, Kruskal-Wallis. Comparisons with the same letter are not significantly different at α = 0.05 when applying non-parametric Tukey-type multiple comparison Nemenyi test.

Table 42b. Case study site comparison of difference in oak and red maple regeneration (understory stem density) among management prescriptions on ice-contact terrain (PArVHa / PArVVb Kotar Habitat Type) in the northern regional ecosystem of Lower Michigan(1).

	Ice-Contact Site (PArVHa / PArVVb)			
	GRAY12 *Shelterwood*	GRAY15 *Thinning*	ROSC1 *Thinned and Burned*	GAYL2 *Unmanaged*
Difference in Understory Stem Density (stems ha^{-1})(2)				
All Oak Species and Red Maple Difference	-900.00* (431.28)	-660.00** (217.15)	-80.00 (53.33)	-280.00* (143.60)

1 For each variable, means are shown outside of parentheses, one standard error inside of parentheses.
2 Positive number indicates greater oak than red maple abundance; negative number indicates converse. For all sites: n = 10.
* Difference between All Oak Species and Red Maple understory stem density within each site is significantly different from zero at α = 0.10, paired t-test.
** Difference between All Oak Species and Red Maple understory stem density within each site is significantly different from zero at α = 0.05, paired t-test.

Table 43. Case study profiles of sites among management prescriptions on ice-contact terrain (PVCd / PArVHa Kotar Habitat Type) in the northern regional ecosystem of Lower Michigan.

	Ice-Contact Site (PVCd / PArVHa)		
	GRAY23	GRAY26	GRAY3
Descriptor			
Sub-Subsection[(1)]	VII.2.2	VII.2.2	VII.2.2
Pre-Settlement Vegetation Type[(2)]	jack pine-red pine forest	pine barren	jack pine-red pine forest
Management Prescription	5-spot changed to shelterwood 2/4/04 with 40% closure	selection 1/29/02	thinning 3/5/03
Kotar Habitat Type[(3)]	PVCd / PArVHa	PVCd / PArVHa	PVCd / PArVHa
Predominant Soil Texture B-horizon	loamy sand	loamy sand	loamy sand
Categorical Deer Abundance	low	low	low
Variable[4]			
Percent Canopy Closure[†]	44.57 (8.69)[a]	68.18 (4.21)[ab]	73.12 (6.42)[b]
Overstory Density - stems ha^{-1}[†]	120.00 (23.81)[a]	145.00 (28.33)[a]	325.00 (38.91)[b]
Overstory Basal Area - m^2 ha^{-1}[†]	6.71 (1.54)[a]	11.38 (3.26)[ab]	16.00 (1.74)[b]
Understory Density - stems ha^{-1}	2220.00 (793.00)	820.00 (243.04)	1100.00 (715.08)
Understory Basal Area - m^2 ha^{-1}	0.78 (0.27)	0.37 (0.15)	0.76 (0.65)
Groundcover Species Richness[†]	5.10 (0.32)[a]	7.75 (0.54)[b]	6.45 (0.54)[ab]
Percent Groundcover Coverage	36.30 (4.87)	56.88 (4.66)	49.06 (8.12)
Shrubs - # per 4 m^2 plot[†]	61.90 (15.85)[a]	184.10 (56.29)[b]	27.90 (10.64)[a]
pH[†]	4.49 (0.04)[a]	4.39 (0.05)[a]	4.67 (0.06)[b]
P[†]	18.40 (2.37)[a]	11.78 (1.13)[b]	14.70 (0.90)[ab]
K	21.40 (1.16)	25.78 (2.37)	25.30 (2.75)
Ca[†]	84.30 (8.46)[a]	106.22 (14.81)[a]	173.20 (24.46)[b]
Mg[†]	18.50 (1.28)[a]	25.67 (1.68)[b]	33.80 (4.06)[b]
Percent Slope[†]	-7.50 (0.97)[a]	-2.90 (0.35)[b]	-8.10 (0.89)[a]

[1] Albert, D.A. 1995. Regional landscape ecosystems of Michigan, Minnesota, and Wisconsin: A working map and classification. General Technical Report NC-178, North Central Forest Experiment Station, Forest Service, U.S. Dept. of Agriculture, St. Paul, MN.

[2] Comer, P.J., D.A. Albert, H.A. Wells, B.L. Hart, J.B. Raab, D.L. Price, D.M. Kashian, R.A. Corner, and D.W. Schuen. 1995. Michigan's presettlement vegetation, as interpreted from the General Land Office Surveys 1816-1856. Michigan Natural Features Inventory, Lansing, MI. Digital Map.

[3] http://www.mcgi.state.mi.us/forestHabitatTypes/

[4] For each variable, means are shown outside of parentheses, one standard error inside of parentheses. P = phosphorus ($\mu g\ g^{-1}$), K = potassium ($\mu g\ g^{-1}$), Ca = calcium ($\mu g\ g^{-1}$), Mg = magnesium ($\mu g\ g^{-1}$). For all variables and sites, except pH, P, K, Ca, and Mg for GRAY26: n = 10. For the exceptions: n = 9.

[†] Indicates significant difference at $\alpha = 0.05$, ANOVA. Significance for Percent Canopy Closure applies to arcsine-transformation of original values (i.e. arcsin $\sqrt{(x)} = x'$). Significance for P, Ca, and Mg applies to log-transformation of original values (i.e. $Log_{10}(x) = x'$). Comparisons with the same letter are not significantly different at $\alpha = 0.05$ when applying Tukey's HSD test.

Table 44a. Case study site comparison of oak and red maple regeneration (understory stem density) and seedling and sapling abundance among management prescriptions on ice-contact terrain (PVCd / PArVHa Kotar Habitat Type) in the northern regional ecosystem of Lower Michigan[1, 2].

	Ice-Contact Site (PVCd / PArVHa)		
	GRAY23 *Shelterwood*	GRAY26 *Selection*	GRAY3 *Thinning*
Understory Stem Density (stems ha^{-1})			
All Oak Species	340.00 (276.57)	380.00 (191.95)	740.00 (718.05)
White Oak[†]	260.00 (260.00)	280.00 (120.00)	720.00 (720.00)
Black Oak-Northern Pin Oak[(3)]	0.00 (0.00)	0.00 (0.00)	20.00 (20.00)
Northern Red Oak	80.00 (44.22)	100.00 (80.28)	0.00 (0.00)
Red Maple	440.00 (236.27)	300.00 (225.59)	340.00 (155.06)
Seedling and Sapling Abundance[(4)]			
All Oak Species Seedlings	16.00 (3.65)	25.90 (6.14)	14.40 (4.30)
All Oak Species Saplings[†]	0.00 (0.00)[a]	1.10 (0.41)[b]	0.20 (0.20)[a]
Red Maple Seedlings[†]	5.20 (2.58)[a]	38.50 (7.88)[b]	9.60 (3.68)[a]
Red Maple Saplings	0.20 (0.20)	0.70 (0.70)	0.10 (0.10)

[1] For each variable, means are shown outside of parentheses, one standard error inside of parentheses.
[2] For all variables and sites: n = 10.
[3] Stems of black oak and northern pin oak are aggregated due to difficulties with field identification between these closely related species.
[4] Units are numbers per 4 m^2 plot for All Oak Species and Red Maple Seedlings/Saplings.
[†] Indicates significance at α = 0.05, Kruskal-Wallis. Comparisons with the same letter are not significantly different at α = 0.05 when applying non-parametric Tukey-type multiple comparison Nemenyi test. However, pairwise significant differences may not have been detected with this test for certain variables.

Table 44b. Case study site comparison of difference in oak and red maple regeneration (understory stem density) among management prescriptions on ice-contact terrain (PVCd / PArVHa Kotar Habitat Type) in the northern regional ecosystem of Lower Michigan[(1)].

	Ice-Contact Site (PVCd / PArVHa)		
	GRAY23 *Shelterwood*	GRAY26 *Selection*	GRAY3 *Thinning*
Difference in Understory Stem Density (stems ha^{-1})[(2)]			
All Oak Species and Red Maple Difference	-100.00 (367.88)	80.00 (336.25)	400.00 (771.72)

[1] For each variable, means are shown outside of parentheses, one standard error inside of parentheses.
[2] Positive number indicates greater oak than red maple abundance; negative number indicates converse.
For all sites: n = 10.

Table 45. Case study profiles of sites among management prescriptions on moraine in the northern regional ecosystem of Lower Michigan.

	Moraine Site			
	ATL12	MAN4B	CAD7	CAD26
Descriptor				
Sub-Subsection[(1)]	VII.6.1	VII.3	VII.2.1	VII.2.1
Pre-Settlement Vegetation Type[(2)]	jack pine-red pine forest	white pine-white oak forest	white pine-mixed hardwood forest	white pine-mixed hardwood forest
Management Prescription	clearcut 1996	shelterwood 1994	thinning ~1999	unmanaged
Kotar Habitat Type[(3)]	PArVHa	n/a	PArVHa	n/a
Predominant Soil Texture B-horizon	sandy loam / sandy clay loam	loamy sand	sandy loam / sandy clay loam	sandy loam / sandy clay loam
Categorical Deer Abundance	low	high	medium	medium
Variable[(4)]				
Percent Canopy Closure†	35.05 (12.70)[a]	94.12 (1.05)[b]	77.22 (4.41)[b]	96.88 (0.45)[b]
Overstory Density - stems ha^{-1}†	30.00 (11.06)[a]	170.00 (22.61)[ab]	230.00 (26.03)[b]	530.00 (81.04)[c]
Overstory Basal Area - m^2 ha^{-1}†	0.32 (0.12)[a]	18.13 (2.73)[b]	23.00 (3.18)[b]	39.09 (4.90)[c]
Understory Density - stems ha^{-1}‡	4140.00 (982.99)	4020.00 (799.14)	2660.00 (1022.00)	1480.00 (585.91)
Understory Basal Area - m^2 ha^{-1}‡	5.12 (1.16)[a]	4.32 (1.29)[ab]	1.10 (0.45)[b]	1.98 (0.85)[ab]
Groundcover Species Richness†	9.35 (0.53)[a]	7.00 (0.33)[b]	6.25 (0.31)[b]	4.65 (0.36)[c]
Percent Groundcover Coverage†	53.62 (7.19)[a]	37.47 (5.50)[a]	51.27 (6.12)[a]	8.17 (1.55)[b]
Shrubs - # per 4 m^2 plot‡	108.40 (14.51)[a]	60.50 (14.46)[ab]	11.50 (4.50)[bc]	4.40 (1.34)[c]
pH†	4.68 (0.07)[a]	4.43 (0.06)[b]	4.50 (0.06)[ab]	4.43 (0.07)[b]
P†	24.20 (5.40)[a]	59.30 (7.30)[b]	21.60 (2.74)[a]	72.60 (9.59)[b]
K	28.70 (4.10)	26.80 (1.93)	31.30 (1.86)	24.30 (1.24)
Ca†	215.50 (50.43)[a]	67.70 (9.76)[b]	217.20 (23.66)[a]	77.60 (6.57)[b]
Mg†	30.40 (5.71)[ab]	19.30 (1.89)[a]	41.70 (4.48)[b]	20.70 (2.52)[a]
Percent Slope	-5.40 (1.80)	-8.35 (0.98)	-5.20 (1.27)	-11.10 (2.60)

[1] Albert, D.A. 1995. Regional landscape ecosystems of Michigan, Minnesota, and Wisconsin: A working map and classification. General Technical Report NC-178, North Central Forest Experiment Station, Forest Service, U.S. Dept. of Agriculture, St. Paul, MN.

[2] Comer, P.J., D.A. Albert, H.A. Wells, B.L. Hart, J.B. Raab, D.L. Price, D.M. Kashian, R.A. Corner, and D.W. Schuen. 1995. Michigan's presettlement vegetation, as interpreted from the General Land Office Surveys 1816-1856. Michigan Natural Features Inventory, Lansing, MI. Digital Map.

[3] http://www.mcgi.state.mi.us/forestHabitatTypes/

[4] For each variable, means are shown outside of parentheses, one standard error inside of parentheses. P = phosphorus (µg g^{-1}), K = potassium (µg g^{-1}), Ca = calcium (µg g^{-1}), Mg = magnesium (µg g^{-1}). For all variables and sites: n = 10.

† Indicates significant difference at $\alpha = 0.05$, ANOVA. Significance for Percent Canopy Closure applies to arcsine-transformation of original values (i.e. arcsin $\sqrt{(x)} = x'$). Significance for P, Ca, and Mg applies to log-transformation of original values (i.e. $Log_{10}(x) = x'$). Comparisons with the same letter are not significantly different at $\alpha = 0.05$ when applying Tukey's HSD test.

‡ Indicates significance at $\alpha = 0.05$, Kruskal-Wallis. Comparisons with the same letter are not significantly different at $\alpha = 0.05$ when applying non-parametric Tukey-type multiple comparison Nemenyi test. However, pairwise significant differences may not have been detected with this test for certain variables.

Table 46a. Case study site comparison of oak and red maple regeneration (understory stem density) and seedling and sapling abundance among management prescriptions on moraine in the northern regional ecosystem of Lower Michigan[1, 2].

	Moraine Site			
	ATL12 *Clearcut*	MAN4B *Shelterwood*	CAD7 *Thinning*	CAD26 *Unmanaged*
Understory Stem Density (stems ha^{-1})				
All Oak Species†	2680.00[a]	260.00[ab]	40.00[b]	0.00[b]
	(688.44)	(119.44)	(40.00)	(0.00)
White Oak†	0.00	100.00	0.00	0.00
	(0.00)	(61.46)	(0.00)	(0.00)
Black Oak-Northern Pin Oak[3]	0.00	140.00	0.00	0.00
	(0.00)	(119.44)	(0.00)	(0.00)
Northern Red Oak†	2680.00[a]	20.00[b]	40.00[b]	0.00[b]
	(688.44)	(20.00)	(40.00)	(0.00)
Red Maple	680.00	2360.00	1580.00	700.00
	(377.36)	(687.54)	(677.55)	(504.43)
Seedling and Sapling Abundance[4]				
All Oak Species Seedlings†	4.20[ab]	7.20[a]	3.30[ab]	1.20[b]
	(1.38)	(0.93)	(0.67)	(0.42)
All Oak Species Saplings	0.70	0.20	0.00	0.30
	(0.37)	(0.20)	(0.00)	(0.21)
Red Maple Seedlings†	10.30[a]	3.70[a]	16.00[ab]	39.00[b]
	(3.27)	(0.79)	(2.86)	(6.78)
Red Maple Saplings	1.00	2.40	4.40	0.40
	(0.68)	(0.87)	(2.02)	(0.22)

[1] For each variable, means are shown outside of parentheses, one standard error inside of parentheses.
[2] For all variables and sites: n = 10.
[3] Stems of black oak and northern pin oak are aggregated due to difficulties with field identification between these closely related species.
[4] Units are numbers per 4 m^2 plot for All Oak Species and Red Maple Seedlings/Saplings.
† Indicates significance at $\alpha = 0.05$, Kruskal-Wallis. Comparisons with the same letter are not significantly different at $\alpha = 0.05$ when applying non-parametric Tukey-type multiple comparison Nemenyi test. However, pairwise significant differences may not have been detected with this test for certain variables.

Table 46b. Case study site comparison of difference in oak and red maple regeneration (understory stem density) among management prescriptions on moraine in the northern regional ecosystem of Lower Michigan(1).

	Moraine Site			
	ATL12 *Clearcut*	MAN4B *Shelterwood*	CAD7 *Thinning*	CAD26 *Unmanaged*
Difference in Understory Stem Density (stems ha^{-1})(2)				
All Oak Species and Red Maple Difference†	2000.00** a	-2100.00** b	-1540.00* b	-700.00b
	(607.36)	(713.21)	(687.70)	(504.43)

1 For each variable, means are shown outside of parentheses, one standard error inside of parentheses.

2 Positive number indicates greater oak than red maple abundance; negative number indicates converse. For all sites: n = 10.

* Difference between All Oak Species and Red Maple understory stem density within each site is significantly different from zero at α = 0.10, paired t-test.

** Difference between All Oak Species and Red Maple understory stem density within each site is significantly different from zero at α = 0.05, paired t-test.

† Difference among sites is significantly different at α = 0.05, ANOVA. Comparisons with the same letter are not significantly different at α = 0.05 when applying Tukey's HSD test.

Table 47. Case study profiles of sites among management prescriptions on outwash in the northern regional ecosystem of Lower Michigan.

	Outwash Site			
	BRAD1B	MAN9B	MAN1B	BRAD1
Descriptor				
Sub-Subsection[(1)]	VII.3	VII.3	VII.3	VII.3
Pre-Settlement Vegetation Type[(2)]	white pine-white oak forest	white pine-white oak forest	white pine-white oak forest	white pine-white oak forest
Management Prescription	clearcut between 1977-1987	shelterwood 1995	prescribed burn 2001	unmanaged
Kotar Habitat Type[(3)]	n/a	PArVHa	n/a	n/a
Predominant Soil Texture B-horizon	loamy sand	loamy sand	fine sand	loamy sand
Categorical Deer Abundance	high	medium	medium	high
Variable[(4)]				
Percent Canopy Closure†	94.38 (1.41)[a]	38.28 (11.15)[b]	92.62 (1.26)[a]	91.99 (1.50)[a]
Overstory Density - stems ha^{-1}†	575.00 (79.67)[a]	35.00 (13.02)[b]	765.00 (64.14)[ac]	830.00 (53.85)[c]
Overstory Basal Area - m^2 ha^{-1}†	7.19 (1.04)[a]	2.85 (1.19)[a]	31.26 (2.66)[b]	28.87 (2.46)[b]
Understory Density - stems ha^{-1}†	3840.00 (420.37)[a]	2800.00 (621.83)[a]	180.00 (46.67)[b]	180.00 (46.67)[b]
Understory Basal Area - m^2 ha^{-1}†	8.69 (1.03)[a]	1.32 (0.36)[b]	0.50 (0.17)[b]	0.60 (0.27)[b]
Groundcover Species Richness†	3.50 (0.24)[a]	5.60 (0.59)[b]	5.00 (0.21)[ab]	4.55 (0.43)[ab]
Percent Groundcover Coverage†	9.25 (1.62)[a]	44.71 (5.07)[b]	17.11 (2.28)[a]	11.89 (1.49)[a]
Shrubs - # per 4 m^2 plot	40.30 (9.29)	66.10 (28.75)	26.00 (6.31)	26.40 (8.05)
pH†	4.37 (0.03)[a]	4.71 (0.04)[b]	4.51 (0.04)[c]	4.34 (0.03)[a]
P†	35.30 (5.10)[a]	33.40 (3.33)[a]	17.40 (1.97)[b]	32.50 (4.29)[a]
K†	19.90 (1.14)[a]	20.20 (1.08)[a]	27.40 (1.95)[b]	26.10 (1.75)[b]
Ca	61.30 (9.18)	90.80 (9.96)	63.10 (9.77)	52.40 (7.86)
Mg†	14.30 (1.43)[ab]	14.10 (1.89)[a]	21.10 (2.29)[b]	15.70 (1.66)[ab]
Percent Slope†	-2.05 (0.30)[a]	-1.20 (0.13)[a]	-2.05 (0.34)[a]	-3.95 (0.75)[b]

[1] Albert, D.A. 1995. Regional landscape ecosystems of Michigan, Minnesota, and Wisconsin: A working map and classification. General Technical Report NC-178, North Central Forest Experiment Station, Forest Service, U.S. Dept. of Agriculture, St. Paul, MN.

[2] Comer, P.J., D.A. Albert, H.A. Wells, B.L. Hart, J.B. Raab, D.L. Price, D.M. Kashian, R.A. Corner, and D.W. Schuen. 1995. Michigan's presettlement vegetation, as interpreted from the General Land Office Surveys 1816-1856. Michigan Natural Features Inventory, Lansing, MI. Digital Map.

[3] http://www.mcgi.state.mi.us/forestHabitatTypes/

[4] For each variable, means are shown outside of parentheses, one standard error inside of parentheses. P = phosphorus ($\mu g\ g^{-1}$), K = potassium ($\mu g\ g^{-1}$), Ca = calcium ($\mu g\ g^{-1}$), Mg = magnesium ($\mu g\ g^{-1}$). For all variables and sites: n = 10.

† Indicates significant difference at $\alpha = 0.05$, ANOVA. Significance for Percent Canopy Closure applies to arcsine-transformation of original values (i.e. arcsin $\sqrt{(x)} = x'$). Significance for P, K, and Mg applies to log-transformation of original values (i.e. $Log_{10}(x) = x'$). Comparisons with the same letter are not significantly different at $\alpha = 0.05$ when applying Tukey's HSD test.

Table 48a. Case study site comparison of oak and red maple regeneration (understory stem density) and seedling and sapling abundance among management prescriptions on outwash in the northern regional ecosystem of Lower Michigan[1, 2].

	Outwash Site			
	BRAD1B *Clearcut*	MAN9B *Shelterwood*	MAN1B *Burned*	BRAD1 *Unmanaged*
Understory Stem Density (stems ha^{-1})				
All Oak Species†	3840.00[a]	2720.00[a]	100.00[b]	80.00[b]
	(420.37)	(579.81)	(44.72)	(44.22)
White Oak†	3340.00[a]	1760.00[ab]	100.00[b]	60.00[b]
	(418.52)	(523.92)	(44.72)	(30.55)
Black Oak-Northern Pin Oak[(3)†]	500.00[a]	960.00[a]	0.00[b]	20.00[b]
	(149.82)	(355.03)	(0.00)	(20.00)
Northern Red Oak	0.00	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)
Red Maple	0.00	0.00	0.00	60.00
	(0.00)	(0.00)	(0.00)	(42.69)
Seedling and Sapling Abundance[(4)]				
All Oak Species Seedlings†	3.70[a]	9.40[ab]	29.40[b]	8.50[ab]
	(1.08)	(2.44)	(6.84)	(1.59)
All Oak Species Saplings†	1.70	3.00	0.20	0.30
	(0.58)	(1.34)	(0.13)	(0.21)
Red Maple Seedlings†	0.50[ab]	0.00[a]	4.90[bc]	5.90[c]
	(0.22)	(0.00)	(2.21)	(2.25)
Red Maple Saplings	0.00	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)

1 For each variable, means are shown outside of parentheses, one standard error inside of parentheses.
2 For all variables and sites: n = 10.
3 Stems of black oak and northern pin oak are aggregated due to difficulties with field identification between these closely related species.
4 Units are numbers per 4 m^2 plot for All Oak Species and Red Maple Seedlings/Saplings.
† Indicates significance at $\alpha = 0.05$, Kruskal-Wallis. Comparisons with the same letter are not significantly different at $\alpha = 0.05$ when applying non-parametric Tukey-type multiple comparison Nemenyi test. However, pairwise significant differences may not have been detected with this test for certain variables.

Table 48b. Case study site comparison of difference in oak and red maple regeneration (understory stem density) among management prescriptions on outwash in the northern regional ecosystem of Lower Michigan[1].

	Outwash Site			
	BRAD1B *Clearcut*	MAN9B *Shelterwood*	MAN1B *Burned*	BRAD1 *Unmanaged*
Difference in Understory Stem Density (stems ha^{-1})[2]				
All Oak Species and Red Maple Difference†	3840.00** a (420.37)	2720.00** a (579.81)	100.00* b (44.72)	20.00b (69.60)

1 For each variable, means are shown outside of parentheses, one standard error inside of parentheses.
2 Positive number indicates greater oak than red maple abundance; negative number indicates converse. For all sites: n = 10.
* Difference between All Oak Species and Red Maple understory stem density within each site is significantly different from zero at α = 0.10, paired t-test.
** Difference between All Oak Species and Red Maple understory stem density within each site is significantly different from zero at α = 0.05, paired t-test.
† Difference among sites is significantly different at α = 0.05, ANOVA. Comparisons with the same letter are not significantly different at α = 0.05 when applying Tukey's HSD test.

Table 49. Case study profiles of sites among management prescriptions on sand lake plain in the northern regional ecosystem of Lower Michigan.

	Sand Lake Plain Site			
	GLA1C	GLA3B	HUR3C	GLA8
Descriptor				
Sub-Subsection[(1)]	VII.1.1	VII.1.1	VII.1.1	VII.1.1
Pre-Settlement Vegetation Type[(2)]	jack pine-red pine forest	jack pine-red pine forest	jack pine-red pine forest	white pine-red pine forest
Management Prescription	clearcut 1999	shelterwood ~2003	1) wildfire 1984 2) removal of jack pine 1999 3) prescribed burns and grass planting	unmanaged
Kotar Habitat Type[(3)]	PVCd / PArVHa	PArVCo / PArVHa	PVCd	PArVHa
Predominant Soil Texture B-horizon	coarse sand	loamy sand w/ mottling	medium sand	medium sand
Categorical Deer Abundance	medium	medium	high	medium
Variable[(4)]				
Percent Canopy Closure†	19.92 (8.94)[a]	59.28 (9.28)[bc]	31.67 (6.47)[ab]	84.92 (3.13)[c]
Overstory Density - stems ha^{-1}†	70.00 (44.85)[a]	280.00 (66.33)[b]	290.00 (43.33)[b]	440.00 (58.12)[b]
Overstory Basal Area - m^2 ha^{-1}†	1.49 (0.94)[a]	14.04 (4.13)[b]	3.69 (0.50)[a]	22.43 (3.18)[b]
Understory Density - stems ha^{-1}†	1680.00 (481.85)[a]	380.00 (113.33)[b]	360.00 (145.45)[b]	280.00 (90.43)[b]
Understory Basal Area - m^2 ha^{-1}†	1.67 (0.36)[a]	0.44 (0.23)[b]	0.56 (0.23)[b]	0.31 (0.11)[b]
Groundcover Species Richness†	2.40 (0.25)[a]	8.55 (0.42)[b]	5.10 (0.30)[c]	4.50 (0.55)[c]
Percent Groundcover Coverage†	73.57 (6.37)[a]	38.56 (5.83)[b]	19.53 (5.22)[b]	20.44 (3.51)[b]
Shrubs - # per 4 m^2 plot†	30.40 (10.30)[a]	99.50 (17.02)[a]	262.30 (44.83)[b]	25.20 (9.66)[a]
pH†	4.80 (0.08)[a]	4.08 (0.04)[b]	4.60 (0.03)[c]	4.46 (0.04)[c]
P†	20.60 (1.75)[a]	6.30 (1.07)[b]	11.30 (1.51)[c]	18.70 (1.96)[ac]
K†	28.20 (3.31)[a]	26.90 (2.77)[a]	15.10 (0.78)[b]	22.20 (3.75)[ab]
Ca†	250.80 (36.75)[a]	91.30 (7.96)[b]	84.50 (10.58)[b]	98.90 (13.49)[b]
Mg†	32.70 (2.51)[a]	22.30 (1.90)[b]	15.40 (1.49)[c]	19.60 (1.61)[bc]
Percent Slope	-1.55 (0.51)	-1.70 (0.78)	-2.89 (0.59)	-2.60 (0.87)

[1] Albert, D.A. 1995. Regional landscape ecosystems of Michigan, Minnesota, and Wisconsin: A working map and classification. General Technical Report NC-178, North Central Forest Experiment Station, Forest Service, U.S. Dept. of Agriculture, St. Paul, MN.

[2] Comer, P.J., D.A. Albert, H.A. Wells, B.L. Hart, J.B. Raab, D.L. Price, D.M. Kashian, R.A. Corner, and D.W. Schuen. 1995. Michigan's presettlement vegetation, as interpreted from the General Land Office Surveys 1816-1856. Michigan Natural Features Inventory, Lansing, MI. Digital Map.

[3] http://www.mcgi.state.mi.us/forestHabitatTypes/

[4] For each variable, means are shown outside of parentheses, one standard error inside of parentheses. P = phosphorus ($\mu g\ g^{-1}$), K = potassium ($\mu g\ g^{-1}$), Ca = calcium ($\mu g\ g^{-1}$), Mg = magnesium ($\mu g\ g^{-1}$). For all variables and sites, except Percent Slope for HUR3C: n = 10. For the exception: n = 9.

† Indicates significant difference at $\alpha = 0.05$, ANOVA. Significance for Percent Canopy Closure applies to arcsine-transformation of original values (i.e. arcsin $\sqrt{(x)}$ = x'). Significance for P, K, Ca, and Mg applies to log-transformation of original values (i.e. Log_{10} (x) = x'). Comparisons with the same letter are not significantly different at $\alpha = 0.05$ when applying Tukey's HSD test.

Table 50a. Case study site comparison of oak and red maple regeneration (understory stem density) and seedling and sapling abundance among management prescriptions on sand lake plain in the northern regional ecosystem of Lower Michigan[1, 2].

	Sand Lake Plain Site			
	GLA1C *Clearcut*	GLA3B *Shelterwood*	HUR3C *Cut and Burned*	GLA8 *Unmanaged*
Understory Stem Density (stems ha^{-1})				
All Oak Species†	820.00[a]	0.00[b]	320.00[ab]	240.00[ab]
	(301.77)	(0.00)	(127.19)	(71.80)
White Oak	40.00	0.00	0.00	120.00
	(40.00)	(0.00)	(0.00)	(67.99)
Black Oak-Northern Pin Oak[(3)†]	780.00[a]	0.00[b]	320.00[ab]	120.00[ab]
	(307.61)	(0.00)	(127.19)	(61.10)
Northern Red Oak	0.00	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)
Red Maple†	0.00[a]	140.00[b]	0.00[a]	0.00[a]
	(0.00)	(67.00)	(0.00)	(0.00)
Seedling and Sapling Abundance[(4)]				
All Oak Species Seedlings†	2.90[a]	8.00[ab]	7.00[ab]	13.70[b]
	(1.08)	(2.75)	(3.02)	(2.46)
All Oak Species Saplings	0.10	0.10	0.00	0.40
	(0.10)	(0.10)	(0.00)	(0.22)
Red Maple Seedlings†	0.00[a]	4.50[b]	0.00[a]	3.20[b]
	(0.00)	(1.29)	(0.00)	(0.81)
Red Maple Saplings	0.00	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)

1 For each variable, means are shown outside of parentheses, one standard error inside of parentheses.
2 For all variables and sites: n = 10.
3 Stems of black oak and northern pin oak are aggregated due to difficulties with field identification between these closely related species.
4 Units are numbers per 4 m^2 plot for All Oak Species and Red Maple Seedlings/Saplings.
† Indicates significance at α = 0.05, Kruskal-Wallis. Comparisons with the same letter are not significantly different at α = 0.05 when applying non-parametric Tukey-type multiple comparison Nemenyi test.

Table 50b. Case study site comparison of difference in oak and red maple regeneration (understory stem density) among management prescriptions on sand lake plain in the northern regional ecosystem of Lower Michigan[1].

	Sand Lake Plain Site			
	GLA1C *Clearcut*	GLA3B *Shelterwood*	HUR3C *Cut and Burned*	GLA8 *Unmanaged*
Difference in Understory Density (stems ha^{-1})[2]				
All Oak Species and Red Maple Difference†	820.00** a	-140.00* b	320.00** ab	240.00** ab
	(301.773)	(67.00)	(127.19)	(71.80)

1 For each variable, means are shown outside of parentheses, one standard error inside of parentheses.

2 Positive number indicates greater oak than red maple abundance; negative number indicates converse. For all sites: n = 10.

* Difference between All Oak Species and Red Maple understory stem density within each site is significantly different from zero at α = 0.10, paired t-test.

** Difference between All Oak Species and Red Maple understory stem density within each site is significantly different from zero at α = 0.05, paired t-test.

† Difference among sites is significantly different at α = 0.05, ANOVA. Comparisons with the same letter are not significantly different at α = 0.05 when applying Tukey's HSD test.

Table 51. Logistic regression model selection based on Akaike Information Criterion (AIC) weights, wi.

Model Name	K	AIC	$\Delta i = AIC_i - AIC_{min}$	$e^{(-\Delta i/2)}$	w_i
Global	14	63.090	5.584	0.061	0.020
A	12	59.559	2.053	0.358	0.116
B	9	66.598	9.092	0.011	0.003
C	11	57.650	0.144	0.931	0.302
D	11	61.784	4.278	0.118	0.038
E	8	64.679	7.173	0.028	0.009
F	8	67.615	10.109	0.006	0.002
G	10	60.457	2.951	0.229	0.074
H	10	59.670	2.164	0.339	0.110
I	11	57.506	0.000	1.000	0.325
		AIC_{min} = 57.506		$\sum = 3.080$	$\sum = 1$

K = number of model parameters including constant.
$w_i = [e^{(-\Delta i/2)} / 3.080]$

Table 52a. Logistic regression analysis (Model C) of oak regeneration success among 92 oak-dominated sites of Lower Michigan.

Predictor	β	SE β	p-value	OR[(1)]	95 % CI of OR
Constant	16.534	5.054	0.001		
Total Soil Cation Concentration (P, K, Ca, Mg) - μg g^{-1}	-0.017	0.006	0.004	0.983	0.971 – 0.995
Overstory Basal Area - m^2 ha^{-1}	-0.538	0.141	0.000	0.584	0.443 – 0.770
Understory Basal Area (excluding oaks) - m^2 ha^{-1}	-0.644	0.398	0.106	0.525	0.241 – 1.145
Percent Groundcover Coverage	-0.150	0.052	0.004	0.860	0.777 – 0.952
Shrubs - # per 4 m^2 plot	-0.022	0.016	0.171	0.979	0.949 – 1.009
All Oak Species Seedlings - # per 4 m^2 plot	0.276	0.138	0.046	1.318	1.004 – 1.728
Landform = ice-contact	-3.886	2.028	0.055	0.021	0.000 – 1.093
Landform = lake plain	0.349	1.276	0.785	1.417	0.116 – 17.273
Landform = outwash	3.144	1.647	0.056	23.189	0.918 – 585.595
Soil Classification = sandy	2.502	1.277	0.050	12.209	0.999 – 149.178
Overall Model Evaluation	χ^2	df	p-value		
Likelihood test statistic, *G* = 2*[LL(N)-LL(0)]	86.576	10	0.000		
Goodness-of-Fit Evaluation					
McFadden's Rho-squared	0.708				
Information Criteria					
AIC	57.650				

[1] OR, odds ratio.

Table 52b. The observed and predicted frequencies for oak regeneration success by logistic regression (Model C) with the cutoff of 0.50 among 92 oak-dominated sites of Lower Michigan.

	Predicted		
Observed	Successful	Unsuccessful	% Correct
Successful	31	4	88.6
Unsuccessful	4	53	93.0
Overall			91.3

False positive = [4 / (4 + 31)] * 100 = 11.4%. False negative = [4 / (4 + 53)] * 100 = 7.0%.

Table 53a. Logistic regression analysis (Model I) of oak regeneration success among 92 oak-dominated sites of Lower Michigan.

Predictor	β	SE β	p-value	OR[(1)]	95 % CI of OR
Constant	17.313	5.545	0.002		
Total Soil Cation Concentration (P, K, Ca, Mg) - $\mu g\ g^{-1}$	-0.017	0.006	0.004	0.983	0.971 – 0.995
Overstory Basal Area - $m^2\ ha^{-1}$	-0.561	0.154	0.000	0.571	0.422 – 0.772
Red Maple Understory Basal Area - $m^2\ ha^{-1}$	-1.424	0.855	0.096	0.241	0.045 – 1.286
Percent Groundcover Coverage	-0.166	0.060	0.006	0.847	0.753 – 0.953
Shrubs - # per 4 m^2 plot	-0.020	0.016	0.201	0.980	0.951 – 1.011
All Oak Species Seedlings - # per 4 m^2 plot	0.286	0.140	0.041	1.331	1.012 – 1.750
Landform = ice-contact	-3.868	2.059	0.060	0.021	0.000 – 1.182
Landform = lake plain	0.337	1.287	0.793	1.401	0.112 – 17.462
Landform = outwash	3.130	1.636	0.056	22.868	0.926 – 564.974
Soil Classification = sandy	2.458	1.255	0.050	11.684	0.999 – 136.607
Overall Model Evaluation	χ^2	df	p-value		
Likelihood test statistic, G = 2*[LL(N)-LL(0)]	86.720	10	0.000		
Goodness-of-Fit Evaluation					
McFadden's Rho-squared	0.710				
Information Criteria					
AIC	57.506				

[1] OR, odds ratio.

Table 53b. The observed and predicted frequencies for oak regeneration success by logistic regression (Model I) with the cutoff of 0.50 among 92 oak-dominated sites of Lower Michigan.

	Predicted		
Observed	Successful	Unsuccessful	% Correct
Successful	31	4	88.6
Unsuccessful	4	53	93.0
Overall			91.3

False positive = [4 / (4 + 31)] * 100 = 11.4%. False negative = [4 / (4 + 53)] * 100 = 7.0%.

Table 54. Comparison of relative variation among landforms in the **southern** regional ecosystem of Lower Michigan as determined by discriminant analysis of two soil variables and seven vegetation variables.

Canonical variate	1	2	3
Eigenvalue	3.218	0.855	0.409
Canonical correlation	0.873	0.679	0.539
Cumulative % of variance	0.718	0.909	1.000
Variable[(1)]	Correlation Coefficient		
Soil pH	0.639	0.689	-0.038
Total Soil Cation Concentration (P, K, Ca, Mg) - µg g^{-1}	0.772	0.338	-0.003
Overstory Species Richness	0.700	0.212	0.370
Overstory Basal Area - m^2 ha^{-1}	0.403	-0.118	0.073
Understory Basal Area (excluding oaks) - m^2 ha^{-1}	0.575	-0.391	0.059
Percent Groundcover Coverage	-0.399	0.068	-0.680
All Oak Species Seedlings - # per 4 m^2 plot	-0.566	0.225	0.383
Tree Seedlings - # per 4 m^2 plot	-0.001	0.019	0.461
Shrubs - # per 4 m^2 plot	-0.543	0.469	-0.325

[1] Original values for Total Soil Cation Concentration, Understory Basal Area, All Oak Species Seedlings, Tree Seedlings, and Shrubs were log-transformed (i.e. Log_{10} (x + 1) = x') before analysis.

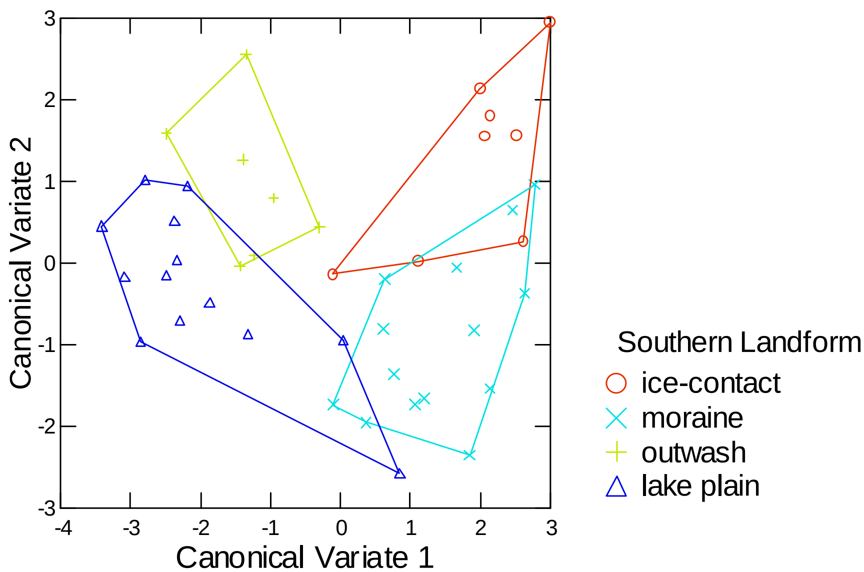


Figure 18. Ordination of 42 sites among 4 landforms in the **southern** regional ecosystem of Lower Michigan along the first 2 canonical variates using 2 soil variable and 7 vegetation variables.

Table 55. Comparison of relative variation among landforms in the **northern** regional ecosystem of Lower Michigan as determined by discriminant analysis of two soil variables, nine vegetation variables, and one physiographic variable.

Canonical variate	1	2	3
Eigenvalue	4.079	0.753	0.034
Canonical correlation	0.896	0.655	0.180
Cumulative % of variance	0.838	0.993	1.000
Variable[(1)]	Correlation Coefficient		
Soil pH	-0.260	-0.388	0.673
Total Soil Cation Concentration (P, K, Ca, Mg) - $\mu g\ g^{-1}$	-0.369	-0.284	0.298
Overstory Species Richness	-0.026	0.414	-0.145
Overstory Basal Area - $m^2\ ha^{-1}$	-0.357	0.093	-0.273
Understory Species Richness	-0.369	-0.136	-0.081
Understory Basal Area (excluding oaks) - $m^2\ ha^{-1}$	-0.491	0.097	-0.324
Percent Groundcover Coverage	0.177	0.136	0.219
All Oak Species Seedlings - # per 4 m^2 plot	0.476	0.307	0.475
Tree Seedlings - # per 4 m^2 plot	-0.634	0.416	-0.130
Shrubs - # per 4 m^2 plot	0.561	0.183	-0.333
Percent Slope	0.825	-0.354	0.044
Percent Canopy Closure	-0.485	0.106	-0.160

[1] Original values for Total Soil Cation Concentration, Understory Basal Area, All Oak Species Seedlings, Tree Seedlings, and Shrubs were log-transformed (i.e. $Log_{10}(x + 1) = x'$) before analysis. Percent Canopy Closure was arcsine-transformed (i.e. arcsin $\sqrt{(x)} = x'$) before analysis.

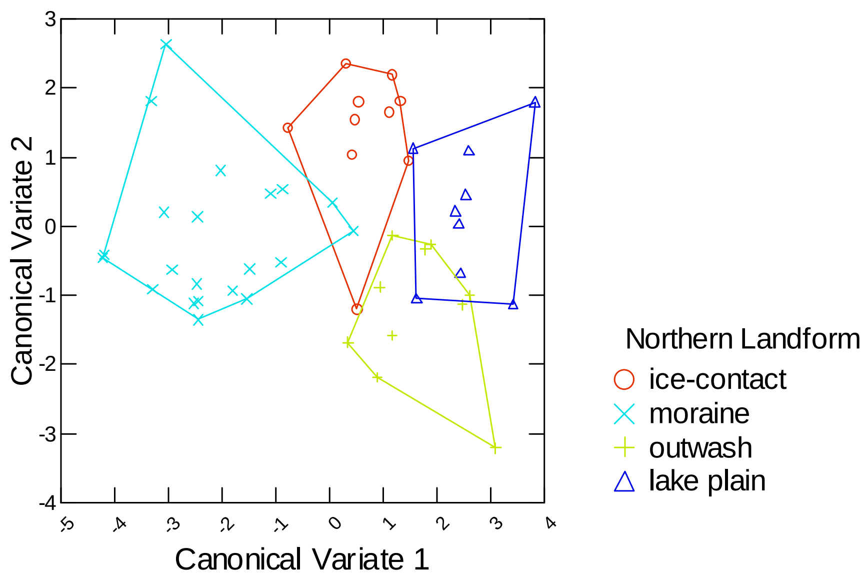


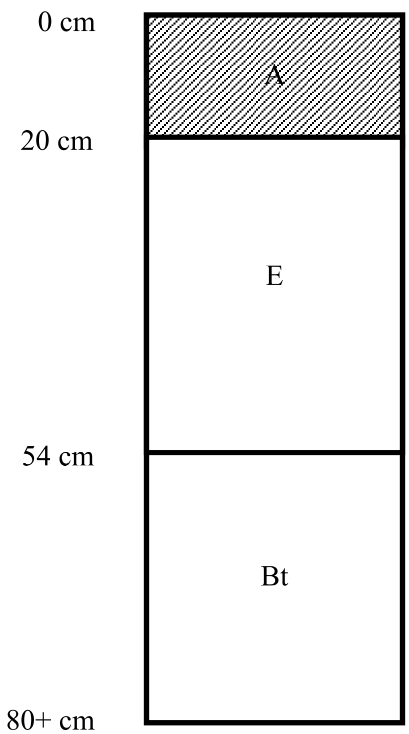
Figure 19. Ordination of 50 sites among 4 landforms in the **northern** regional ecosystem of Lower Michigan along the first 2 canonical variates using 2 soil variables, 9 vegetation variables, and 1 physiographic variable.

APPENDICES

APPENDIX 1A

Example Soil Profiles from Five Different Landform Types in the Southern Regional Ecosystem of Lower Michigan (Region VI)

Ice-Contact Terrain
Example Management Unit: Waterloo State Recreation Area
Representative Sub-Subsection: VI.1.3



Forest Floor

Oi: 3 – 0.5 cm

Oe: 0.5 – 0 cm

Root Mat

3 cm thick

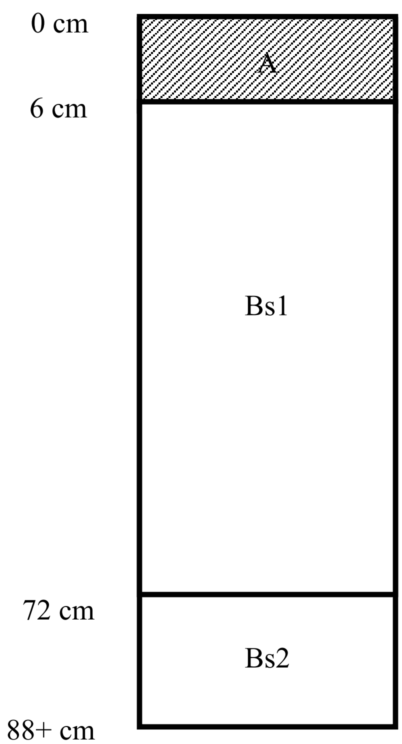
Mineral Horizons

A: black; loam; pH 7.00

E: tan-beige; fine sandy loam; pH 5.00; coarse roots to 45 cm; cobbles up to 17 cm wide

Bt: orange-tan mosaic; sandy loam: pH 6.00; fine roots to 68 cm; horizon is cemented together into a hardpan

<u>Coarse End Moraine</u>
Example Management Unit: Barry State Game Area
Representative Sub-Subsections: VI.2.2, VI.3.1, VI.5.2



Forest Floor

Oi: 10 – 4 cm

Oe: 4 – 0 cm; pH 4.50

Mineral Horizons

A: black; loamy sand; pH 4.50

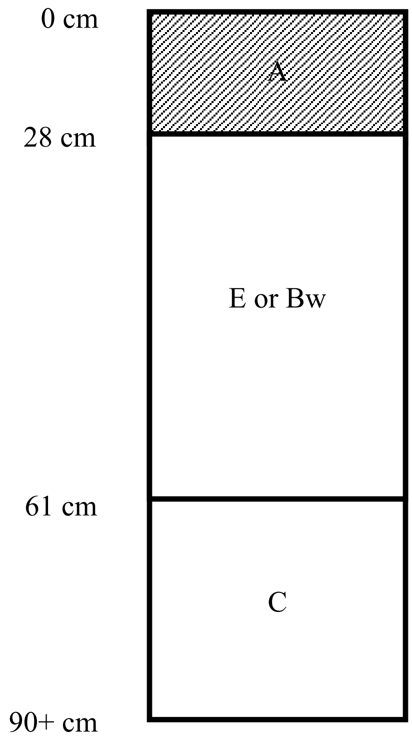
Bs1: orange-reddish; medium loamy sand; pH 5.50; fine roots to 55 cm

Bs2: tan; medium loamy sand: pH 6.0; medium and coarse roots to 82 cm

Notes: large cobbles present common throughout pit

APPENDIX 1A. (continued).

<u>Outwash</u>
Example Management Unit: Fort Custer State Recreation Area
Representative Sub-Subsections: VI.1.3, VI.2.1



Forest Floor

Oi: 3 – 0.5 cm

Oe: 0.5 – 0 cm; pH 4.5

Root Mat

2.5 cm thick

Mineral Horizons

A: black; coarse loamy sand; pH 4.75

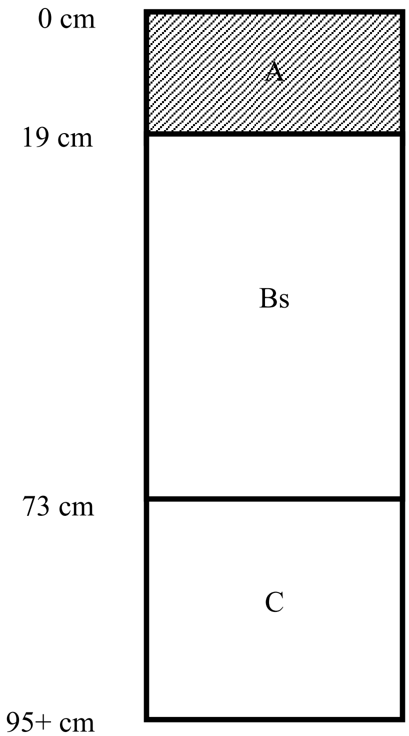
E/Bw: tan-orange; coarse loamy sand; pH 5.00; coarse roots to 61 cm

C: gray-tan; coarse sand: pH 5.50; fine roots to 90 cm

Notes: cobbles up to 3.5 cm wide found occasionally but pebbles more common; loose pebbles found in a distinct sorted and banded layer in C horizon

APPENDIX 1A. (continued).

<u>Sand Lake Plain</u>
Example Management Unit: Allegan State Game Area
Representative Sub-Subsections: VI.3.2, VI.5.1, VI.6 (dune landforms similar)



Forest Floor

Oi: 4 – 0.5 cm

Oe: 0.5 – 0 cm; pH 6.50

Root Mat

3 cm thick

Mineral Horizons

A: black; loamy sand to sandy loam; pH 4.00

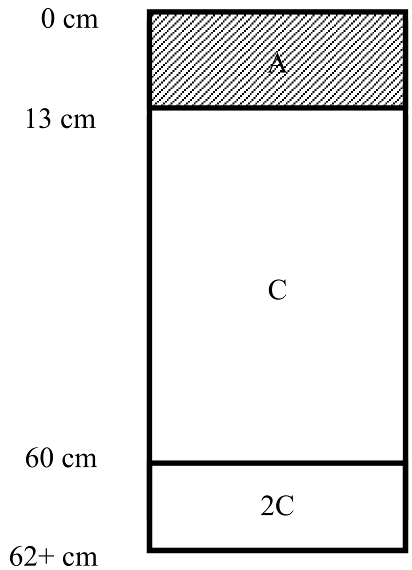
Bs: orange; medium loamy sand; pH 5.00; medium roots to 63 cm

C: tan; medium loamy sand: pH 5.50

Notes: coarse fraction absent

APPENDIX 1A. (continued).

<u>Sand-Over-Clay Lake Plain</u>
Example Management Unit: Oakwoods Metropark
Representative Sub-Subsections: VI.1.1, VI.5.1



Forest Floor

Oi: 4 – 0 cm

Root Mat

3 cm thick

Mineral Horizons

A: black; sandy loam; pH 5.50

C: tan; sandy loam; pH 5.50; roots to 60 cm

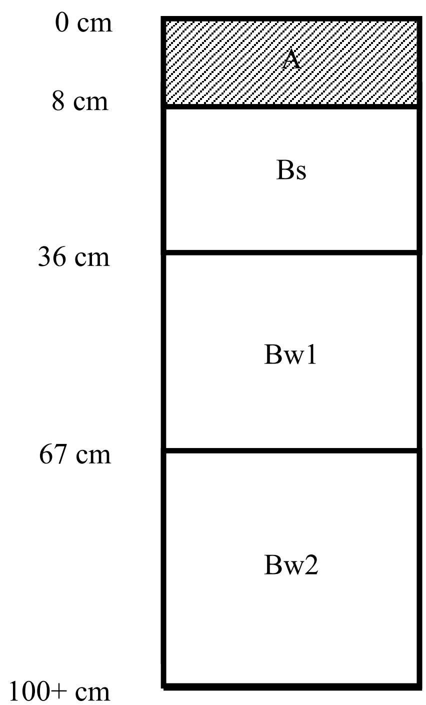
2C: gray with orange mottling; clay loam: pH 6.00

Notes: roots do not penetrate into clay 2C horizon; occasional cobbles up to 6 cm wide occur; clay loam to clay soil occurs at surface in low swales

APPENDIX 1B

Example Soil Profiles From Five Different Landform Types in the Northern Regional Ecosystem of Lower Michigan (Region VII)

<u>Small, Ice-Contact Ridges; Few Kettle Lakes; Excessively-Drained Sand or Loamy Sand</u>
Example Management Unit: Grayling State Forest Management Unit
Landtype Association Code: 3111 (Corner and Albert 1999b)
Representative Sub-Subsection: VII.2.2



Forest Floor

Oi: 0.25 – 0 cm

Root Mat

2 cm thick

Mineral Horizons

A: black; sandy loam; pH 4.25

Bs: dark orange-brown; medium sand; pH 5.50; most of coarse fraction occurs in this horizon, making up about 5% of total soil matrix; mostly pebbles but cobbles up to 8 cm wide occur

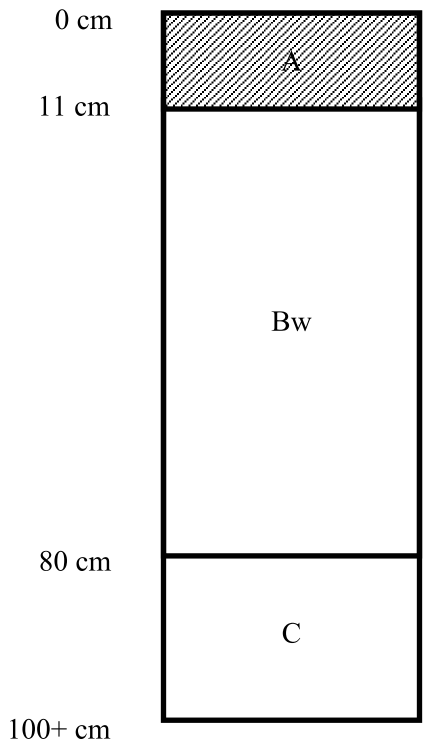
Bw1: medium orange-brown; medium sand: pH 6.00; medium and fine roots to 47 cm

Bw2: tan; fine sand; pH 6.00

Notes: Bs horizon noticeably grittier in texture than either Bw1 or Bw2 horizons

APPENDIX 1B. (continued).

Steep, Broken Moraine Ridges; Well-Drained Loamy Sand
Example Management Unit: Cadillac State Forest Management Unit
Landtype Association Code: 1121(Corner and Albert 1999b)
Representative Sub-Subsection: VII.2.1



Forest Floor

Oi: 5 – 2 cm

Oe: 2 – 0 cm; pH 4.50

Root Mat

3 cm thick

Mineral Horizons

A: black-gray; sandy loam; pH 4.50

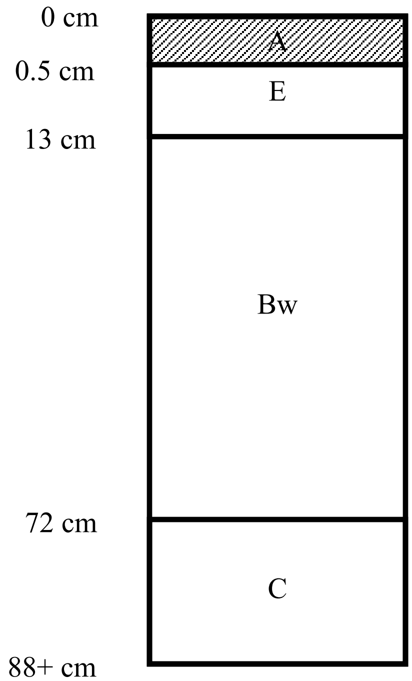
Bw: light brown; fine loamy sand; pH 6.50; coarse and fine roots to 80 cm

C: tan; fine loamy sand: pH 6.50

Notes: coarse fraction makes up about 1% of total soil matrix

APPENDIX 1B. (continued).

Steep, Broken Moraine Ridges; Few Kettle Lakes; Excessively-Drained Sand
Example Management Unit: Atlanta State Forest Management Unit
Landtype Association Code: 1111 (Corner and Albert 1999b, d)
Representative Sub-Subsections: VII.2.1, VII.2.3, VII.6.1



Forest Floor

Oi: 4.5 – 0.25 cm

Oe: 0.25 – 0 cm

Root Mat

4 cm thick

Mineral Horizons

A: black; coarse loamy sand; pH 4.50

E: ashy white; coarse loamy sand; pH 5.50

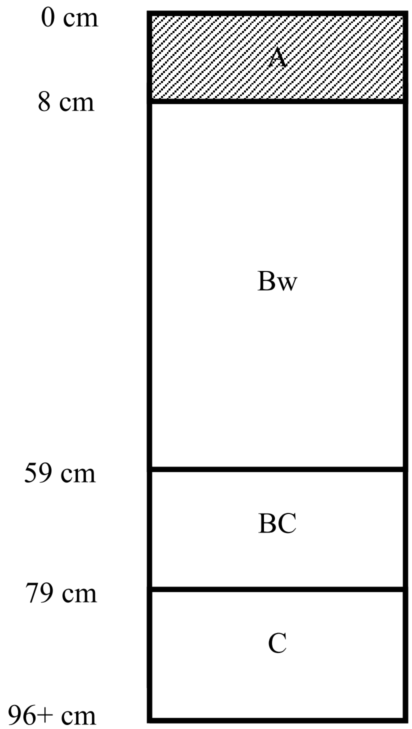
Bw: weak orange tan; coarse loamy sand: pH 6.00; coarse and fine roots to 46 cm

C: tan; coarse loamy sand; pH 6.50

Notes: coarse fraction makes up about 2% of total soil matrix; pebbles up to 3 cm wide; very light-colored soil profile

APPENDIX 1B. (continued).

<u>Broad, Flat Outwash Plain; Few Kettle Lakes; Excessively-Drained Sand or Loamy Sand</u>
Example Management Unit: Huron-Manistee National Forest, Manistee Area
Landtype Association Code: 5111 (Corner and Albert 1999c)
Representative Sub-Subsection: VII.3



Forest Floor

Oi: 1.5 – 0 cm

Root Mat

4 cm thick

Mineral Horizons

A: black; medium loamy sand; pH 4.75

Bw: light orange; fine sand; pH 5.50

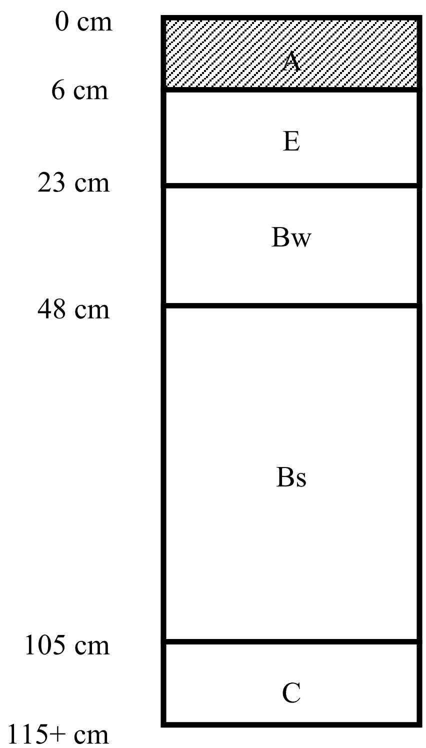
BC: tan; fine sand; pH 6.25; coarse roots to 64 cm

C: tan; coarse sand; pH 6.25; pebbles make up 2% of total soil matrix; fine roots to 90 cm

Notes: cobbles uncommon but some up to 5 cm occur

APPENDIX 1B. (continued).

Broad, Flat Sand Lake Plain; Excessively-Drained Sand
Example Management Unit: Gladwin State Forest Management Unit
Landtype Association Code: 6111 (Corner and Albert 1999a)
Representative Sub-Subsection: VII.1.1



Forest Floor

Oi: 3.5 – 0.5 cm

Oe: 0.5 – 0 cm; pH 4.50

Root Mat

4 cm thick

Mineral Horizons

A: black; fine loamy sand; pH 4.25

E: ashy white; fine loamy sand; pH 4.25

Bw: light orange; medium loamy sand; pH 5.50; coarse roots to 40 cm

Bs: dark orange; medium sand; pH 6.00; fine roots to 94 cm; coarse fraction <1% of total soil matrix concentrated in this horizon

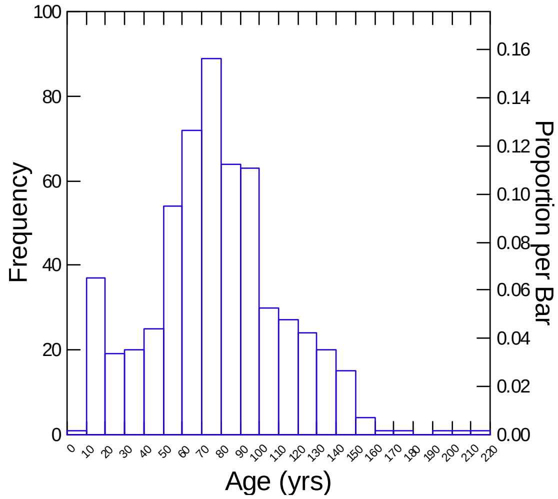
C: tan; medium sand; pH 6.25

APPENDIX 2

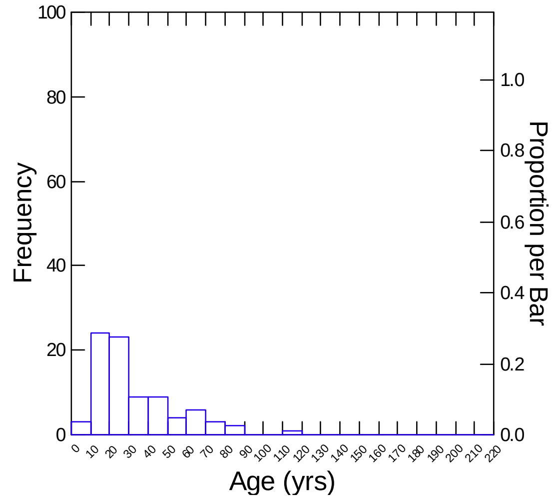
Age Class Distributions for Species Groups among Management Prescriptions: All Selected Sites Combined

Aggregation of 370 Unmanaged Plots

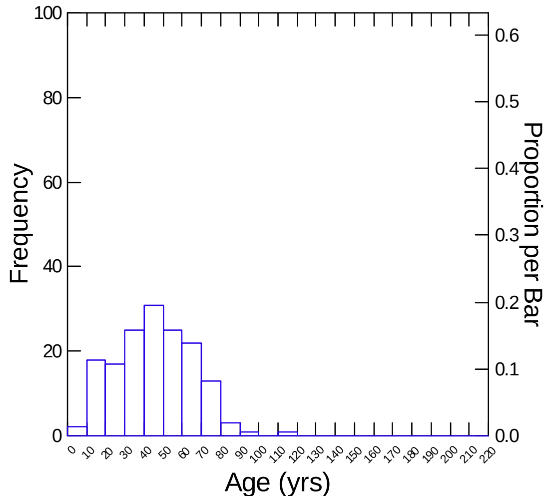
Oaks



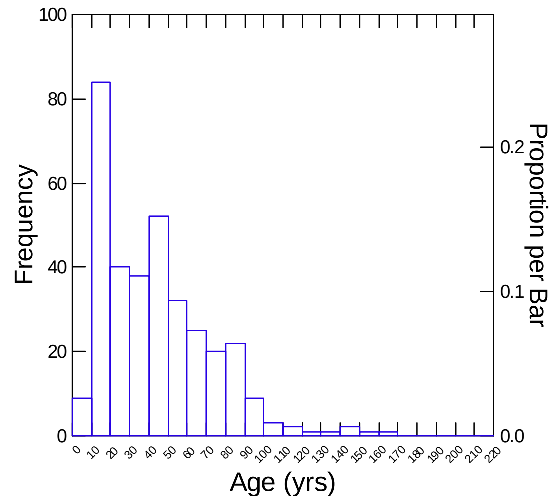
Pines



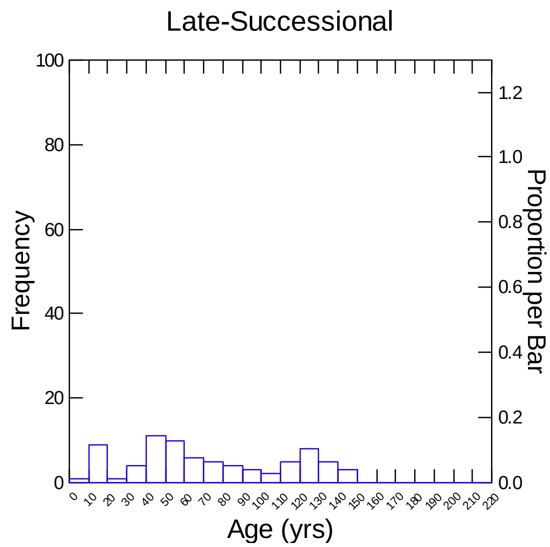
Early-Successional



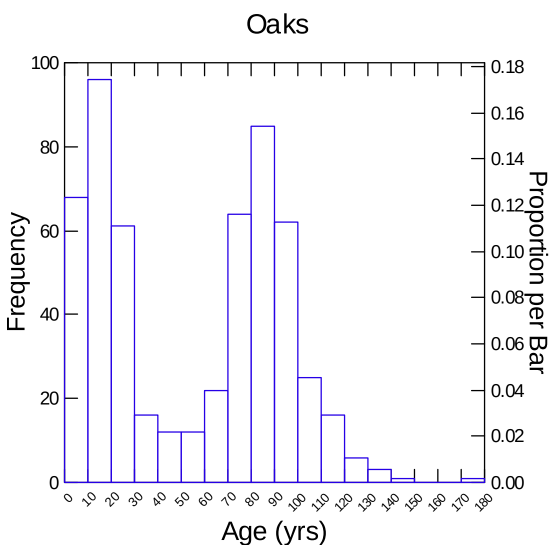
Mid-Successional

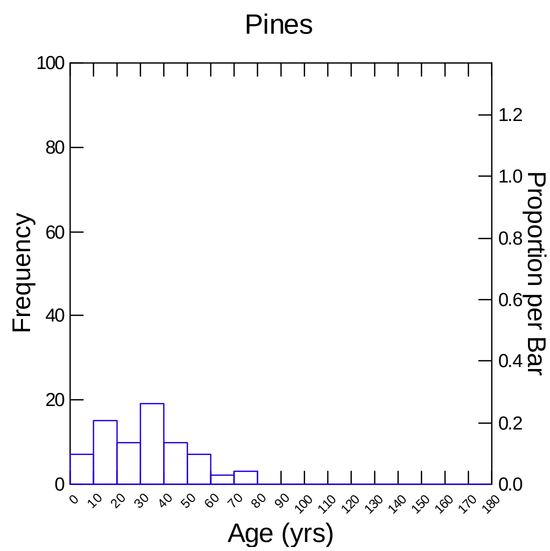


APPENDIX 2. (continued).

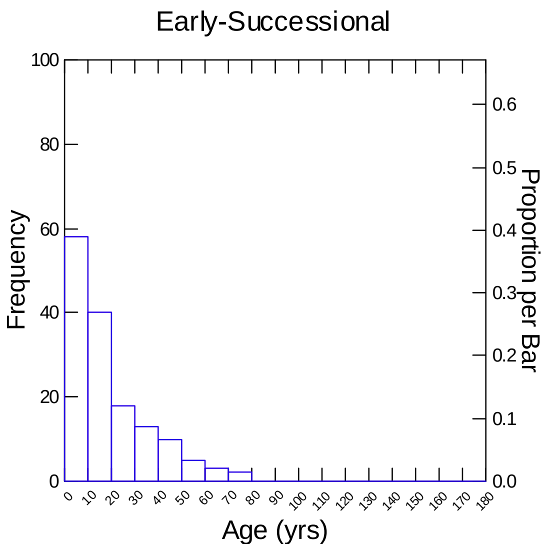


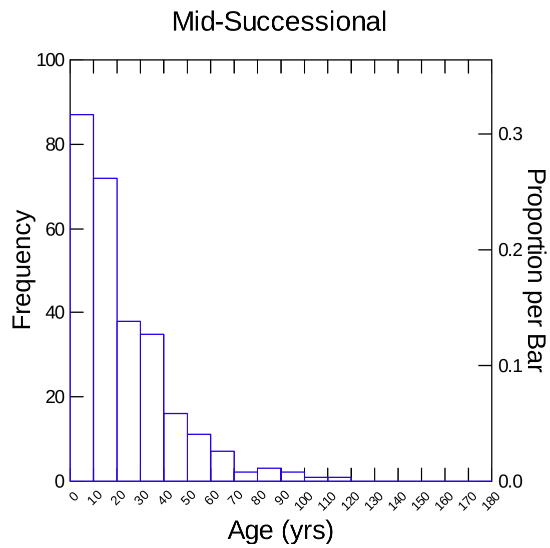
Aggregation of 339 Cut and Cut and Burned Plots

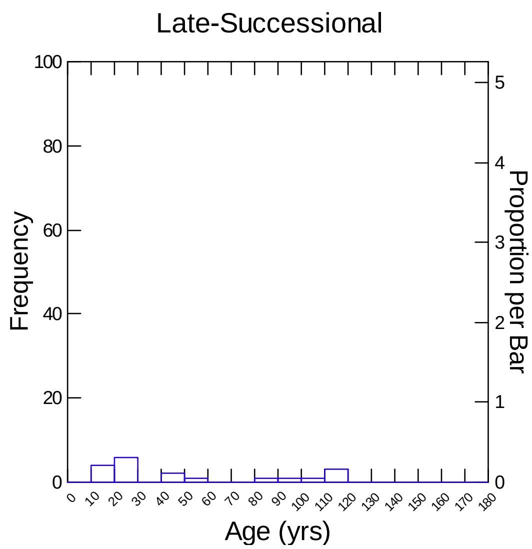




APPENDIX 2. (continued).

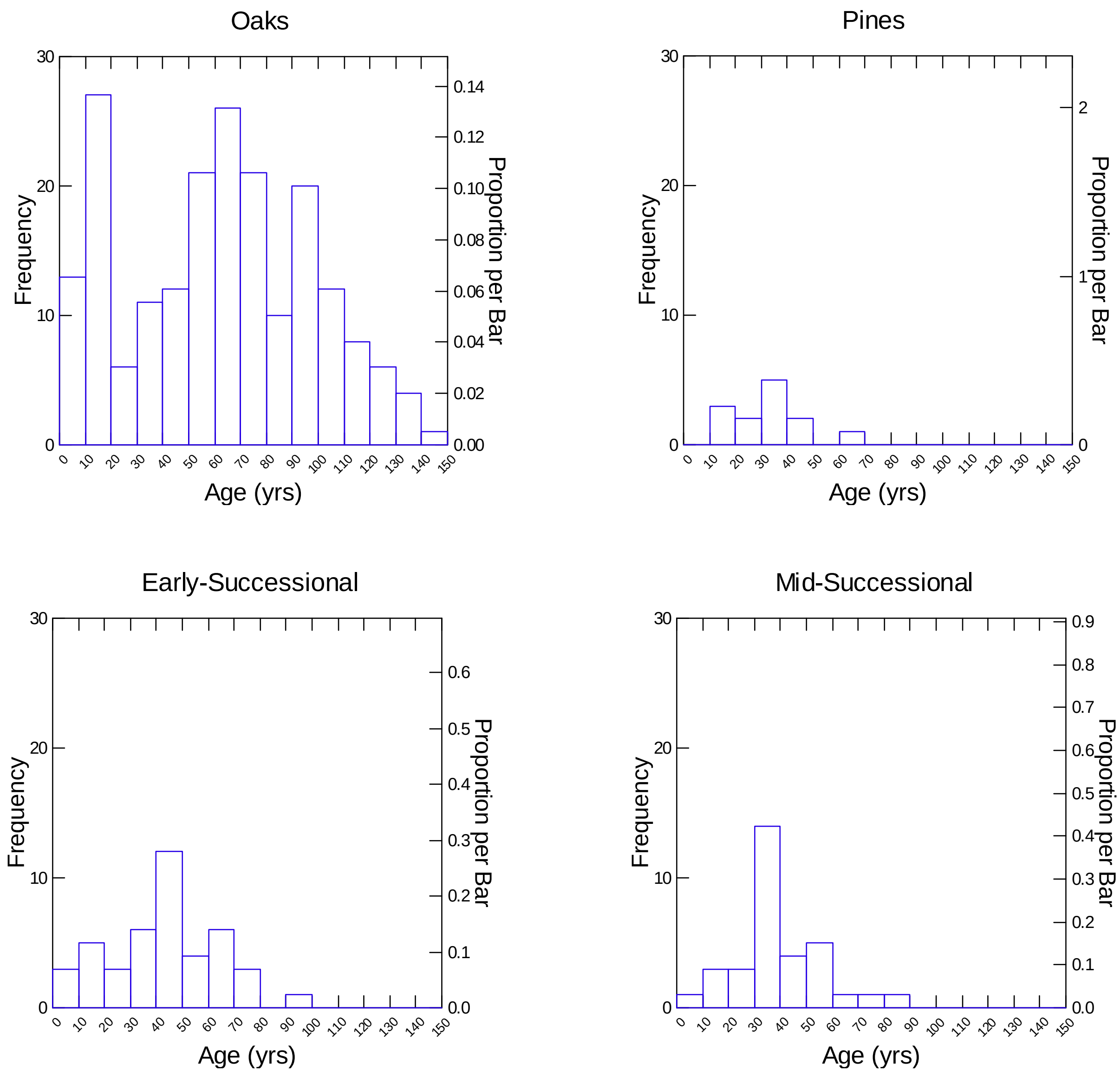




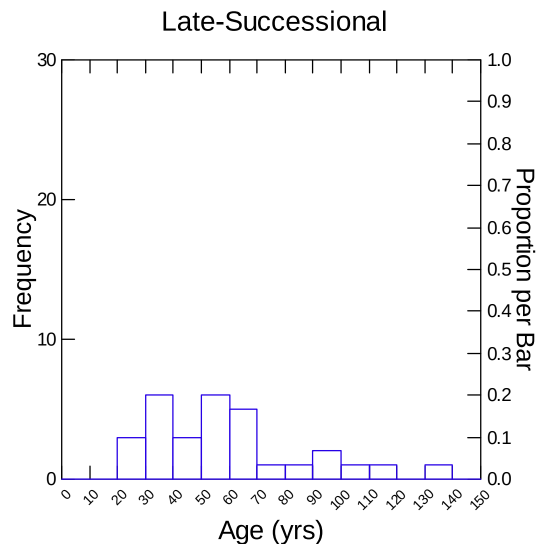


APPENDIX 2. (continued).

Aggregation of 110 Burned-Only Plots



APPENDIX 2. (continued).



APPENDIX 3A

Comparison of Oak and Red Maple Regeneration (Understory Stem Density) and Seedling and Sapling Abundance among Management Prescriptions: Selected Southern Ice-Contact Sites[1, 2]

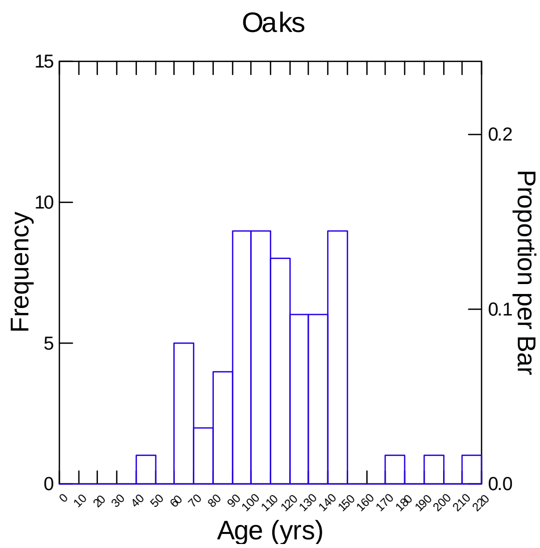
	Management Prescription	
	Unmanaged	Burned
Understory Stem Density (stems ha^{-1})		
All Oak Species	16.00 (16.00)	10.00 (10.00)
White Oak	8.00 (8.00)	10.00 (10.00)
Black Oak-Northern Pin Oak[3]	0.00 (0.00)	0.00 (0.00)
Northern Red Oak	8.00 (8.00)	0.00 (0.00)
Red Maple	264.00 (76.26)	340.00 (340.00)
Seedling and Sapling Abundance[4]		
All Oak Species Seedlings	2.60(1.03)	0.60(0.40)
All Oak Species Saplings	0.06 (0.06)	0.10 (0.00)
Red Maple Seedlings†	1.66 (0.52)	4.95 (2.05)
Red Maple Saplings	0.10 (0.03)	0.30 (0.20)

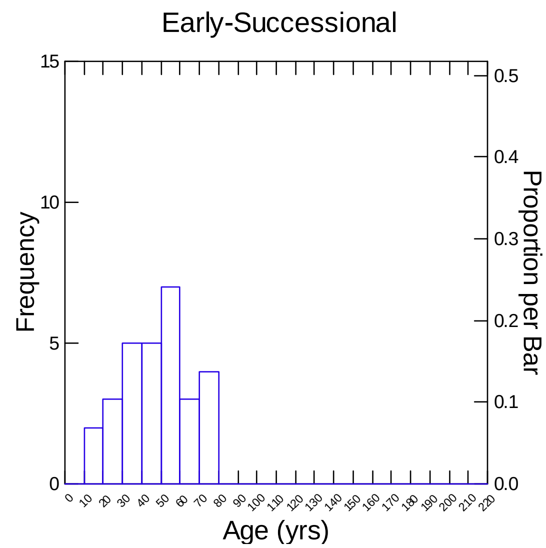
1 For each variable, means are shown outside of parentheses, one standard error inside of parentheses.
2 For all variables: Unmanaged (n = 5), Burned (n = 2).
3 Stems of black oak and northern pin oak are aggregated due to difficulties with field identification between these closely related species.
4 Units are numbers per 4 m^2 plot for All Oak Species and Red Maple Seedlings/Saplings.
† Indicates significance at $\alpha = 0.10$, two-sample independent Mann-Whitney U-Test.

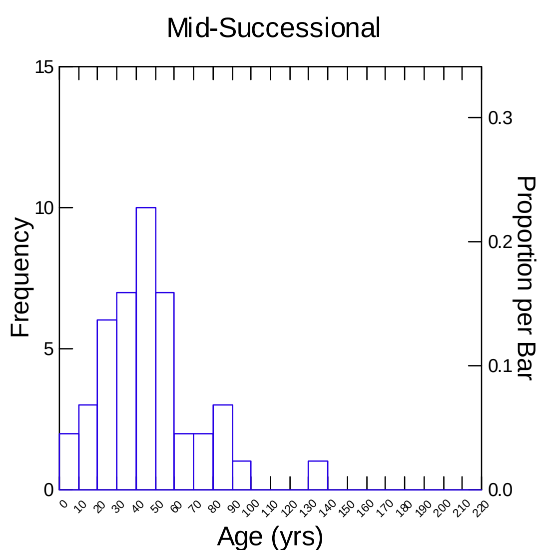
APPENDIX 3B

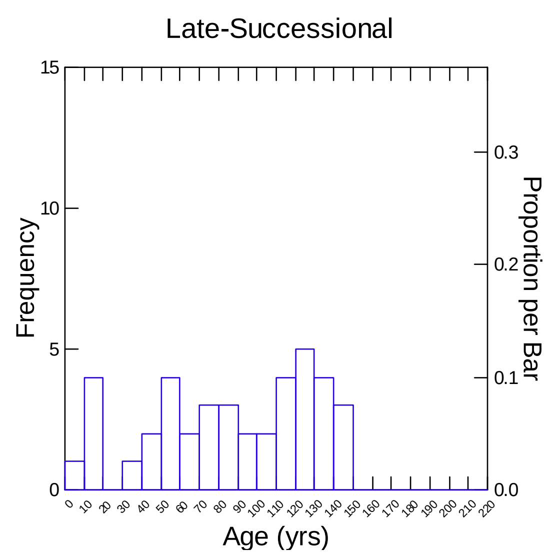
Age Class Distributions for Species Groups among Management Prescriptions: Selected Southern Ice-Contact Sites

Aggregation of 50 Unmanaged Plots



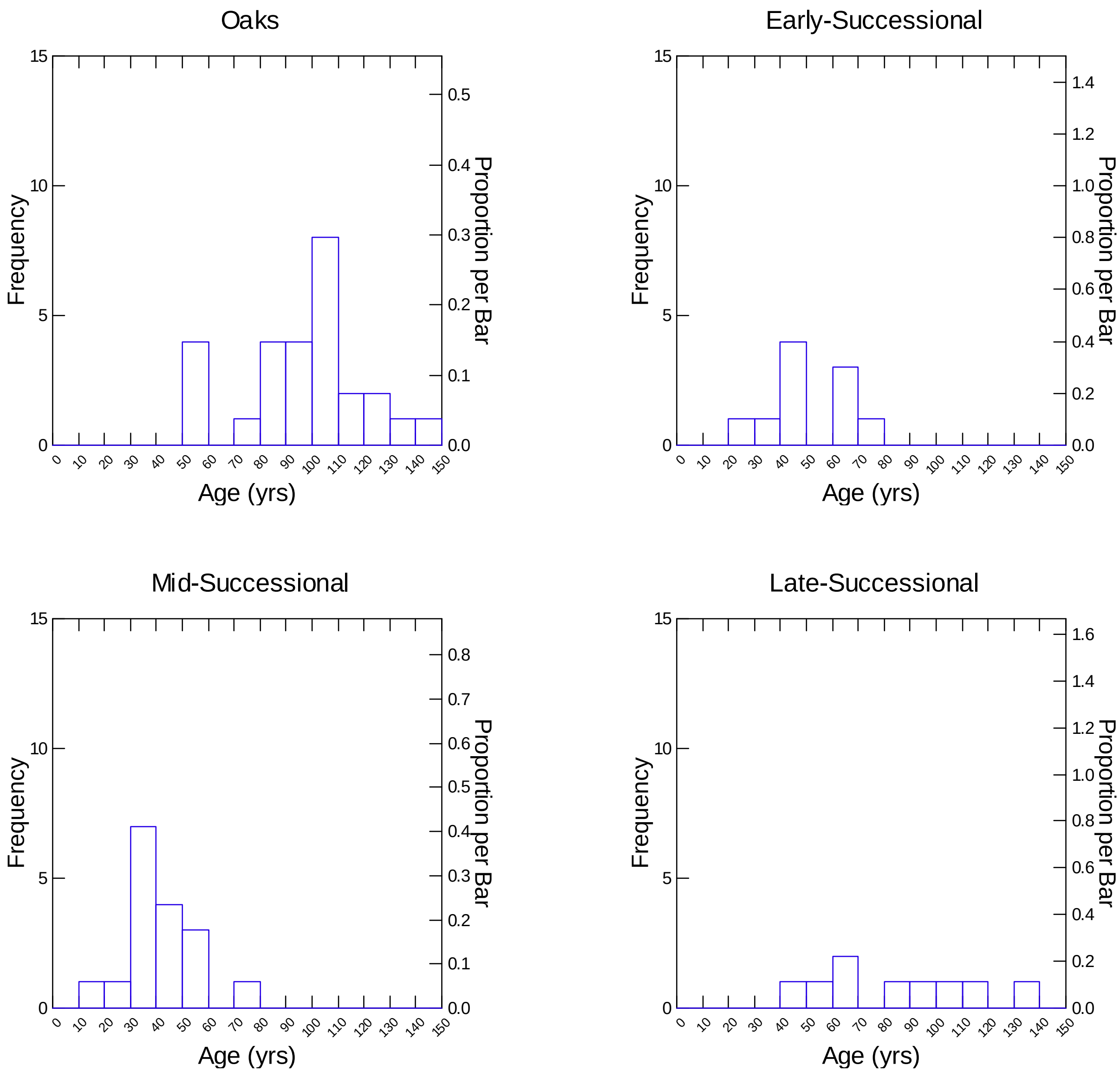






APPENDIX 3B. (continued).

<u>Aggregation of 20 Burned Plots</u>

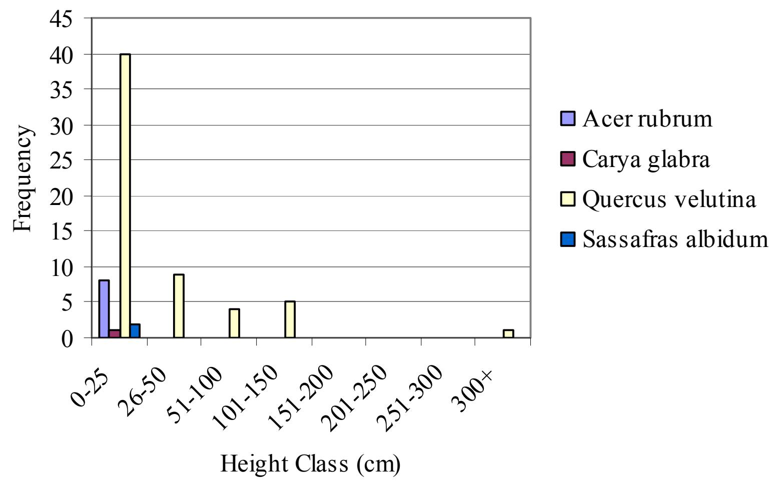


APPENDIX 3C

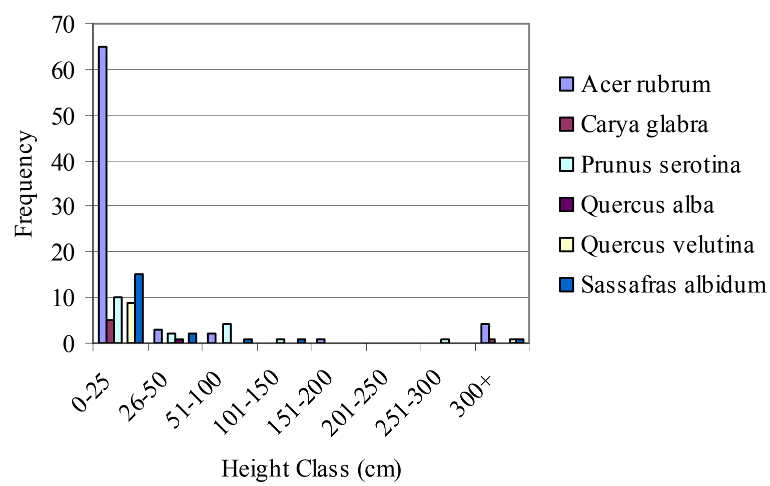
**Height Class Distributions for Seedlings and Saplings of Selected Species among Management Prescriptions:
Case Study – Southern Ice-Contact Sites**

<u>Aggregation of 10 Burned Plots Each</u>

P-PICK

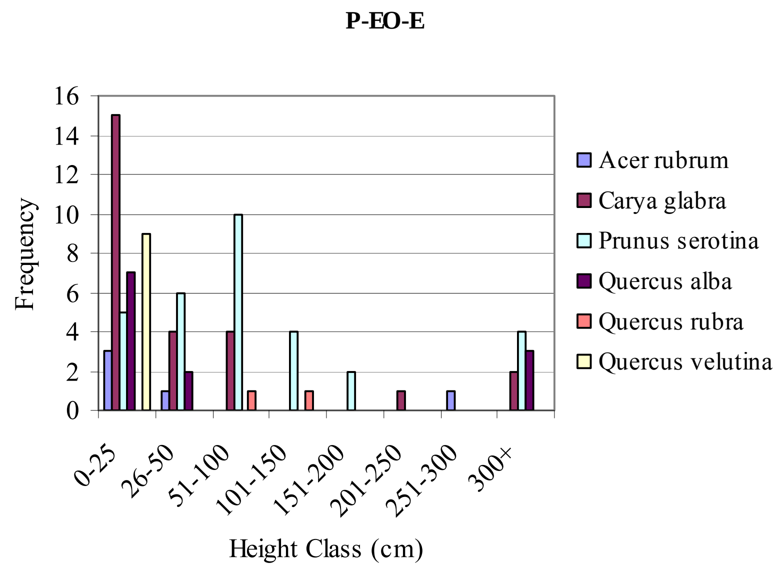


P-BURN



APPENDIX 3C. (continued).

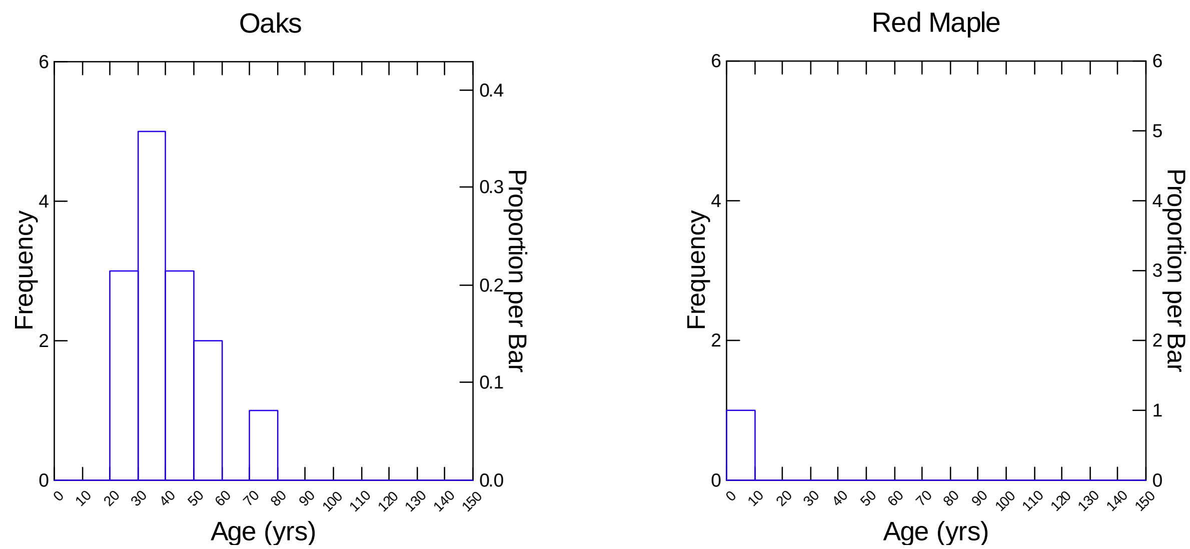
Aggregation of 10 Unmanaged Plots



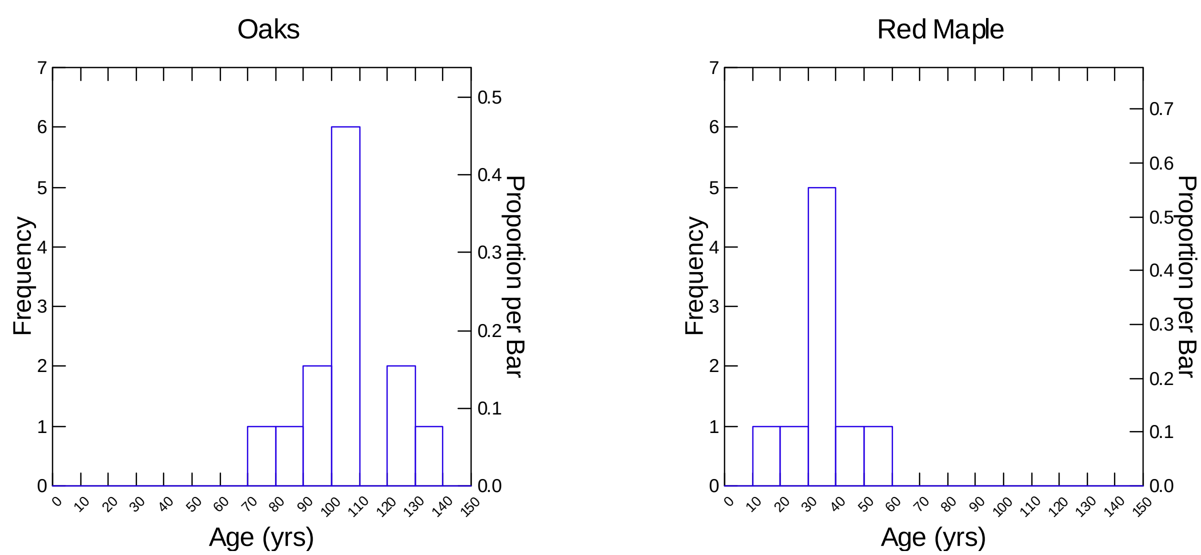
APPENDIX 3D

Age Class Distributions for Oak Species and Red Maple among Management Prescriptions: Case Study – Southern Ice-Contact Sites

<u>P-PICK: Aggregation of 10 Burned Plots</u>

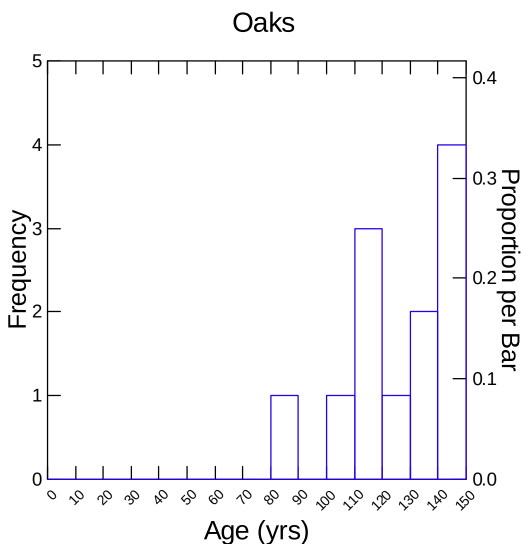


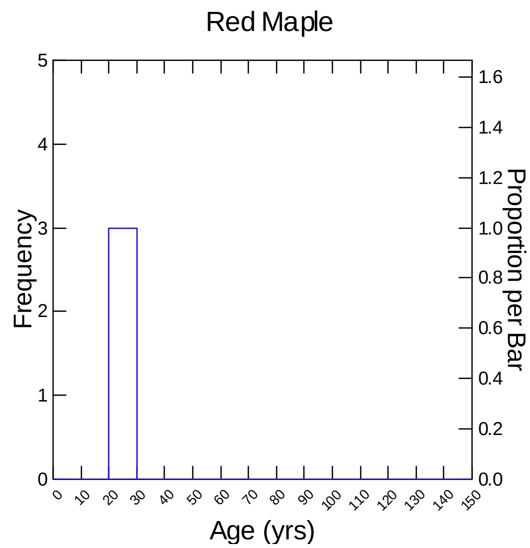
<u>P-BURN: Aggregation of 10 Burned Plots</u>



APPENDIX 3D. (continued).

P-EO-E: Aggregation of 10 Unmanaged Plots





APPENDIX 4A

Comparison of Oak and Red Maple Regeneration (Understory Stem Density) and Seedling and Sapling Abundance among Management Prescriptions: Selected Southern Moraine Sites (Sandy Clay Loam Soil)[1, 2]

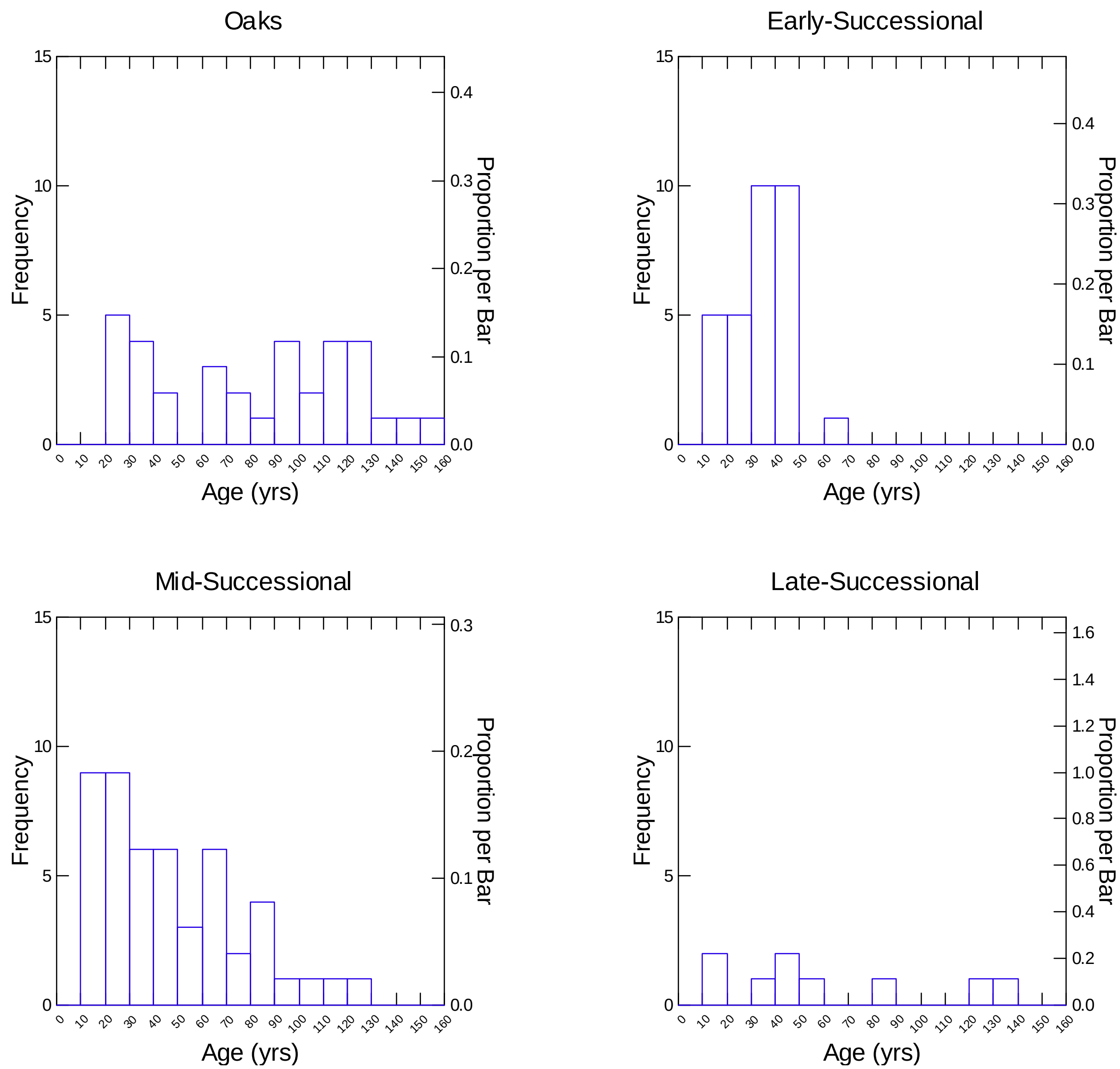
	Management Prescription	
	Unmanaged	Partial Shelterwood
Understory Stem Density (stems ha^{-1})		
All Oak Species	25.00	0.00
White Oak	0.00	0.00
Black Oak-Northern Pin Oak[3]	0.00	0.00
Northern Red Oak	25.00	0.00
Red Maple	325.00	2960.00
Seedling and Sapling Abundance[4]		
All Oak Species Seedlings	2.33	2.60
All Oak Species Saplings	0.08	0.00
Red Maple Seedlings	2.40	0.90
Red Maple Saplings	0.25	2.00

[1] For each variable, means are shown.
[2] For all variables: Unmanaged (n = 4), Partial Shelterwood (n = 1).
[3] Stems of black oak and northern pin oak are aggregated due to difficulties with field identification between these closely related species.
[4] Units are numbers per 4 m^2 plot for All Oak Species and Red Maple Seedlings/Saplings.

APPENDIX 4B

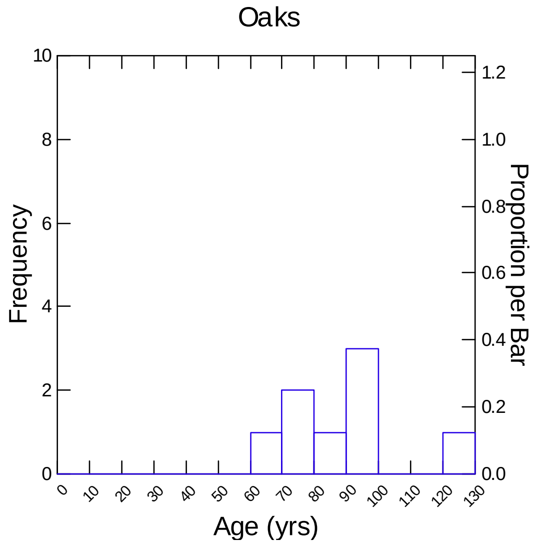
Age Class Distributions for Species Groups among Management Prescriptions: Selected Southern Moraine Sites (Sandy Clay Loam Soil)

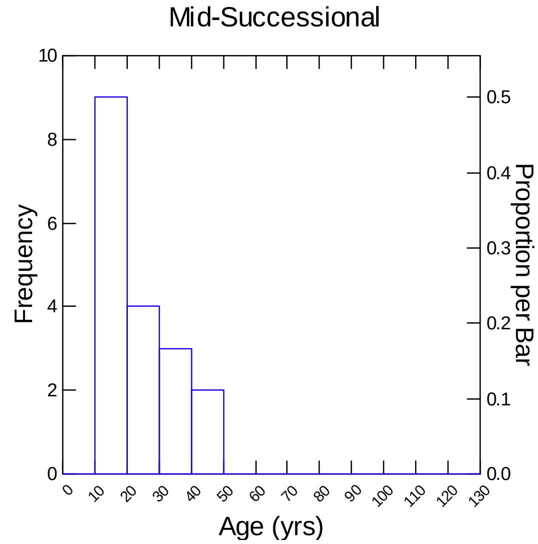
<u>Aggregation of 30 Unmanaged Plots</u>

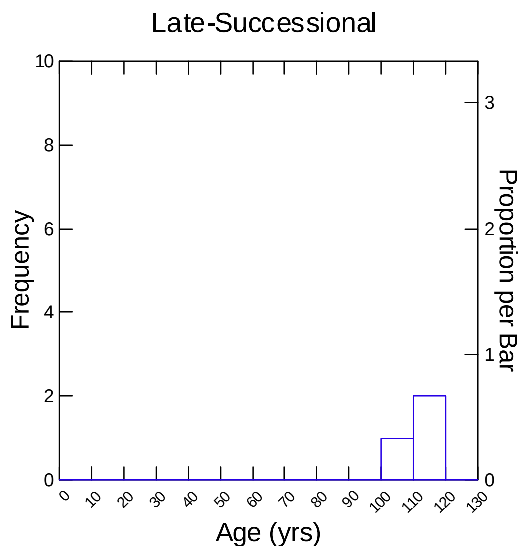


APPENDIX 4B. (continued).

Aggregation of 10 Partial Shelterwood Plots





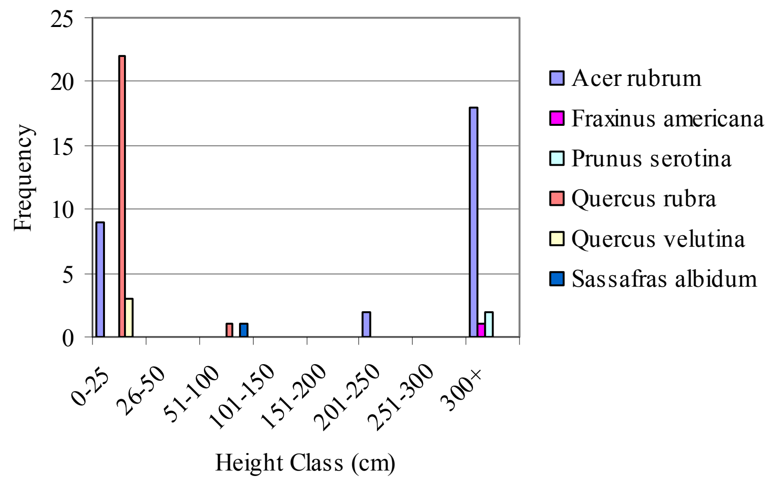


APPENDIX 4C

Height Class Distributions for Seedlings and Saplings of Selected Species among Management Prescriptions:
Case Study – Southern Moraine Sites (Sandy Clay Loam Soil)

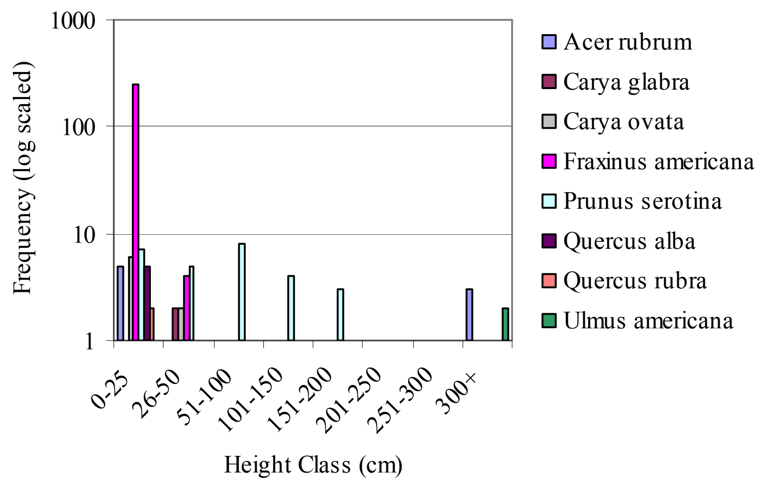
<u>Aggregation of 10 Partial Shelterwood Plots</u>

S1-CUT



<u>Aggregation of 10 Unmanaged Plots</u>

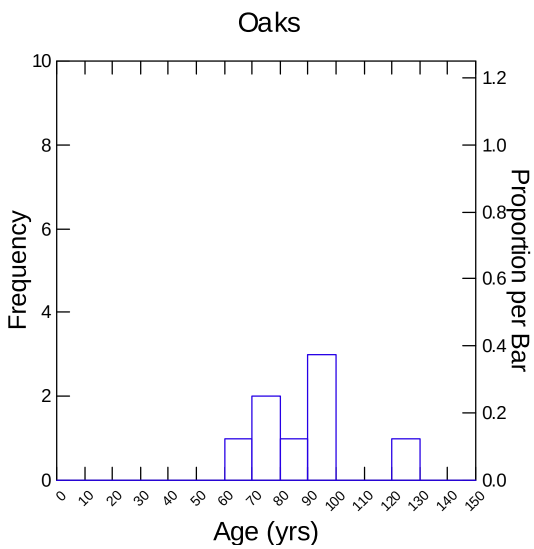
7L-3S

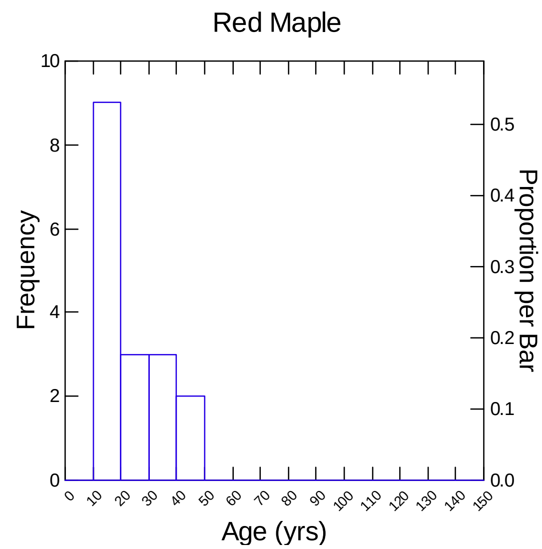


APPENDIX 4D

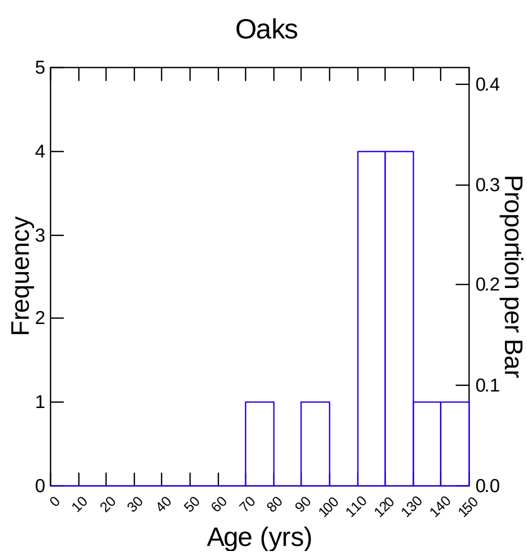
Age Class Distributions for Oak Species and Red Maple among Management Prescriptions: Case Study – Southern Moraine Sites (Sandy Clay Loam Soil)

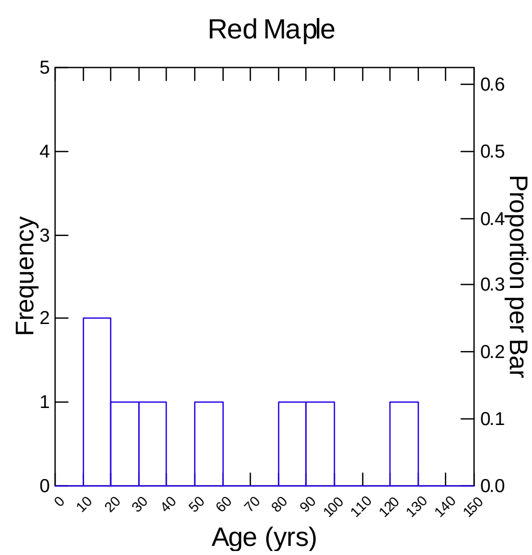
S1-CUT: Aggregation of 10 Partial Shelterwood Plots





7L-3S: Aggregation of 10 Unmanaged Plots





APPENDIX 5A

Comparison of Oak and Red Maple Regeneration (Understory Stem Density) and Seedling and Sapling Abundance among Management Prescriptions: Selected Southern Moraine Sites (Loamy Sand – Sandy Loam Soil)[1, 2]

	Management Prescription	
	Unmanaged	Managed
Understory Stem Density (stems ha^{-1})		
All Oak Species†	36.67 (20.92)	300.00 (181.48)
White Oak†	16.67 (8.03)	186.67 (104.78)
Black Oak-Northern Pin Oak[3]	13.33 (13.33)	73.33 (40.55)
Northern Red Oak	6.67 (6.67)	40.00 (40.00)
Red Maple†	330.00 (123.80)	1046.67 (393.50)
Seedling and Sapling Abundance[4]	2.40 (0.76)	1.93 (0.22)
All Oak Species Saplings	0.17 (0.07)	0.13 (0.07)
Red Maple Seedlings	6.95 (3.11)	3.93 (1.27)
Red Maple Saplings	0.25 (0.12)	1.07 (0.49)

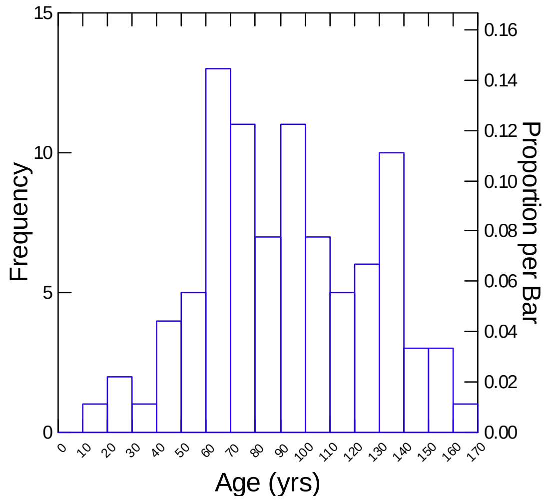
[1] For each variable, means are shown outside of parentheses, one standard error inside of parentheses. For management prescriptions, “Managed” includes a selection cut, clearcut, and clearcut and burn.
[2] For all variables: Unmanaged (n = 6), Managed (n = 3).
[3] Stems of black oak and northern pin oak are aggregated due to difficulties with field identification between these closely related species.
[4] Units are numbers per 4 m^2 plot for All Oak Species and Red Maple Seedlings/Saplings.
† Indicates significance at $\alpha = 0.10$, two-sample independent Mann-Whitney U-Test.

APPENDIX 5B

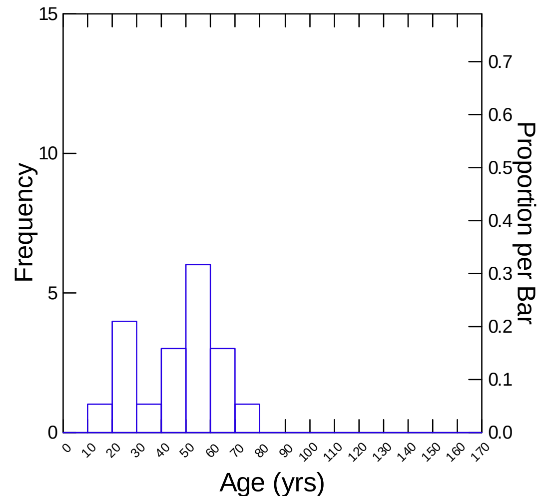
Age Class Distributions for Species Groups among Management Prescriptions: Selected Southern Moraine Sites (Loamy Sand – Sandy Loam Soil)

<u>Aggregation of 60 Unmanaged Plots</u>

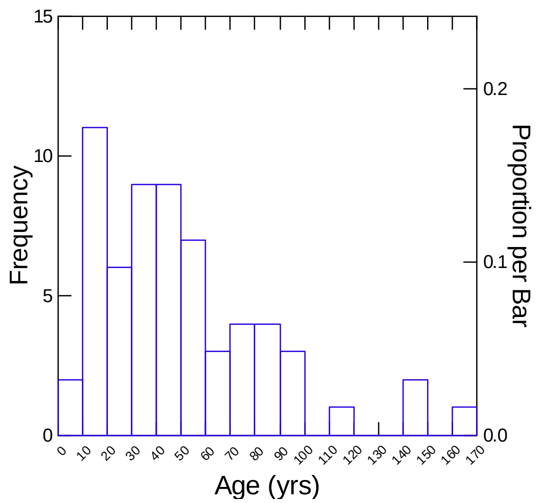
Oaks



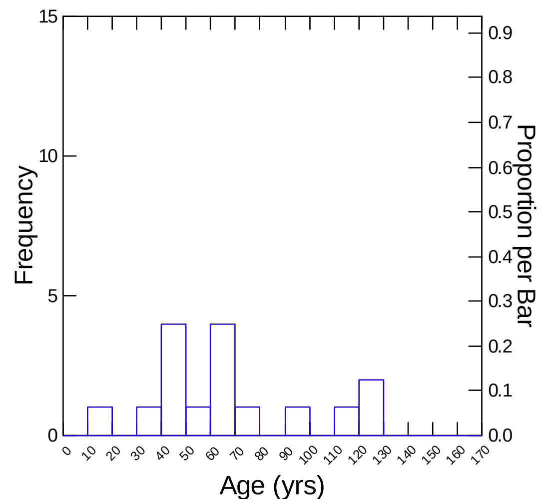
Early-Successional



Mid-Successional

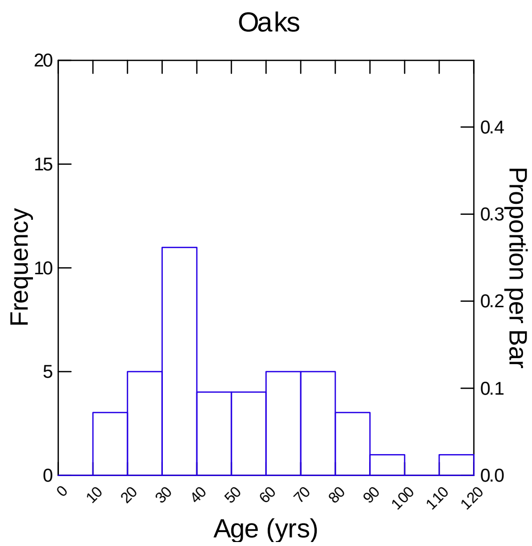


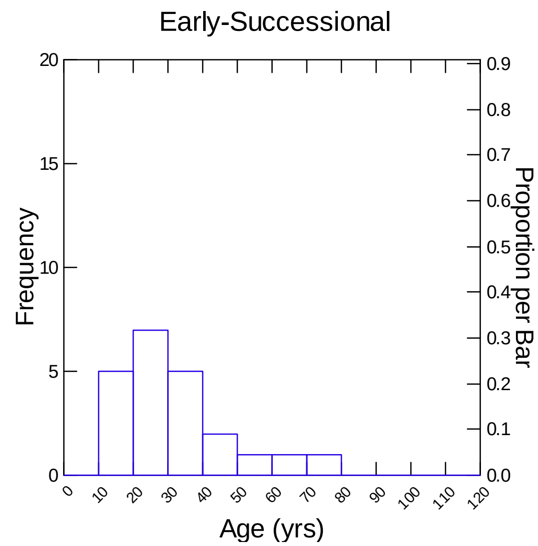
Late-Successional

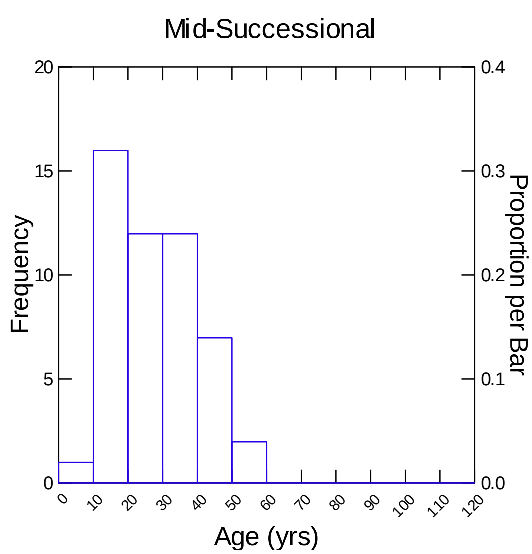


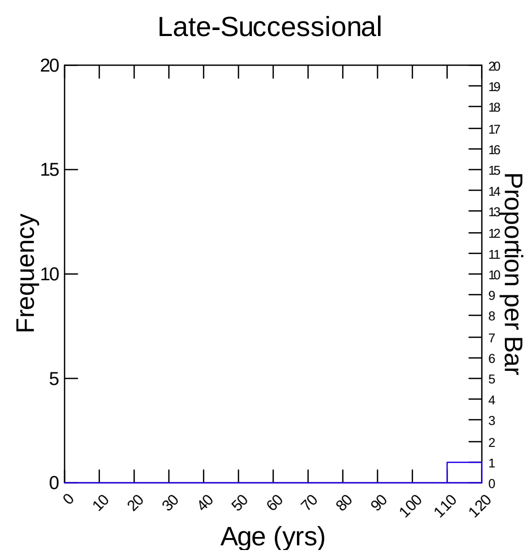
APPENDIX 5B. (continued).

Aggregation of 30 Managed Plots







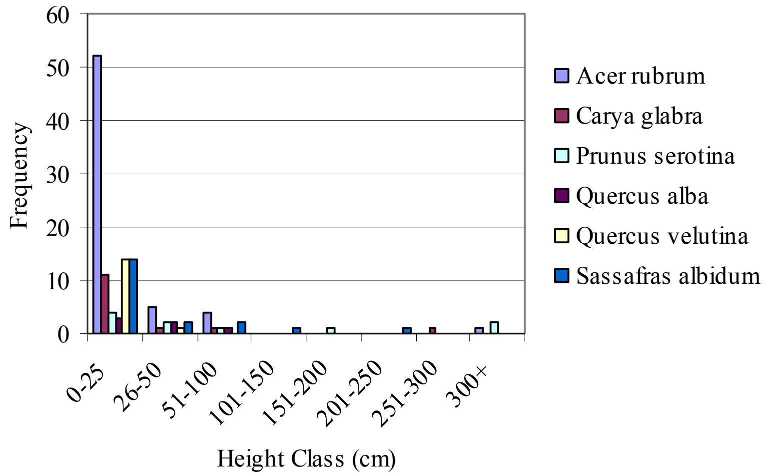


APPENDIX 5C

Height Class Distributions for Seedlings and Saplings of Selected Species among Management Prescriptions:
Case Study – Southern Moraine Sites (Loamy Sand – Sandy Loam Soil)

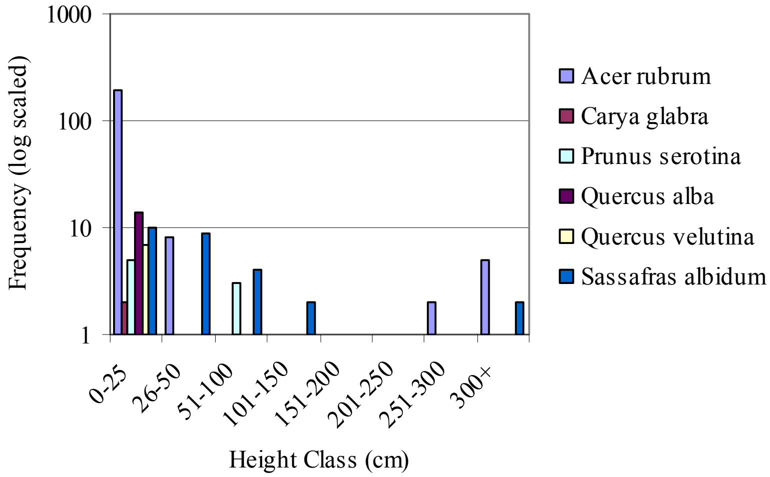
<u>Aggregation of 10 Clearcut and Burned Plots</u>

S24CC1



<u>Aggregation of 10 Unmanaged Plots</u>

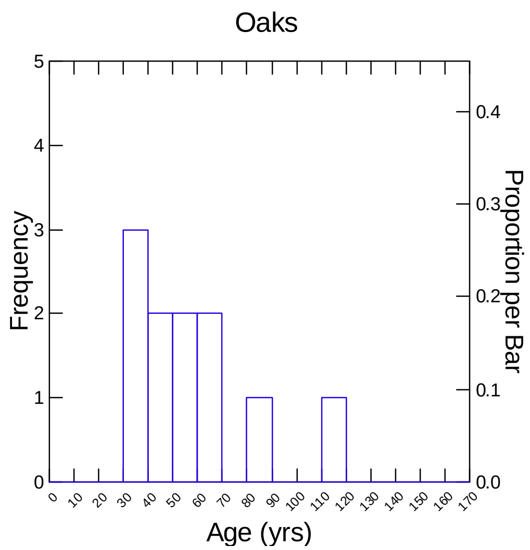
S19-1

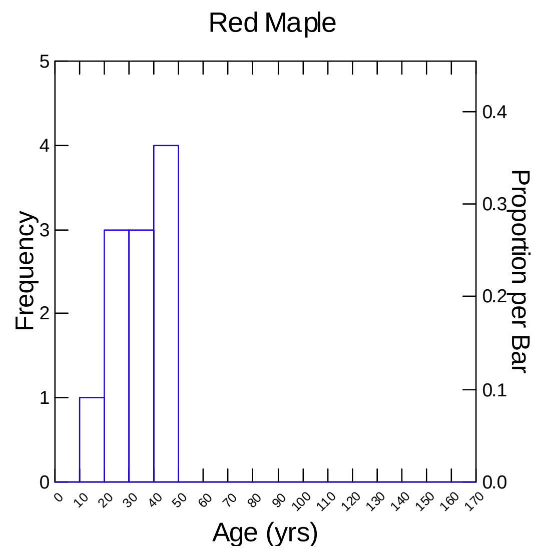


APPENDIX 5D

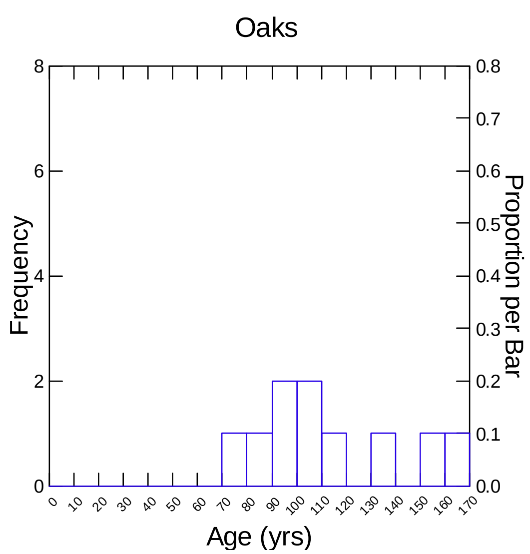
Age Class Distributions for Oak Species and Red Maple among Management Prescriptions: Case Study – Southern Moraine Sites (Loamy Sand – Sandy Loam Soil)

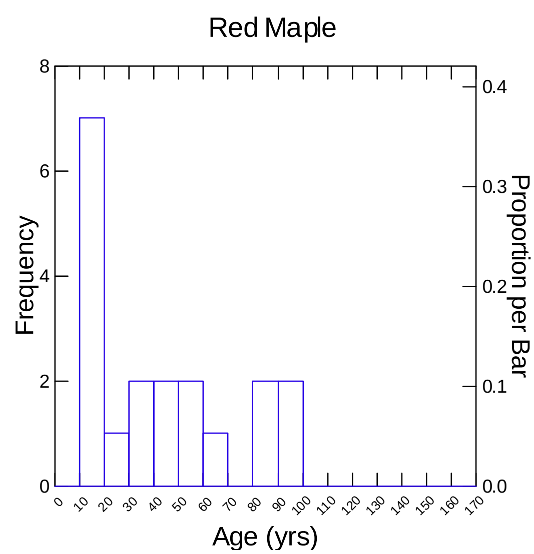
S24CC1: Aggregation of 10 Clearcut and Burned Plots





S19-1: Aggregation of 10 Unmanaged





APPENDIX 6A

Comparison of Oak and Red Maple Regeneration (Understory Stem Density) and Seedling and Sapling Abundance among Management Prescriptions: Selected Southern Outwash Sites[1, 2]

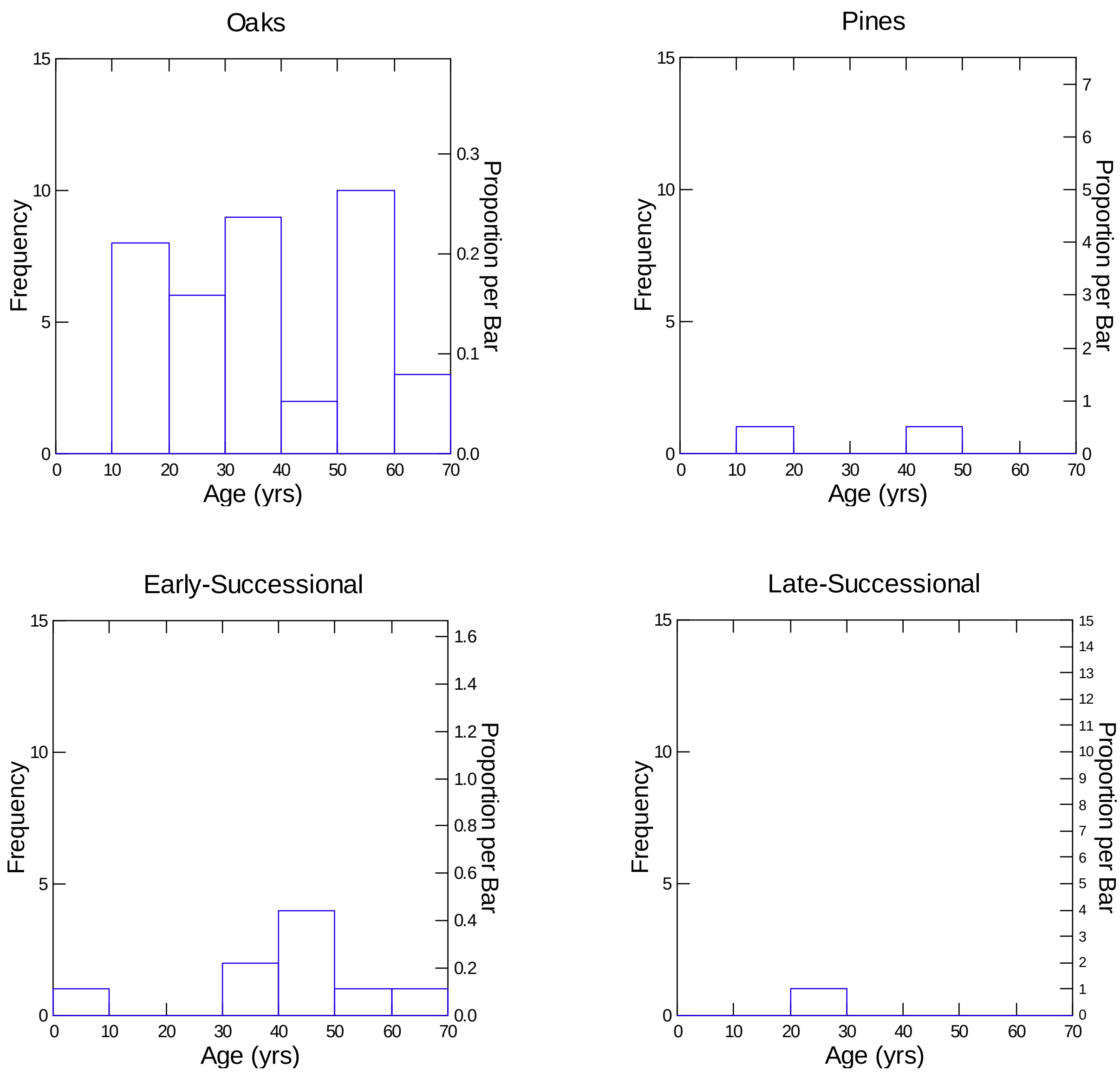
	Management Prescription	
	Unmanaged	Burned
Understory Stem Density (stems ha^{-1})		
All Oak Species†	780.00 (200.00)	26.67 (13.33)
White Oak†	440.00 (60.00)	13.33 (6.67)
Black Oak-Northern Pin Oak[3]†	340.00 (140.00)	13.33 (6.67)
Northern Red Oak	0.00 (0.00)	0.00 (0.00)
Red Maple	0.00 (0.00)	66.67 (35.28)
Seedling and Sapling Abundance[4]		
All Oak Species Seedlings	8.95 (2.15)	8.17 (2.98)
All Oak Species Saplings†	0.50 (0.00)	0.03 (0.03)
Red Maple Seedlings	1.00 (0.80)	4.23 (2.70)
Red Maple Saplings	0.00 (0.00)	0.03 (0.03)

1 For each variable, means are shown outside of parentheses, one standard error inside of parentheses.
2 For all variables: Unmanaged (n = 2), Burned (n = 3).
3 Stems of black oak and northern pin oak are aggregated due to difficulties with field identification between these closely related species.
4 Units are numbers per 4 m^2 plot for All Oak Species and Red Maple Seedlings/Saplings.
† Indicates significance at $\alpha = 0.10$, two-sample independent Mann-Whitney U-Test.

APPENDIX 6B

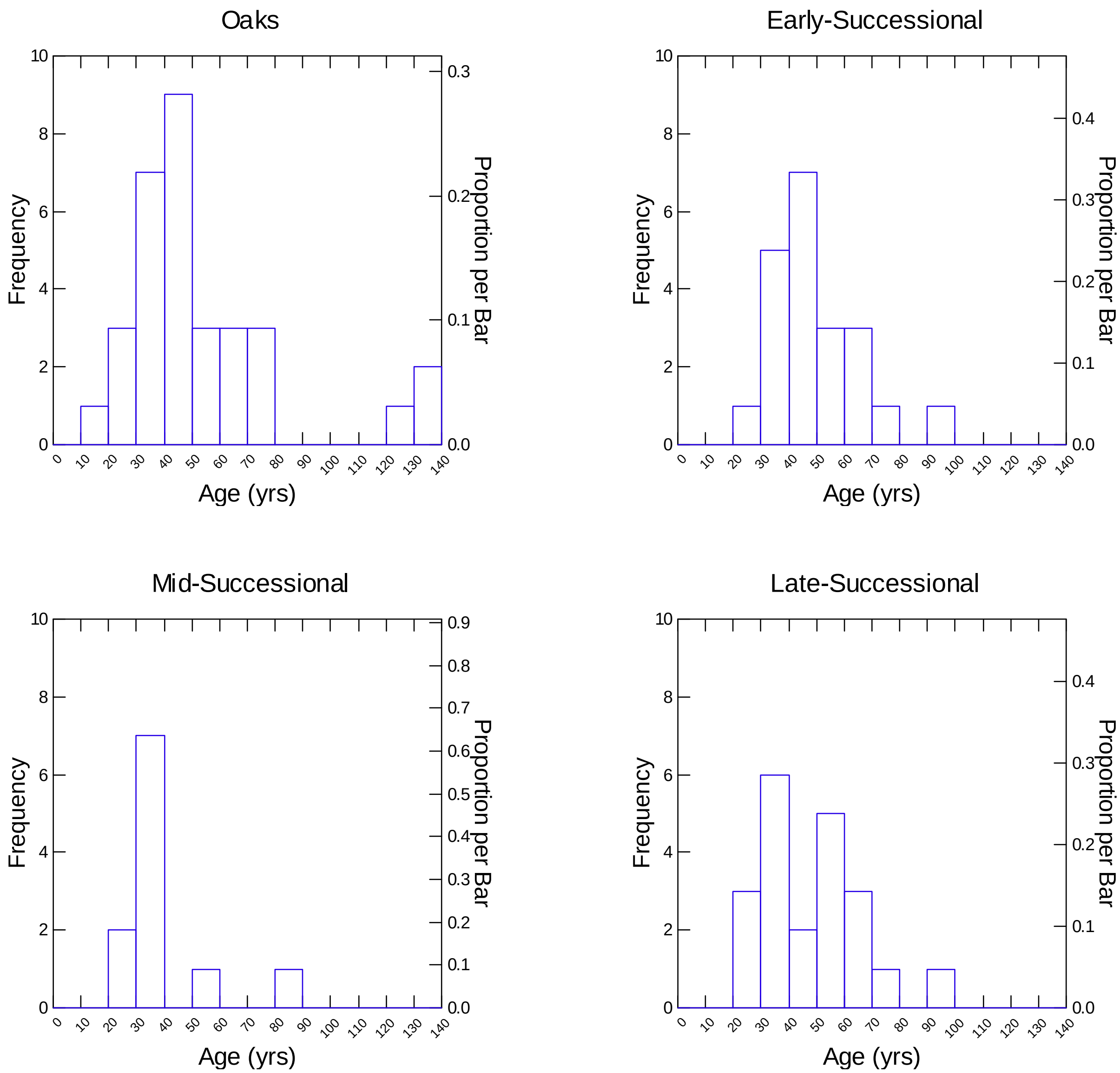
Age Class Distributions for Species Groups among Management Prescriptions: Selected Southern Outwash Sites

<u>Aggregation of 20 Unmanaged Plots</u>



APPENDIX 6B. (continued).

<u>Aggregation of 30 Burned Plots</u>

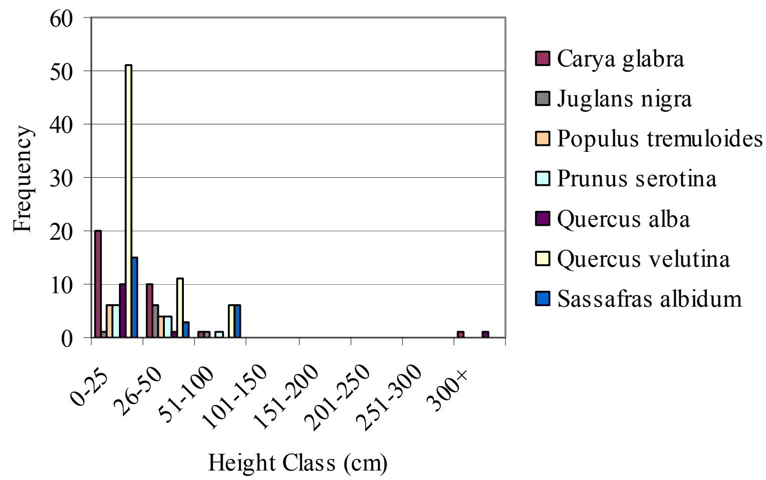


APPENDIX 6C

**Height Class Distributions for Seedlings and Saplings of Selected Species among Management Prescriptions:
Case Study – Southern Outwash Sites**

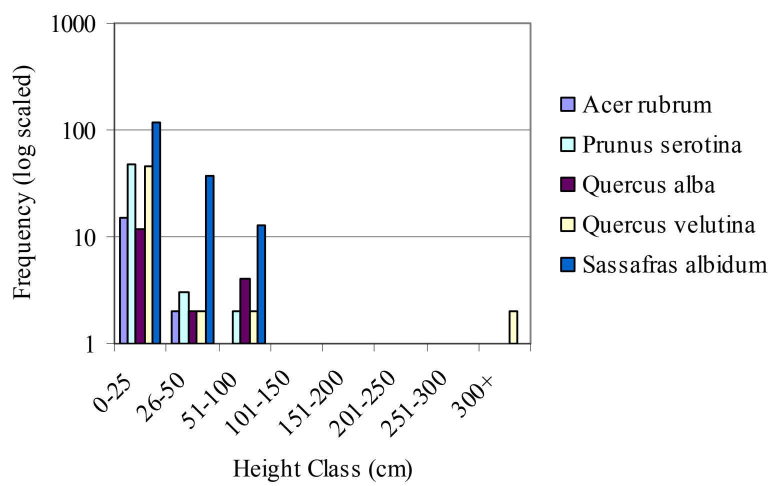
<u>Aggregation of 10 Burned Plots</u>

FC-BRN1



<u>Aggregation of 10 Unmanaged Plots</u>

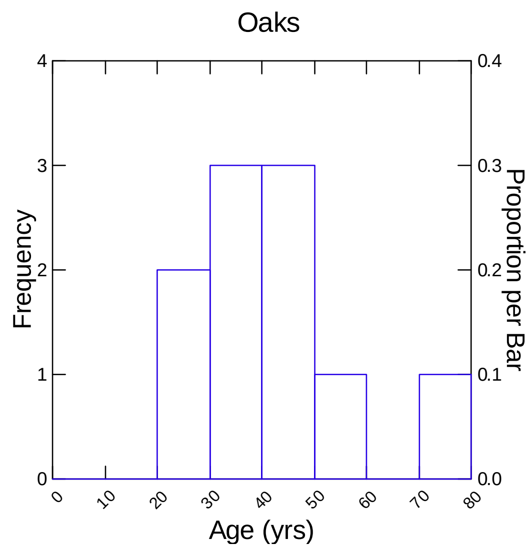
FC-WAY2



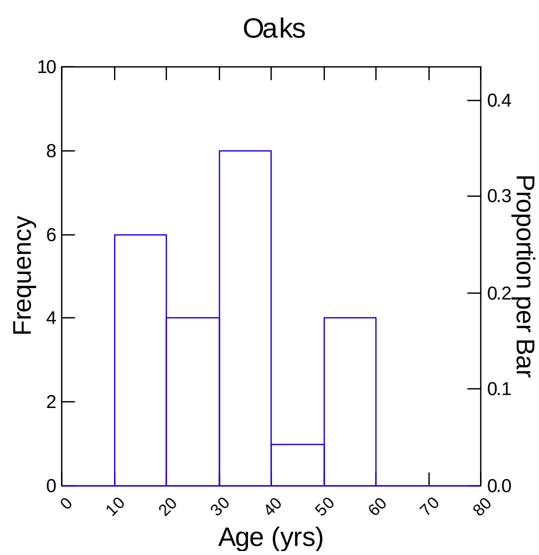
APPENDIX 6D

Age Class Distributions for Oak Species among Management Prescriptions: Case Study – Southern Outwash Sites

FC-BRN1: Aggregation of 10 Burned Plots



FC-WAY2: Aggregation of 10 Unmanaged Plots



APPENDIX 7A

Comparison of Oak and Red Maple Regeneration (Understory Stem Density) and Seedling and Sapling Abundance among Management Prescriptions: Selected Southern Sand Lake Plain Sites[1, 2]

	Management Prescription		
	Unmanaged	Shelterwood	Burned
Understory Stem Density (stems ha^{-1})			
All Oak Species[†]	74.29 (28.19)	3070.00 (850.00)	980.00 (587.23)
White Oak	57.14 (27.75)	2420.00 (920.00)	732.00 (445.09)
Black Oak-Northern Pin Oak[(3)†]	17.14 (11.07)	650.00 (70.00)	248.00 (170.95)
Northern Red Oak	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Red Maple	280.00 (139.11)	10.00 (10.00)	36.00 (19.39)
Seedling and Sapling Abundance[(4)]			
All Oak Species Seedlings	4.70 (1.30)	6.35 (0.85)	6.04 (1.54)
All Oak Species Saplings	0.19 (0.04)	1.80 (0.70)	0.62 (0.32)
Red Maple Seedlings [†]	1.99 (0.44)[a]	0.15 (0.05)[ab]	0.40 (0.24)[b]
Red Maple Saplings	0.23 (0.14)	0.05 (0.05)	0.02 (0.02)

1 For each variable, means are shown outside of parentheses, one standard error inside of parentheses.

2 For all variables: Unmanaged (n = 7), Shelterwood (n = 2), Burned (n = 5).

3 Stems of black oak and northern pin oak are aggregated due to difficulties with field identification between these closely related species.

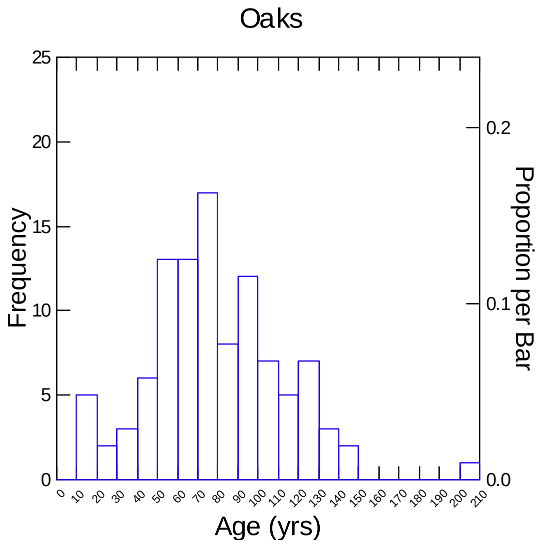
4 Units are numbers per 4 m^2 plot for All Oak Species and Red Maple Seedlings/Saplings.

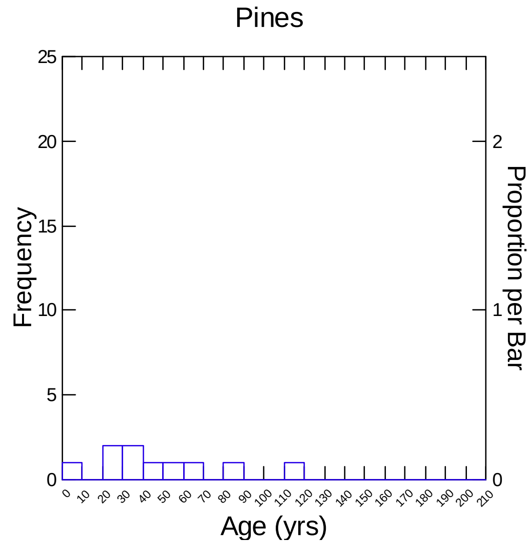
† Indicates significance at $\alpha = 0.05$, Kruskal-Wallis. Comparisons with the same letter are not significantly different at $\alpha = 0.05$ when applying non-parametric Tukey-type multiple comparison Nemenyi test. However, pairwise significant differences may not have been detected with this test for certain variables.

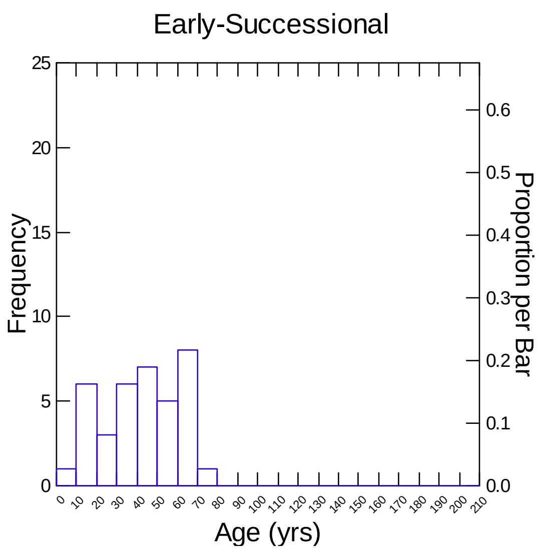
APPENDIX 7B

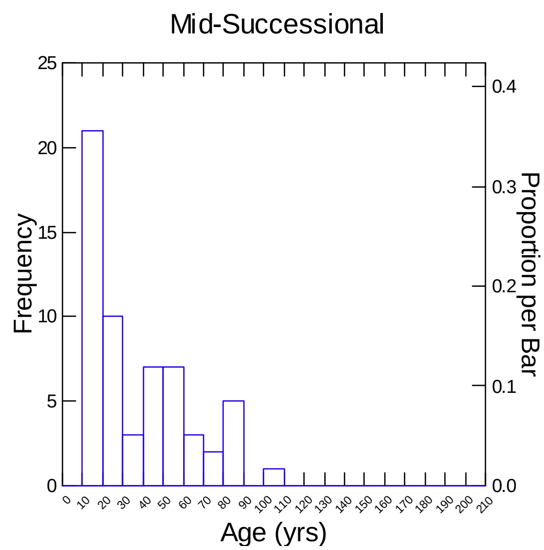
Age Class Distributions for Species Groups among Management Prescriptions: Selected Southern Sand Lake Plain Sites

<u>Aggregation of 70 Unmanaged Plots</u>

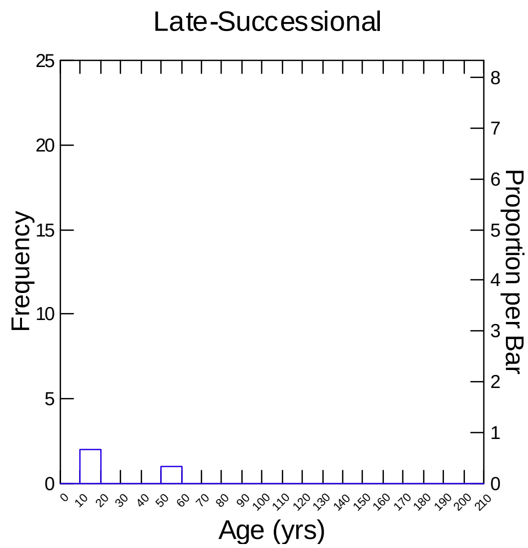




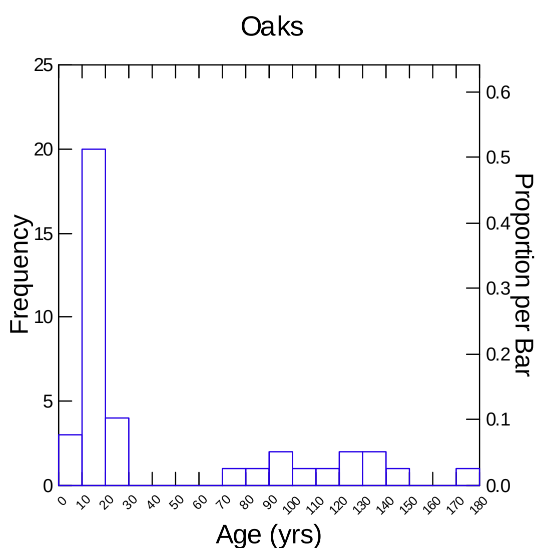


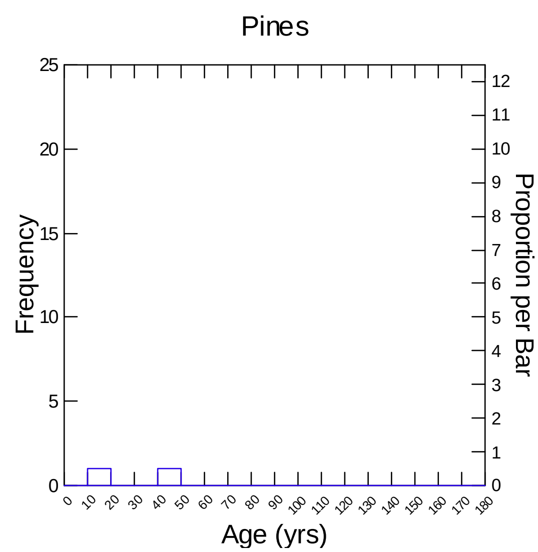


APPENDIX 7B. (continued).

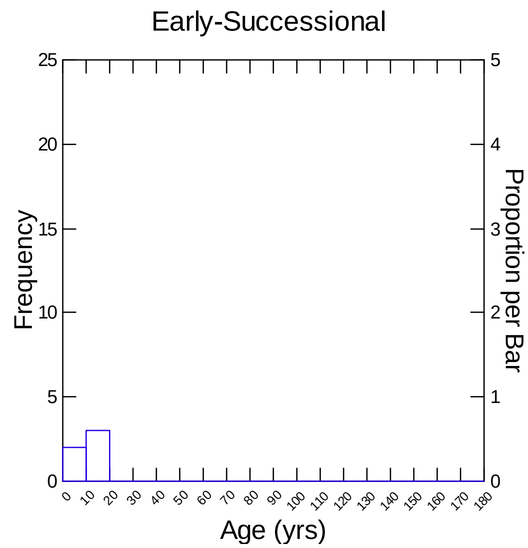


<u>Aggregation of 20 Shelterwood Plots</u>

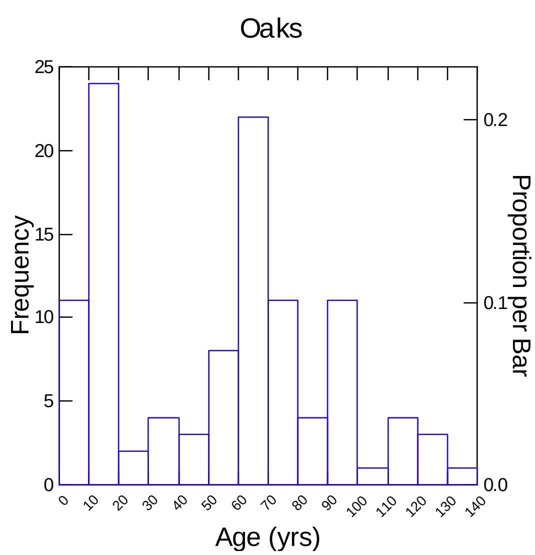


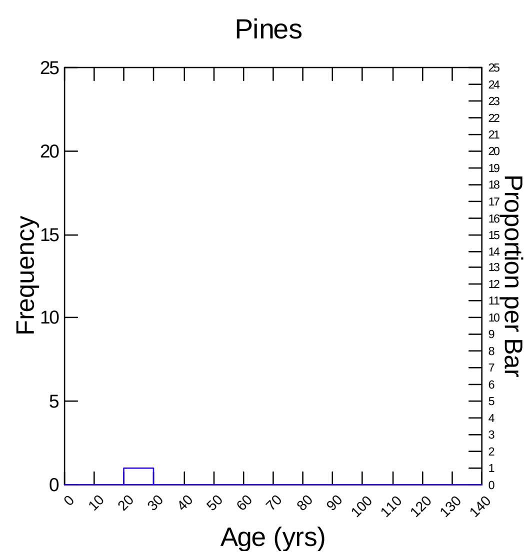


APPENDIX 7B. (continued).

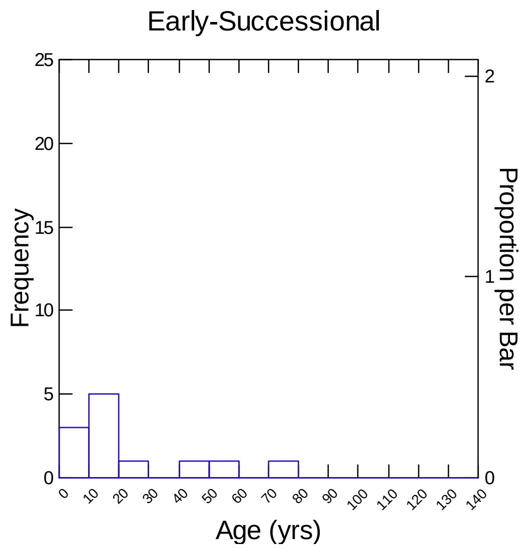


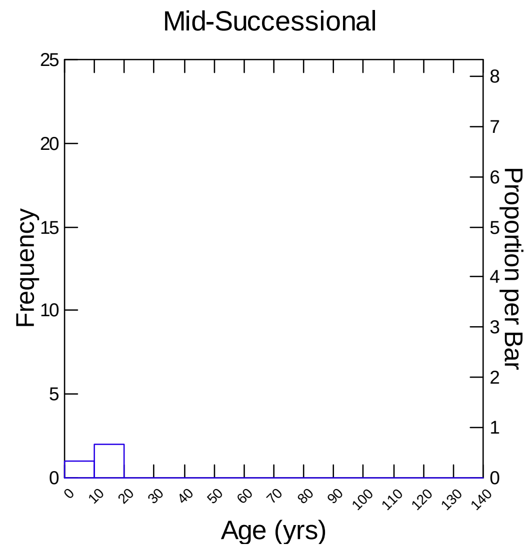
Aggregation of 50 Burned Plots





APPENDIX 7B. (continued).



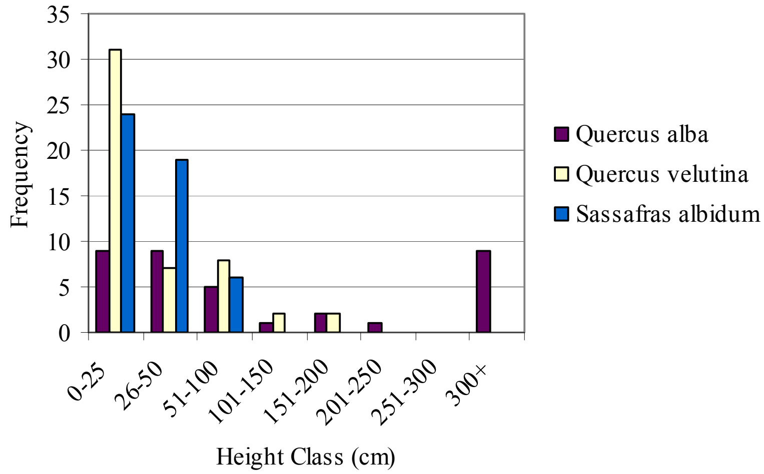


APPENDIX 7C

**Height Class Distributions for Seedlings and Saplings of Selected Species among Management Prescriptions:
Case Study – Southern Sand Lake Plain Sites**

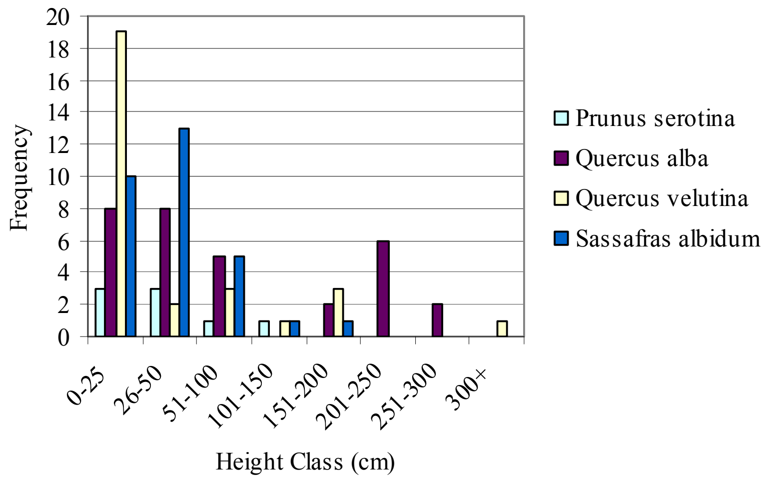
<u>Aggregation of 10 Once-Burned Plots</u>

A11-5B(s)



<u>Aggregation of 10 Twice-Burned Plots</u>

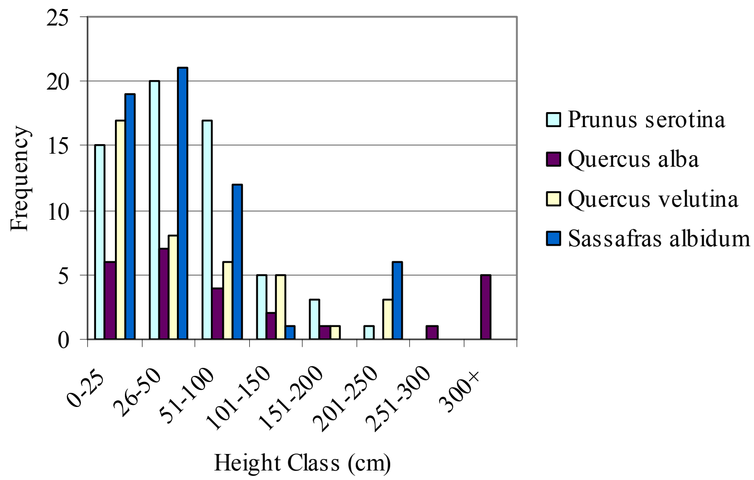
A11-5B(n)



APPENDIX 7C. (continued).

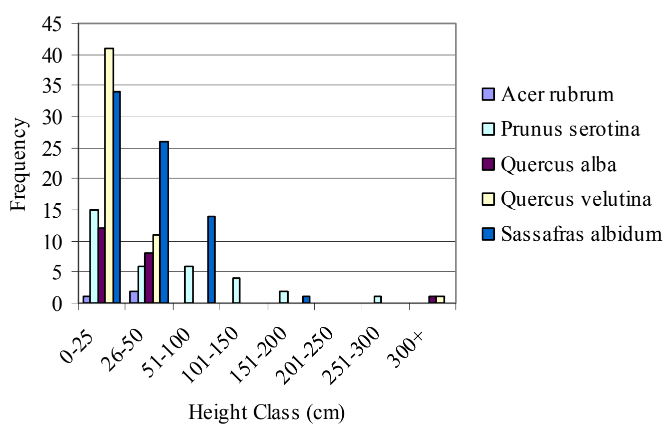
Aggregation of 10 Shelterwood Plots

A18-N



Aggregation of 10 Unmanaged Plots

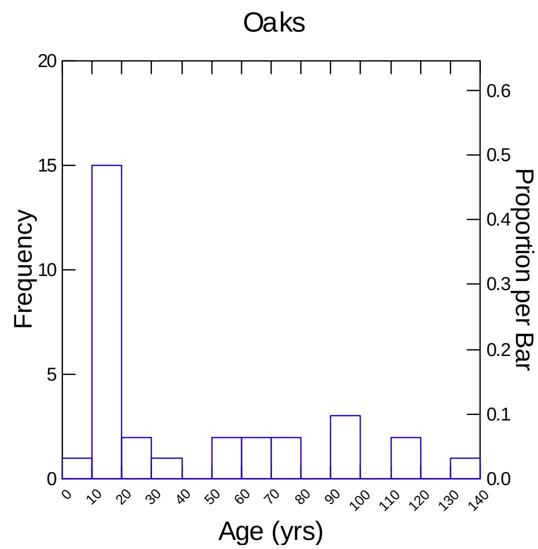
A18-S



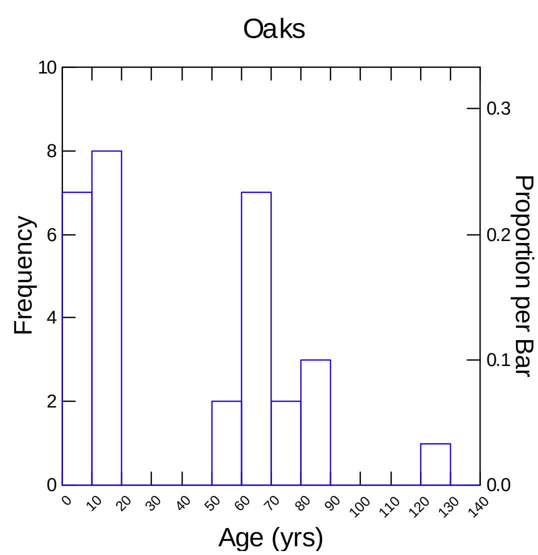
APPENDIX 7D

Age Class Distributions for Oak Species among Management Prescriptions: Case Study – Southern Sand Lake Plain Sites

A11-5B(s): Aggregation of 10 Once-Burned Plots

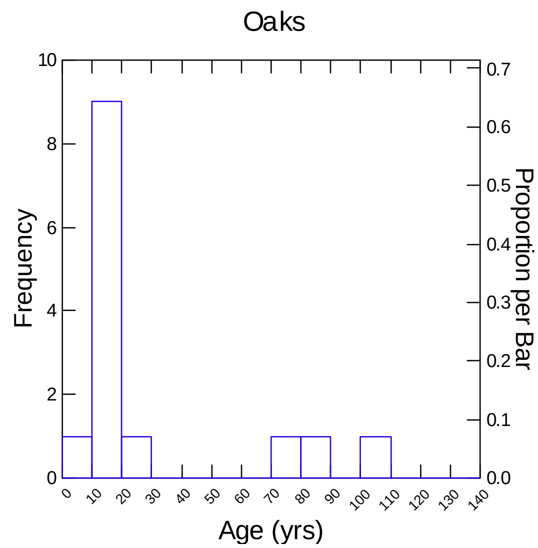


A11-5B(n): Aggregation of 10 Twice-Burned Plots

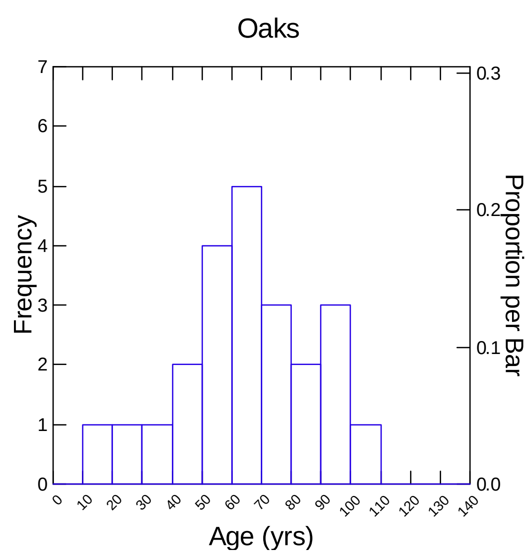


APPENDIX 7D. (continued).

A18-N: Aggregation of 10 Shelterwood Plots



A18-S: Aggregation of 10 Unmanaged Plots



APPENDIX 8A

Comparison of Oak and Red Maple Regeneration (Understory Stem Density) and Seedling and Sapling Abundance among Management Prescriptions: Selected Northern Ice-Contact Sites[1, 2]

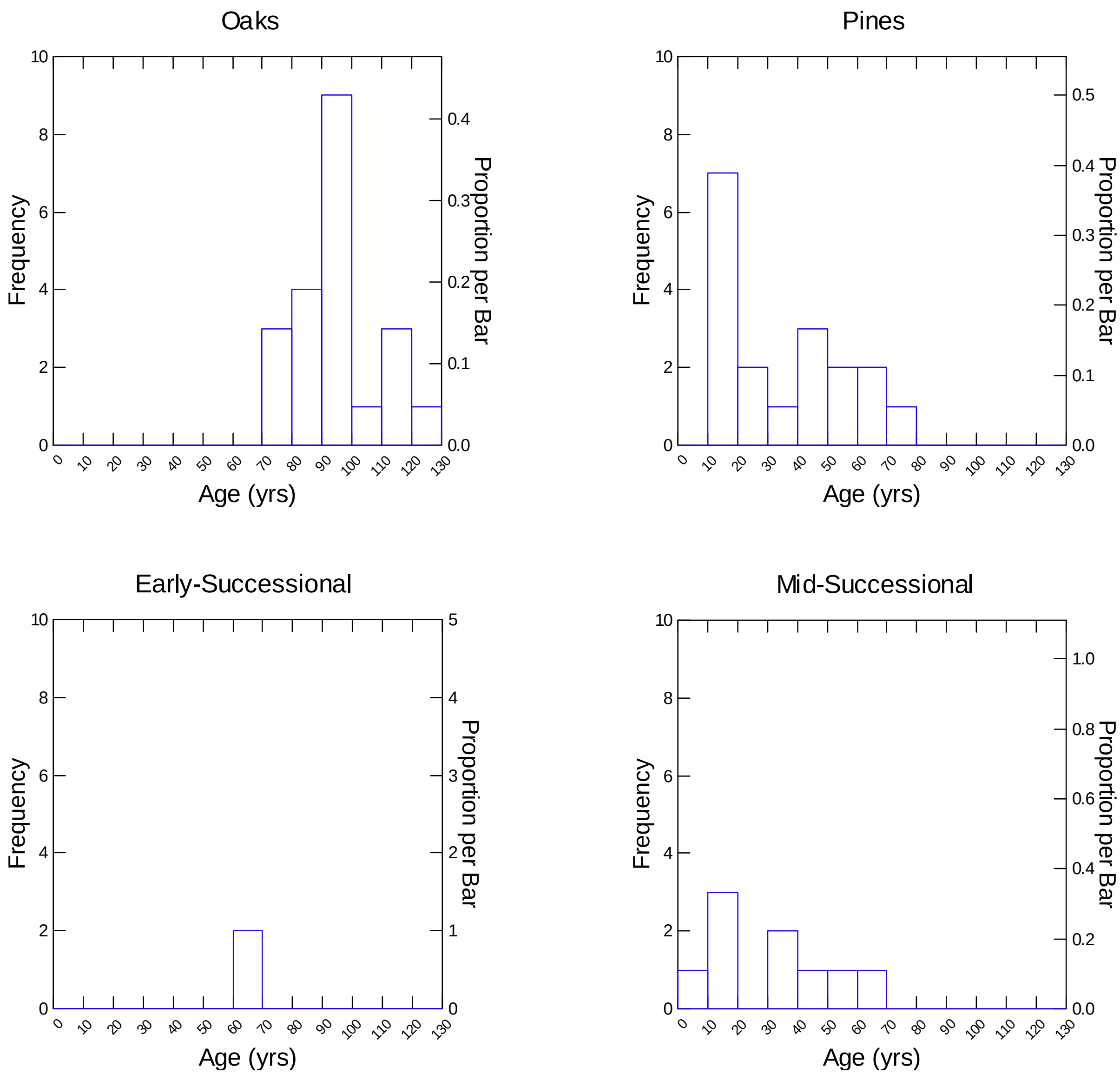
	Management Prescription			
	Unmanaged	Shelterwood	Thinning	Thinned and Burned
Understory Stem Density (stems ha^{-1})				
All Oak Species	0.00	10.00	280.00	0.00
White Oak	0.00	10.00	240.00	0.00
Black Oak-Northern Pin Oak[3]	0.00	0.00	6.67	0.00
Northern Red Oak	0.00	0.00	33.33	0.00
Red Maple	280.00	580.00	746.67	80.00
Seedling and Sapling Abundance[4]				
All Oak Species Seedlings	10.70	7.75	14.10	2.80
All Oak Species Saplings	0.40	0.10	0.37	0.10
Red Maple Seedlings	11.90	4.15	17.03	4.10
Red Maple Saplings	0.20	0.00	1.57	0.00

1 For each variable, means are shown.
2 For all variables: Unmanaged (n = 1), Shelterwood (n = 2), Thinning (n = 3), Thinned and Burned (n = 1).
3 Stems of black oak and northern pin oak are aggregated due to difficulties with field identification between these closely related species.
4 Units are numbers per 4 m^2 plot for All Oak Species and Red Maple Seedlings/Saplings.

APPENDIX 8B

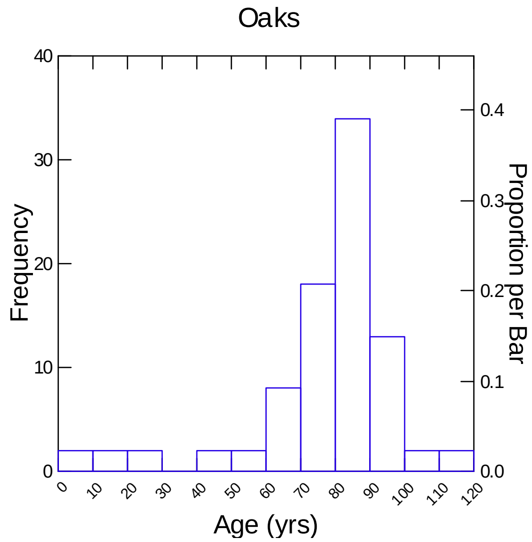
Age Class Distributions for Species Groups among Management Prescriptions: Selected Northern Ice-Contact Sites

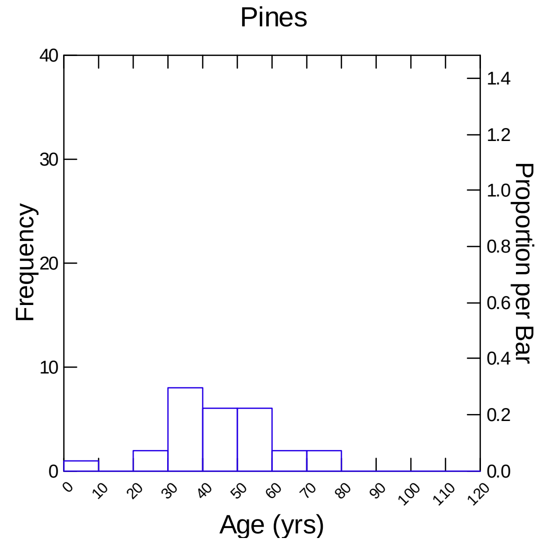
<u>Aggregation of 10 Unmanaged Plots</u>

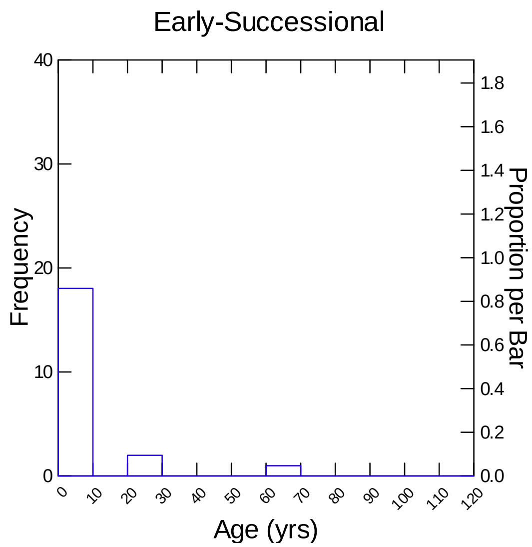


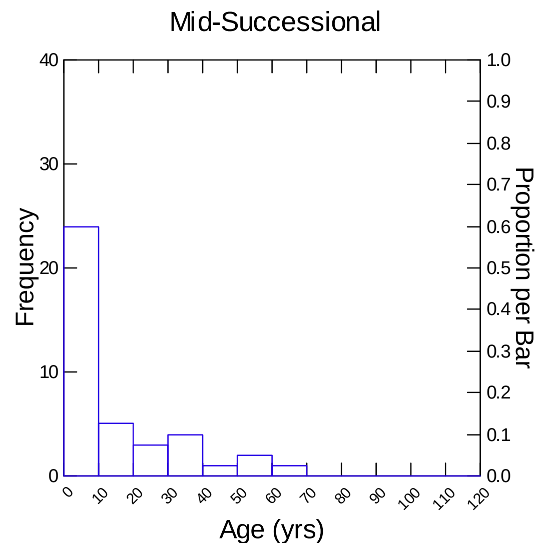
APPENDIX 8B. (continued).

<u>Aggregation of 60 Cut and Cut and Burned Plots</u>

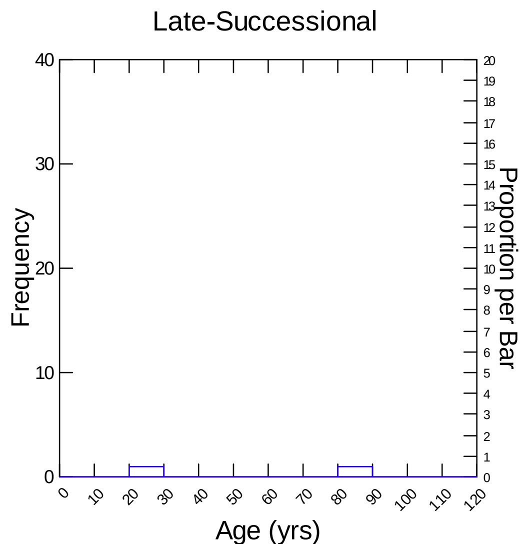








APPENDIX 8B. (continued).

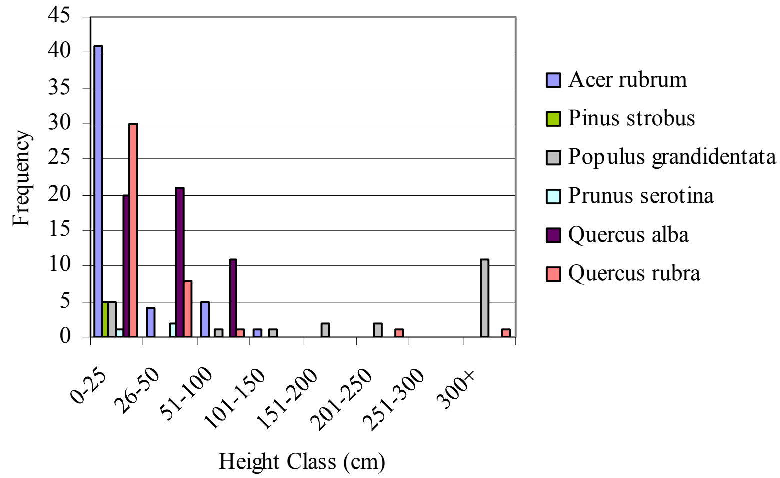


APPENDIX 8C

**Height Class Distributions for Seedlings and Saplings of Selected Species among Management Prescriptions:
Case Study – Northern Ice-Contact Sites**

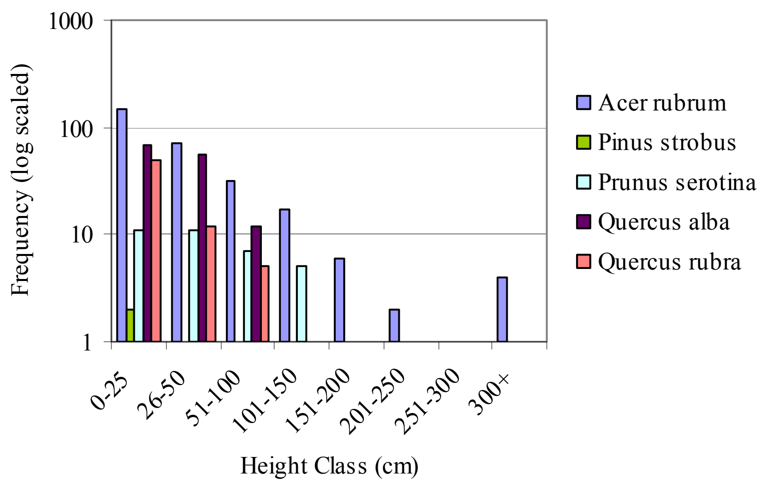
<u>Aggregation of 10 Shelterwood Plots (PArVHa / PArVVb Kotar Habitat Type)</u>

GRAY12



<u>Aggregation of 10 Thinned Plots (PArVHa / PArVVb Kotar Habitat Type)</u>

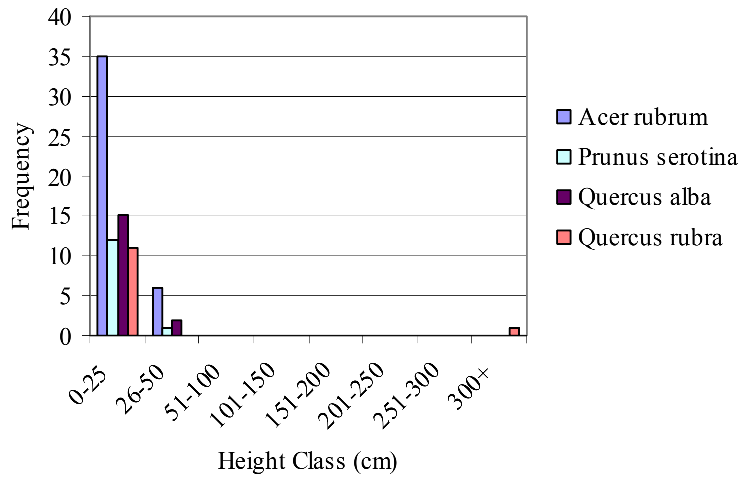
GRAY15



APPENDIX 8C. (continued).

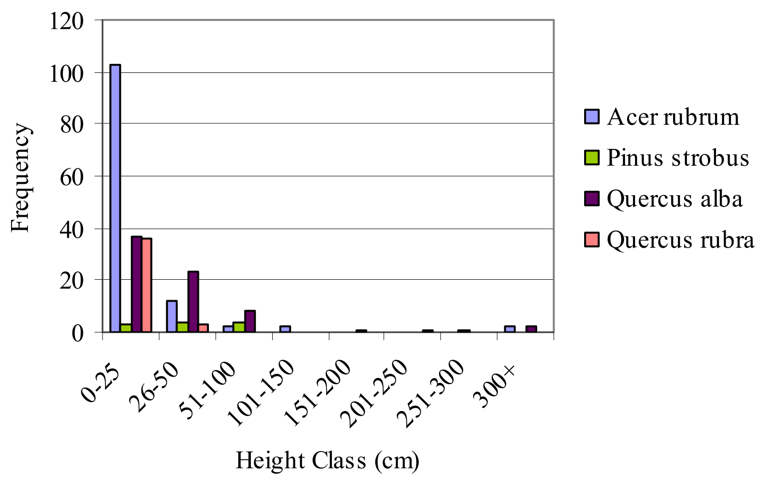
Aggregation of 10 Thinned and Burned Plots (PArVHa / PArVVb Kotar Habitat Type)

ROSC1



Aggregation of 10 Unmanaged Plots (PArVHa / PArVVb Kotar Habitat Type)

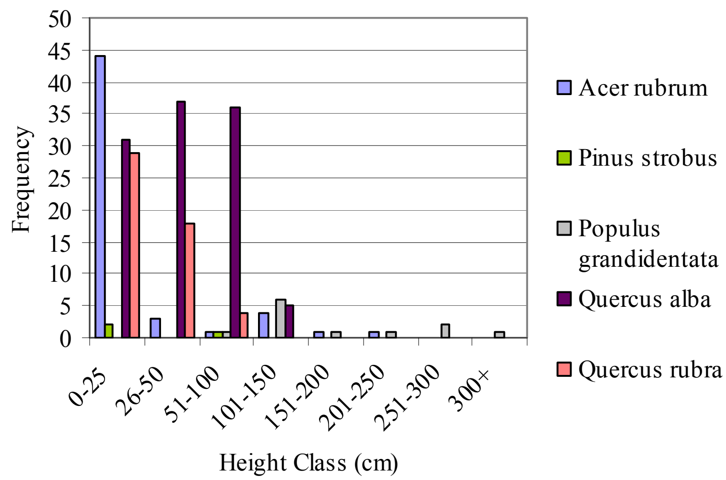
GAYL2



APPENDIX 8C. (continued).

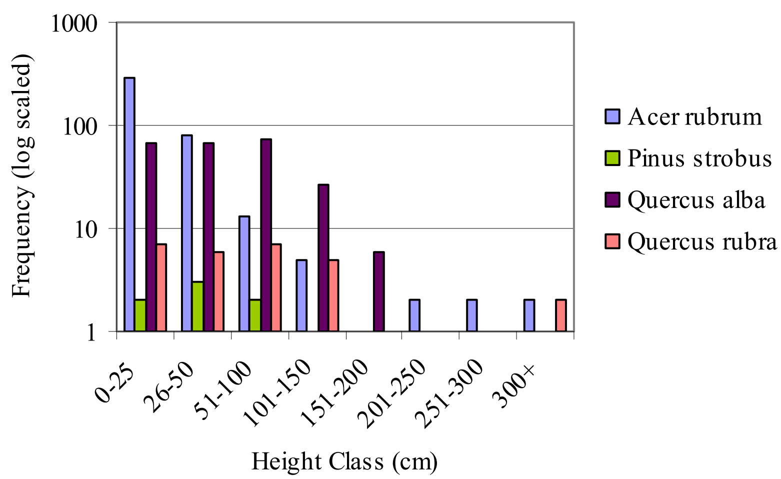
Aggregation of 10 Shelterwood Plots (PVCd / PArVHa Kotar Habitat Type)

GRAY23



Aggregation of 10 Selection Cut Plots (PVCd / PArVHa Kotar Habitat Type)

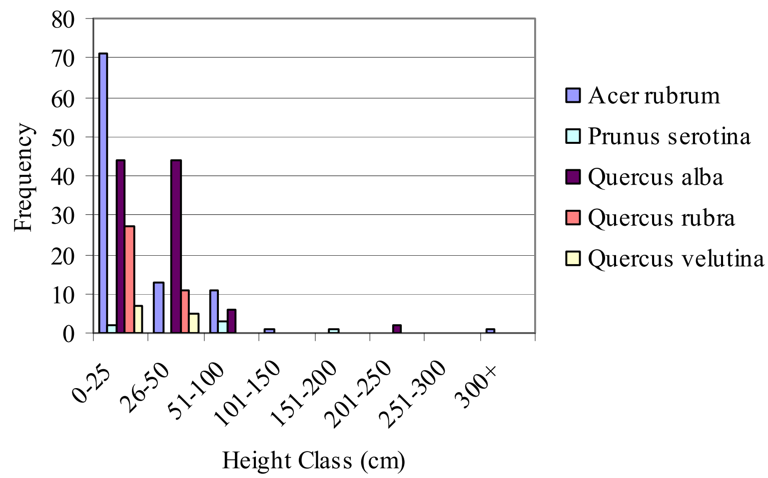
GRAY26



APPENDIX 8C. (continued).

Aggregation of 10 Thinned Plots (PVCd / PArVHa Kotar Habitat Type)

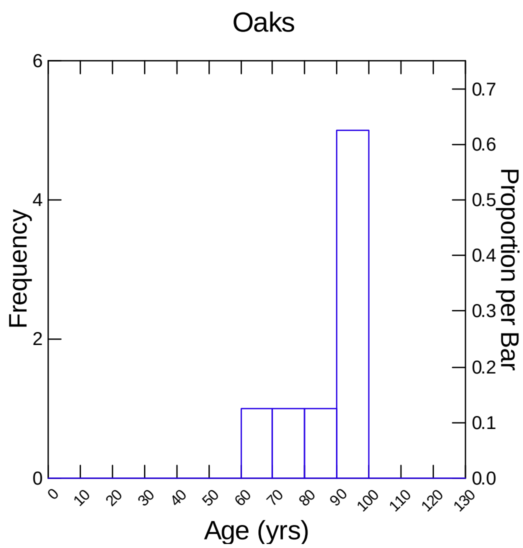
GRAY3

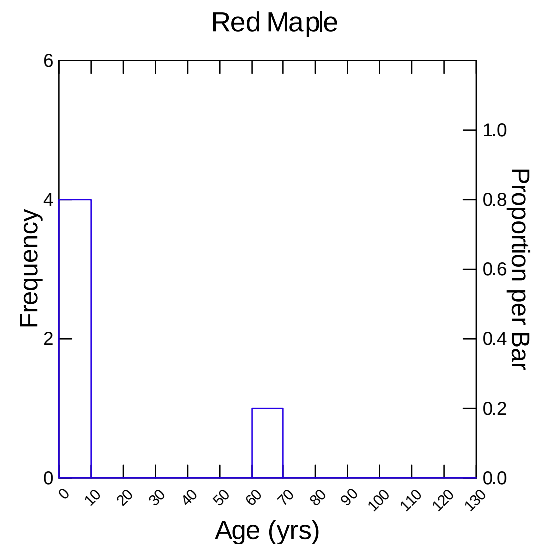


APPENDIX 8D

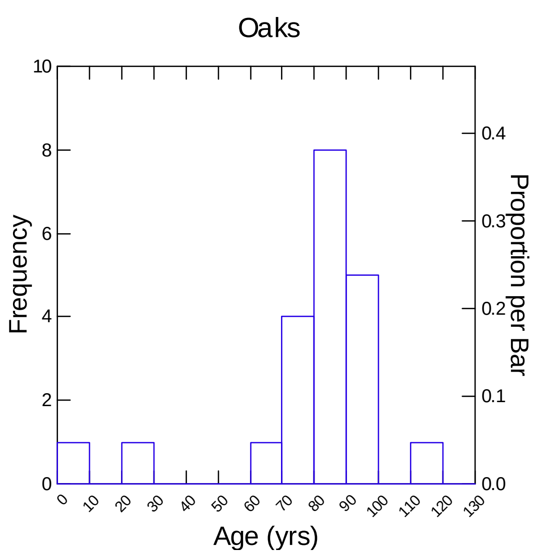
Age Class Distributions for Oak Species and Red Maple among Management Prescriptions: Case Study – Northern Ice-Contact Sites

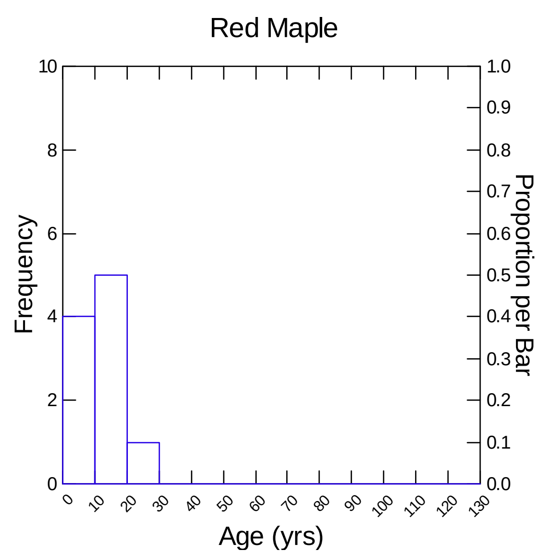
GRAY12: Aggregation of 10 Shelterwood Plots (PArVHa / PArVVb Kotar Habitat Type)





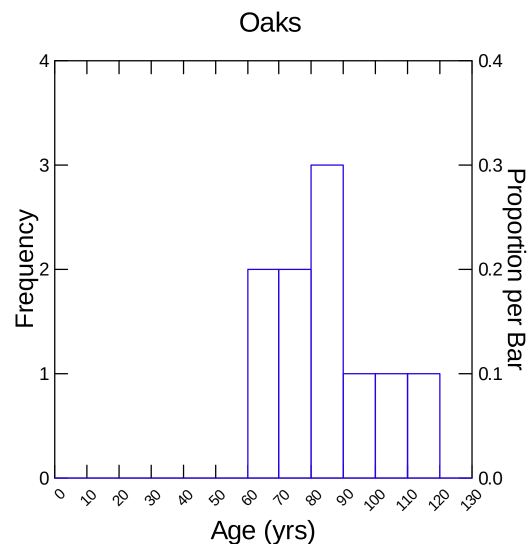
GRAY15: Aggregation of 10 Thinned Plots (PArVHa / PArVVb Kotar Habitat Type)

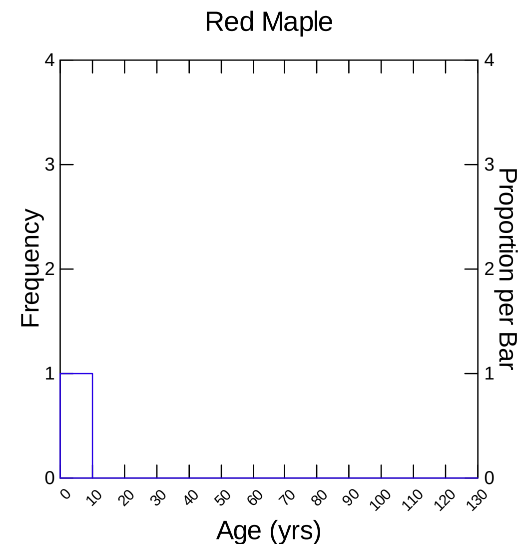




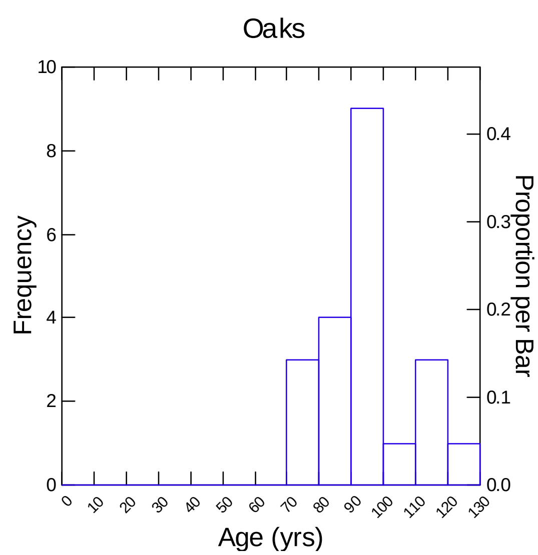
APPENDIX 8D. (continued).

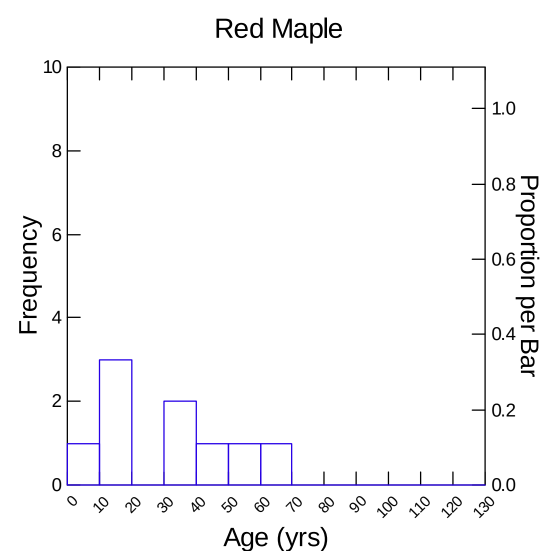
ROSC1: Aggregation of 10 Thinned and Burned Plots (PArVHa / PArVVb Kotar Habitat Type)





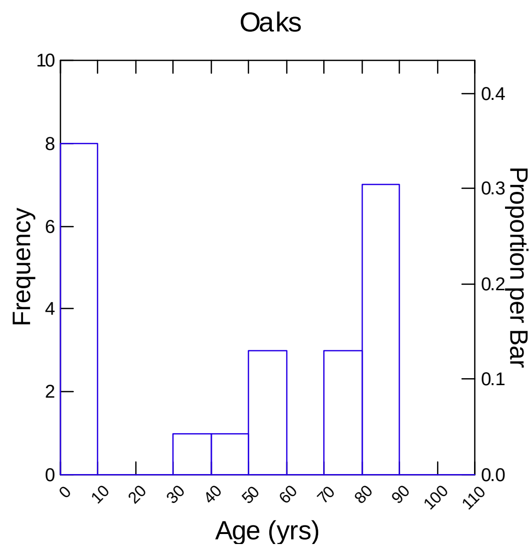
GAYL2: Aggregation of 10 Unmanaged Plots (PArVHa / PArVVb Kotar Habitat Type)

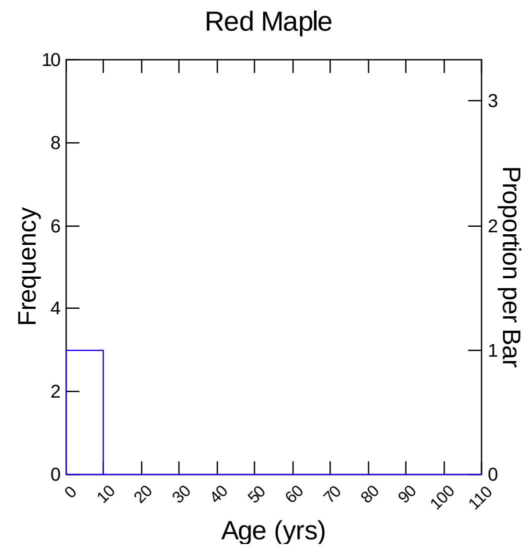




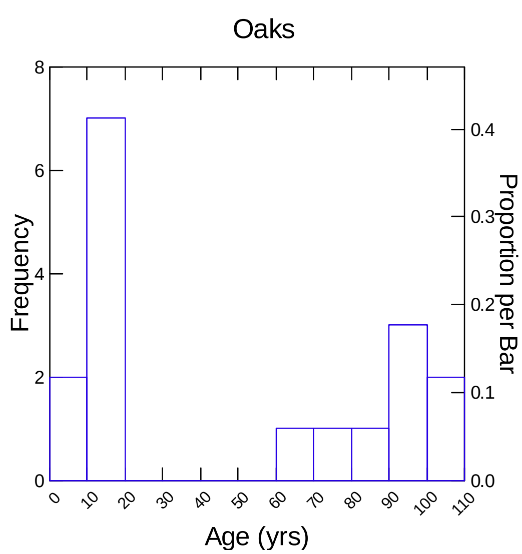
APPENDIX 8D. (continued).

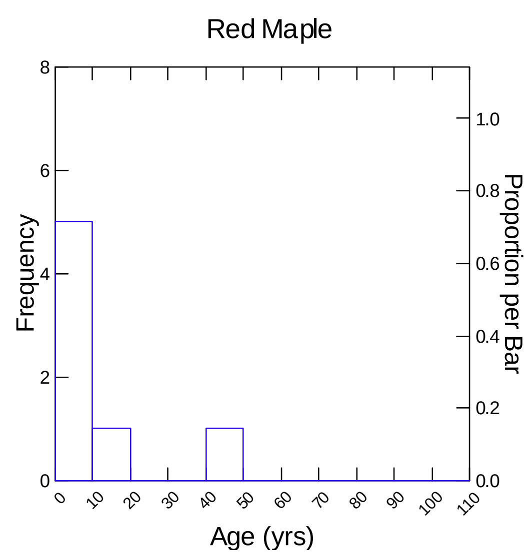
GRAY23: Aggregation of 10 Shelterwood Plots (PVCd / PArVHa Kotar Habitat Type)





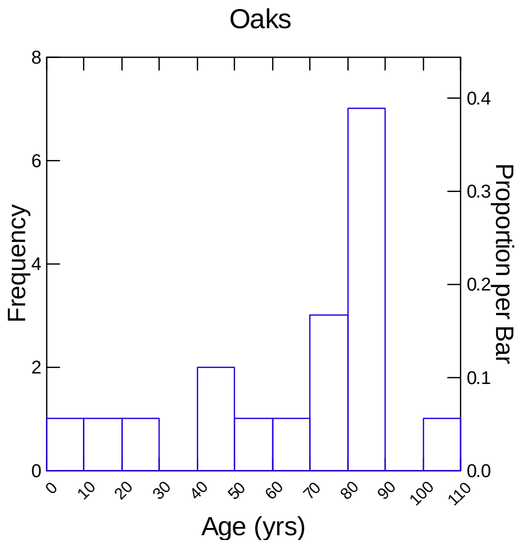
GRAY26: Aggregation of 10 Selection Cut Plots (PVCd / PArVHa Kotar Habitat Type)

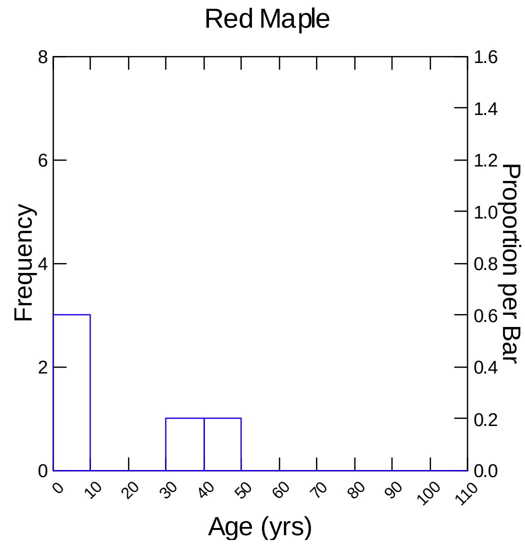




APPENDIX 8D. (continued).

GRAY3: Aggregation of 10 Thinned Plots (PVCd / PArVHa Kotar Habitat Type)





APPENDIX 9A

Comparison of Oak and Red Maple Regeneration (Understory Stem Density) and Seedling and Sapling Abundance among Management Prescriptions: Selected Northern Moraine Sites[(1, 2)]

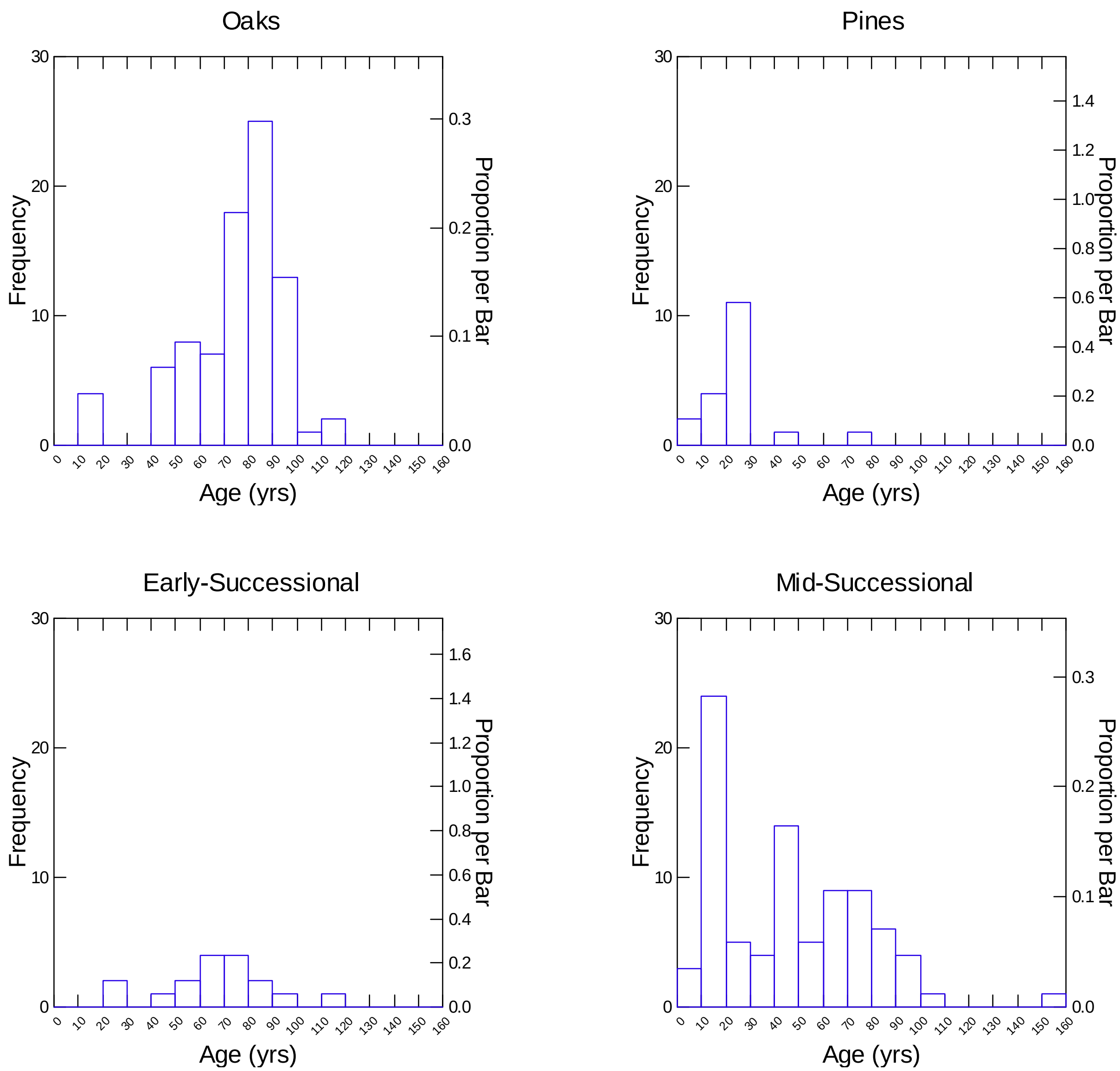
	Management Prescription			
	Unmanaged	Shelterwood	Clearcut	Thinning
Understory Stem Density (stems ha^{-1})				
All Oak Species[†]	16.67[a]	166.67[ab]	1600.00[b]	134.29[ab]
	(13.08)	(83.53)	(1080.00)	(90.89)
White Oak	0.00	46.67	40.00	42.86
	(0.00)	(29.06)	(40.00)	(30.68)
Black Oak-Northern Pin Oak[(3)]	0.00	113.33	80.00	71.43
	(0.00)	(59.26)	(80.00)	(62.01)
Northern Red Oak[†]	16.67	6.67	1480.00	20.00
	(13.08)	(6.67)	(1200.00)	(14.48)
Red Maple	646.67	1153.33	1110.00	1688.57
	(157.20)	(681.80)	(430.00)	(378.01)
Seedling and Sapling Abundance[(4)]				
All Oak Species Seedlings	3.37	8.43	2.40	3.83
	(1.80)	(1.60)	(1.80)	(0.78)
All Oak Species Saplings	0.18	0.10	0.45	0.16
	(0.07)	(0.06)	(0.25)	(0.07)
Red Maple Seedlings[‡]	26.60	4.37	5.30	20.93
	(4.12)	(2.68)	(5.00)	(8.90)
Red Maple Saplings	0.75	1.07	1.25	1.37
	(0.40)	(0.71)	(0.25)	(0.57)

[1] For each variable, means are shown outside of parentheses, one standard error inside of parentheses.
[2] For all variables: Unmanaged (n = 6), Shelterwood (n = 3), Clearcut (n = 2), Thinning (n = 7).
[3] Stems of black oak and northern pin oak are aggregated due to difficulties with field identification between these closely related species.
[4] Units are numbers per 4 m^2 plot for All Oak Species and Red Maple Seedlings/Saplings.
[†] Indicates significance at $\alpha = 0.10$, Kruskal-Wallis. Comparisons with the same letter are not significantly different at $\alpha = 0.10$ when applying non-parametric Tukey-type multiple comparison Nemenyi test. However, pairwise significant differences may not have been detected with this test for certain variables.
[‡] Indicates significance at $\alpha = 0.05$, Kruskal-Wallis. Comparisons with the same letter are not significantly different at $\alpha = 0.05$ when applying non-parametric Tukey-type multiple comparison Nemenyi test. However, pairwise significant differences may not have been detected with this test for certain variables.

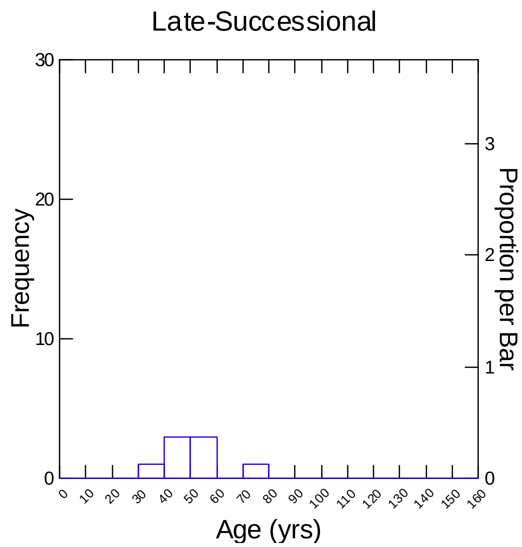
APPENDIX 9B

Age Class Distributions for Species Groups among Management Prescriptions: Selected Northern Moraine Sites

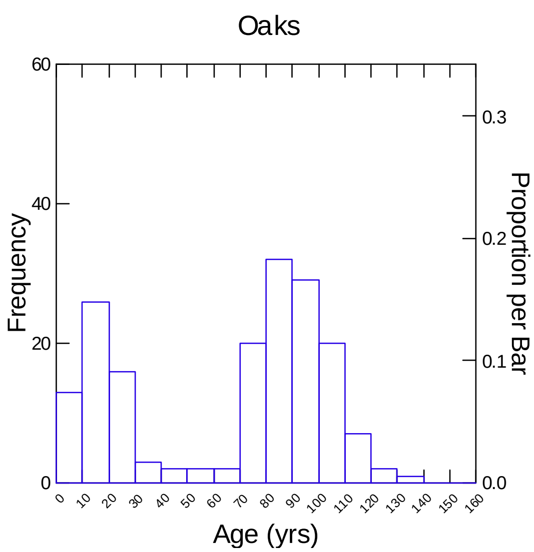
<u>Aggregation of 60 Unmanaged Plots</u>

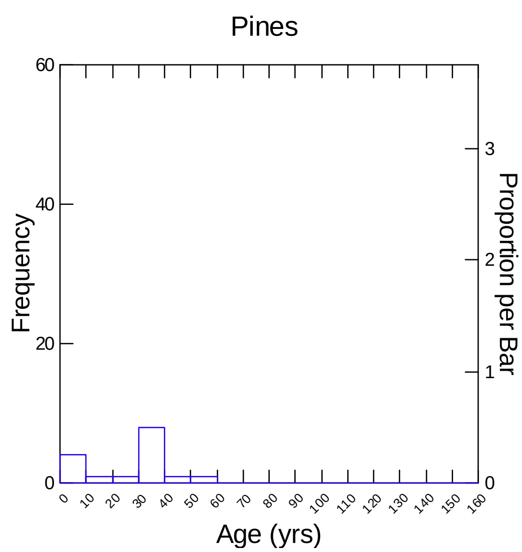


APPENDIX 9B. (continued).

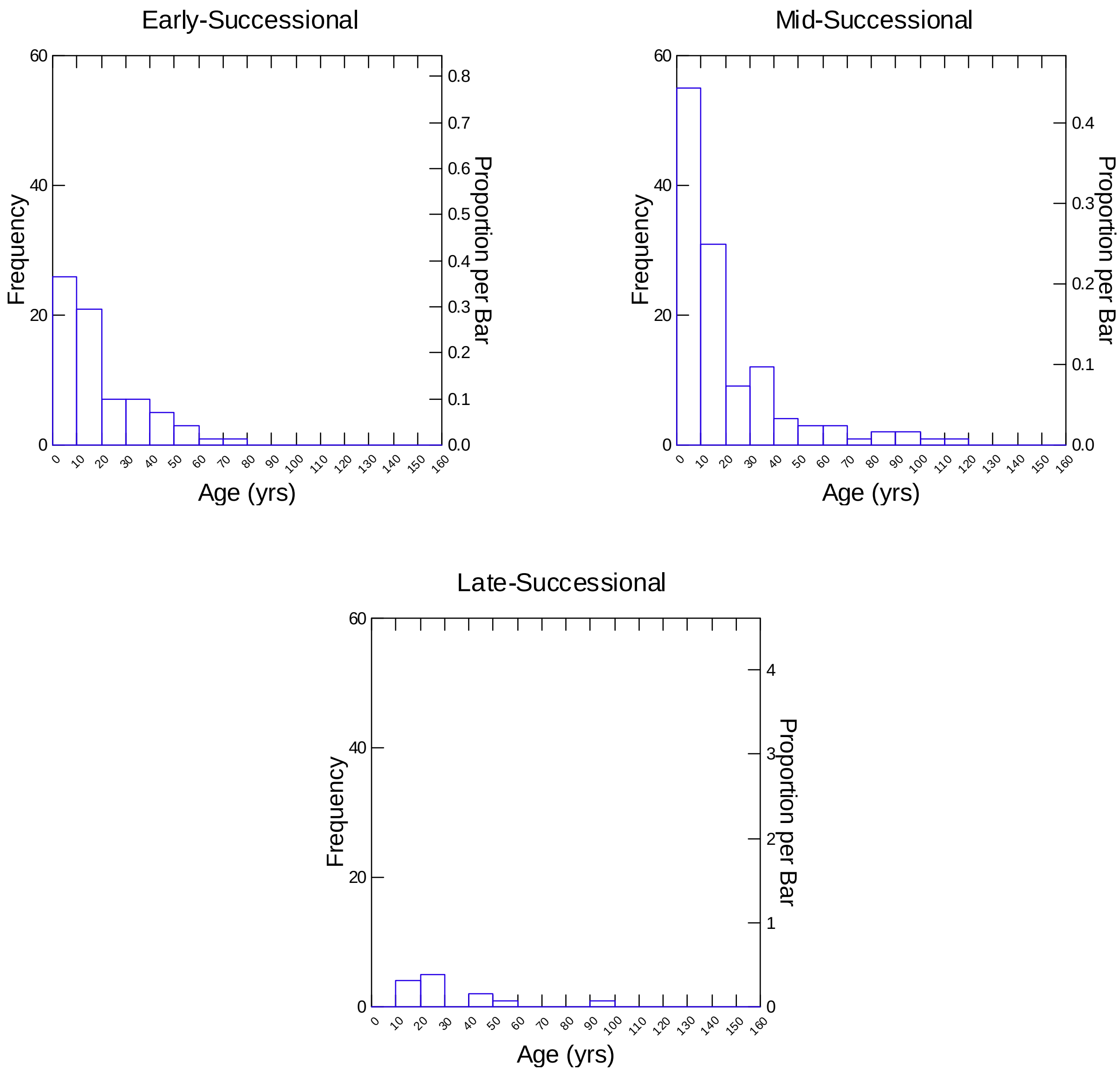


<u>Aggregation of 120 Cut Plots</u>





APPENDIX 9B. (continued).

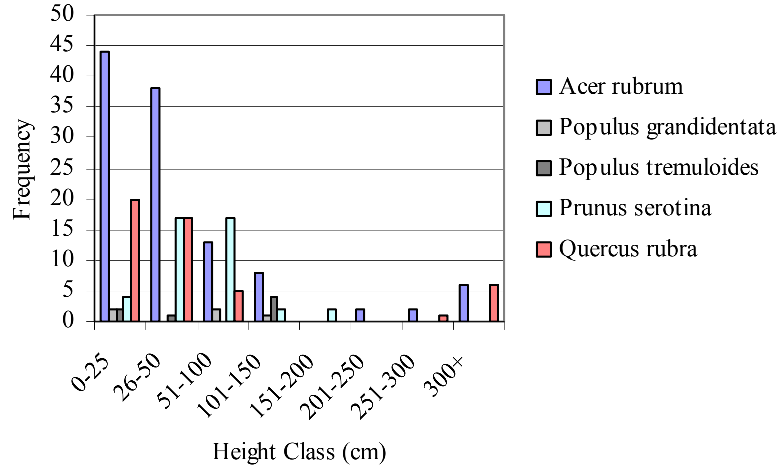


APPENDIX 9C

**Height Class Distributions for Seedlings and Saplings of Selected Species among Management Prescriptions:
Case Study – Northern Moraine Sites**

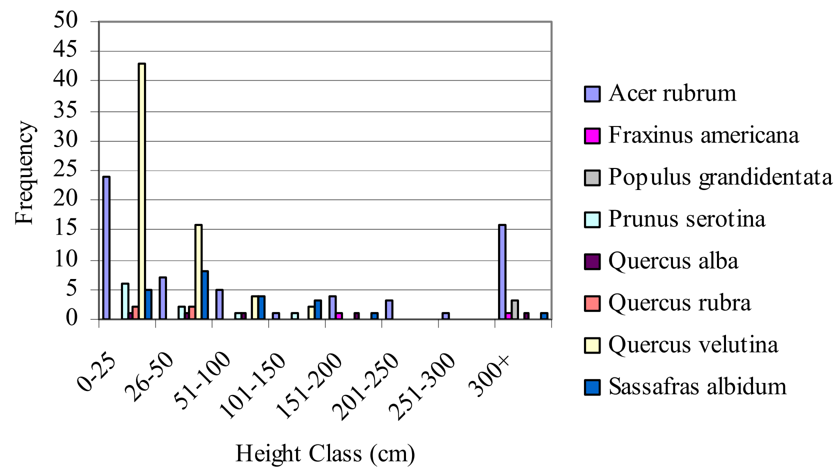
<u>Aggregation of 10 Clearcut Plots</u>

ATL12



<u>Aggregation of 10 Shelterwood Plots</u>

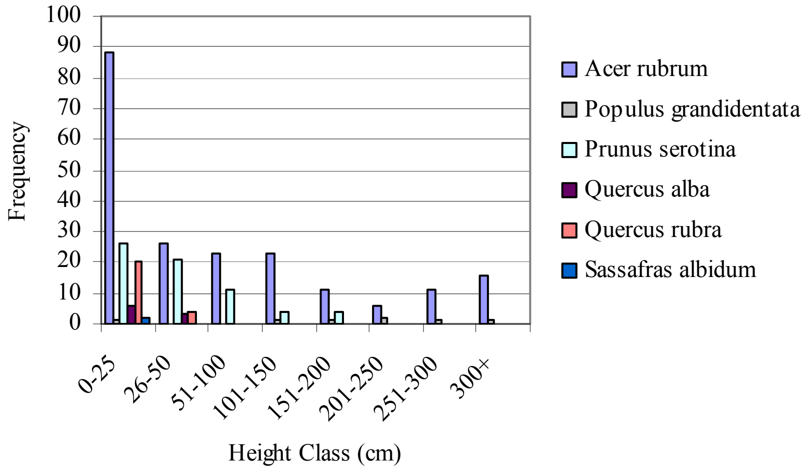
MAN4B



APPENDIX 9C. (continued).

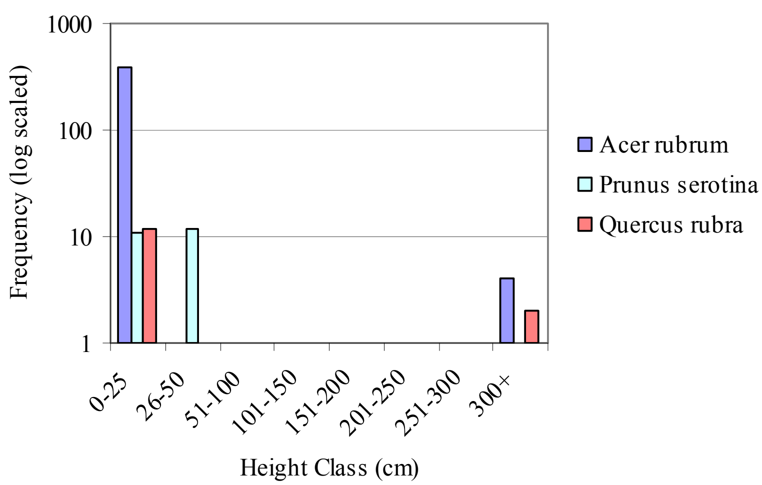
Aggregation of 10 Thinned Plots

CAD7



Aggregation of 10 Unmanaged Plots

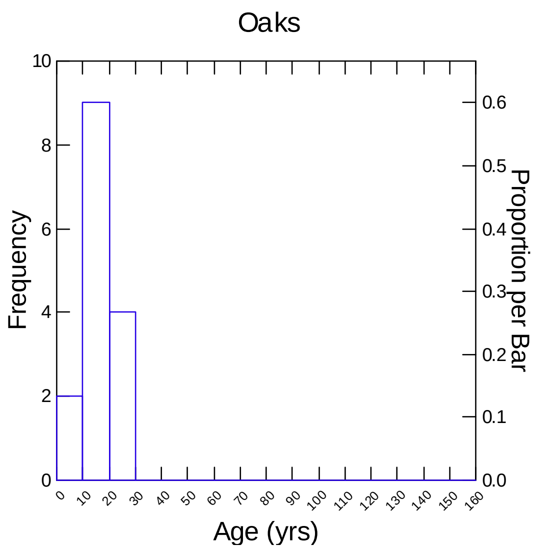
CAD26

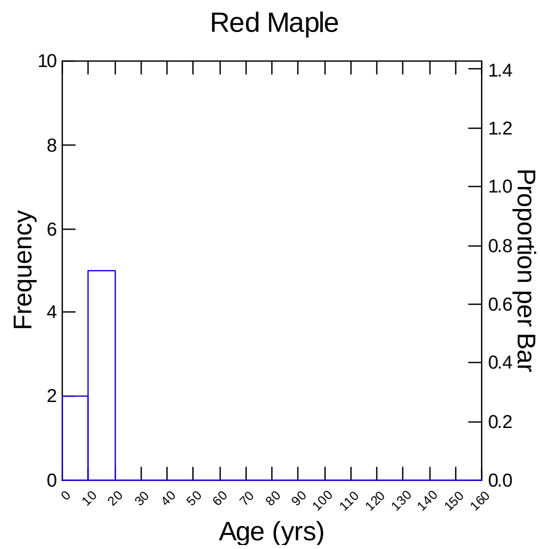


APPENDIX 9D

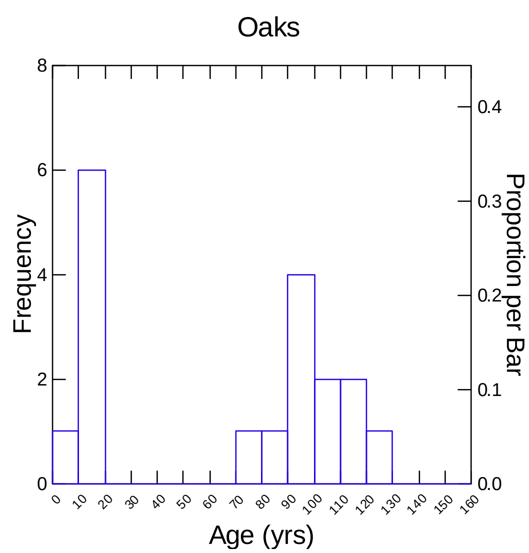
Age Class Distributions for Oak Species and Red Maple among Management Prescriptions: Case Study – Northern Moraine Sites

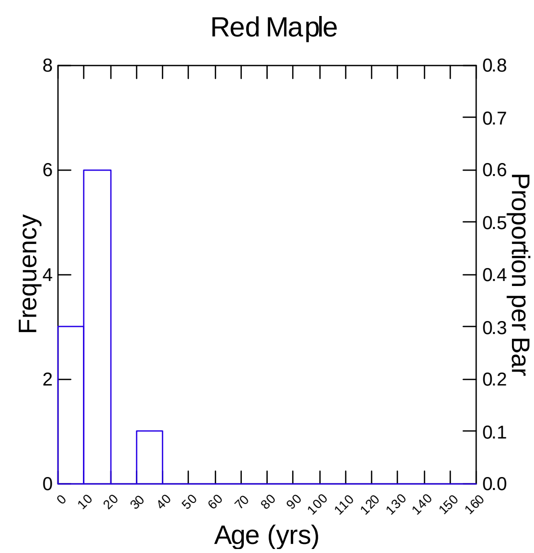
ATL12: Aggregation of 10 Clearcut Plots





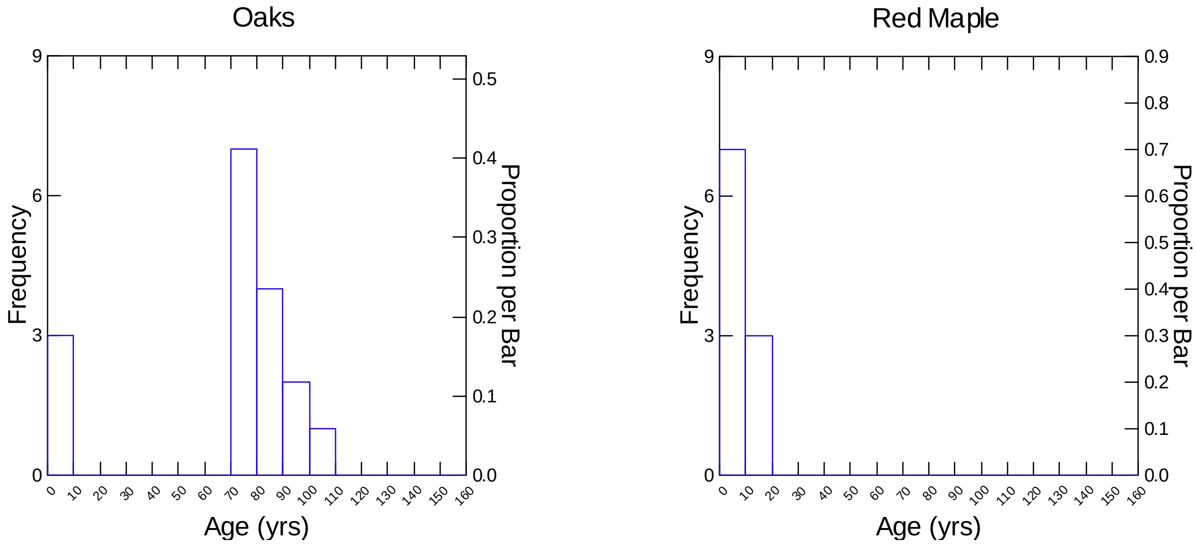
MAN4B: Aggregation of 10 Shelterwood Plots



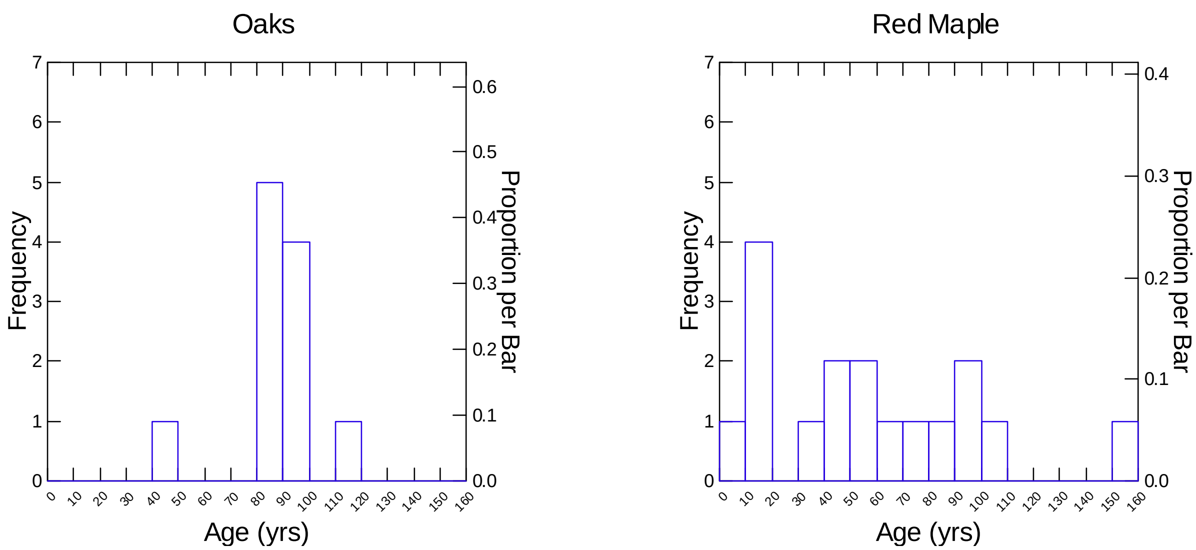


APPENDIX 9D. (continued).

CAD7: Aggregation of 10 Thinned Plots



CAD26: Aggregation of 10 Unmanaged Plots



APPENDIX 10A

Comparison of Oak and Red Maple Regeneration (Understory Stem Density) and Seedling and Sapling Abundance among Management Prescriptions: Selected Northern Outwash Sites[1, 2]

	Management Prescription				
	Unmanaged	Shelterwood	Shelterwood and Burn	Clearcut	Burned
Understory Stem Density (stems ha^{-1})					
All Oak Species	40.00	1490.00	2720.00	3326.32	100.00
White Oak	30.00	1030.00	1760.00	1757.90	100.00
Black Oak-Northern Pin Oak[3]	10.00	460.00	960.00	263.16	0.00
Northern Red Oak	0.00	0.00	0.00	1305.26	0.00
Red Maple	740.00	280.00	0.00	831.58	0.00
Seedling and Sapling Abundance[4]					
All Oak Species Seedlings	6.10	8.10	9.40	5.95	29.40
All Oak Species Saplings	0.20	1.05	3.00	1.21	0.20
Red Maple Seedlings	8.50	0.15	0.00	0.47	4.90
Red Maple Saplings	0.70	0.00	0.50	0.90	0.10

1 For each variable, means are shown.

2 For all variables: Unmanaged (n = 2), Shelterwood (n = 2), Shelterwood and Burn (n = 1), Clearcut (n = 2), Burned (n = 1).

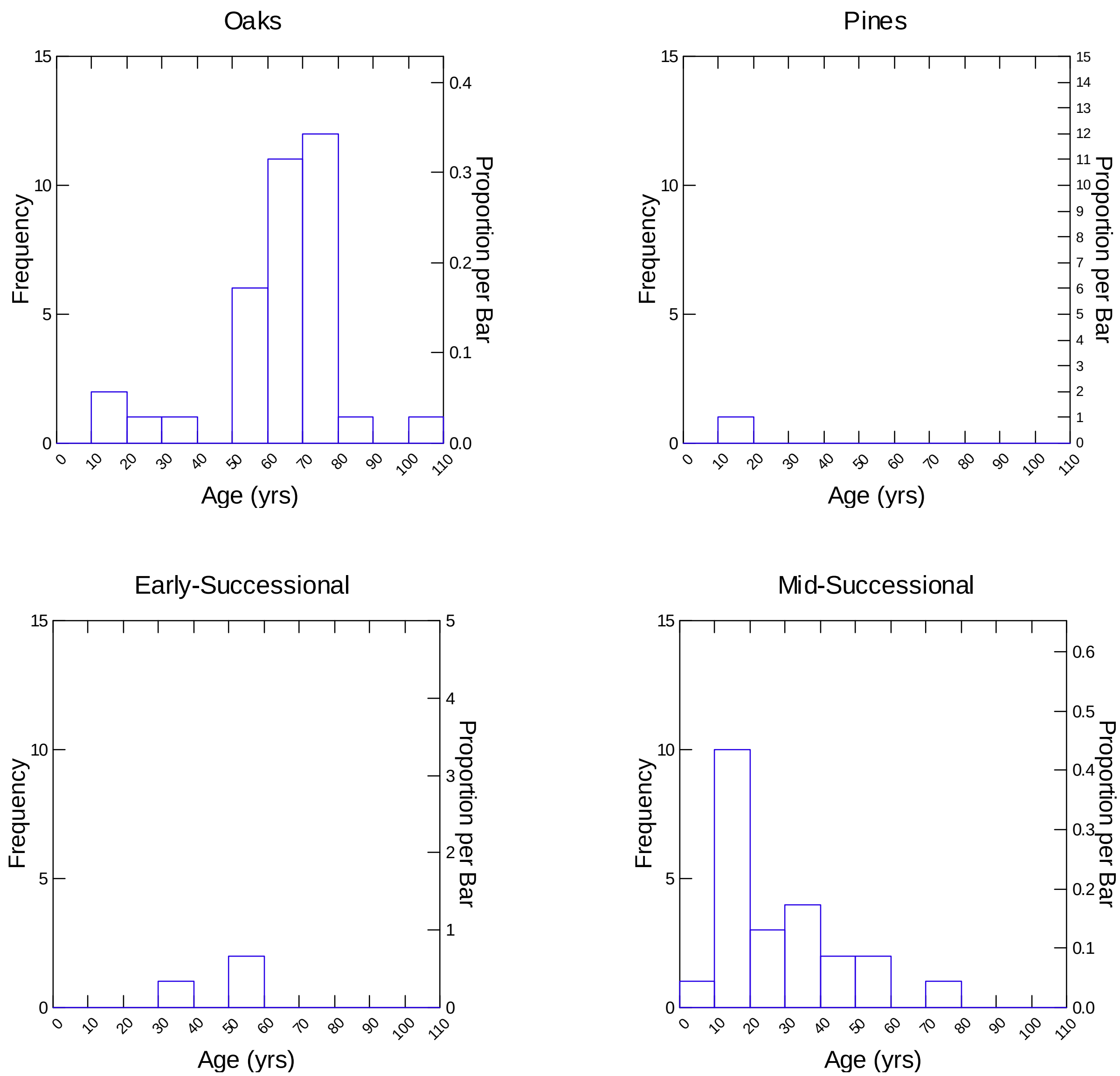
3 Stems of black oak and northern pin oak are aggregated due to difficulties with field identification between these closely related species.

4 Units are numbers per 4 m^2 plot for All Oak Species and Red Maple Seedlings/Saplings.

APPENDIX 10B

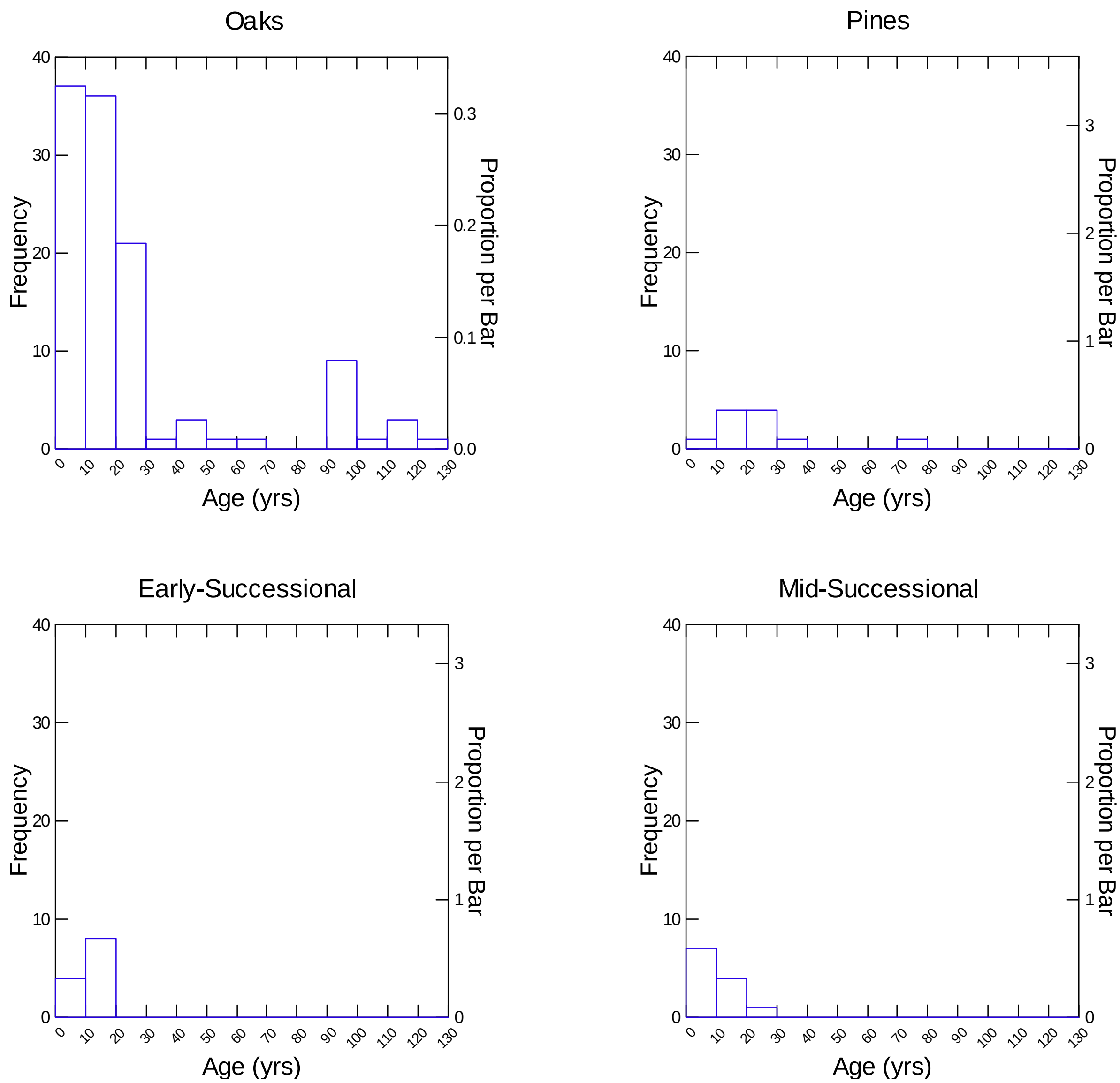
Age Class Distributions for Species Groups among Management Prescriptions: Selected Northern Outwash Sites

Aggregation of 20 Unmanaged Plots



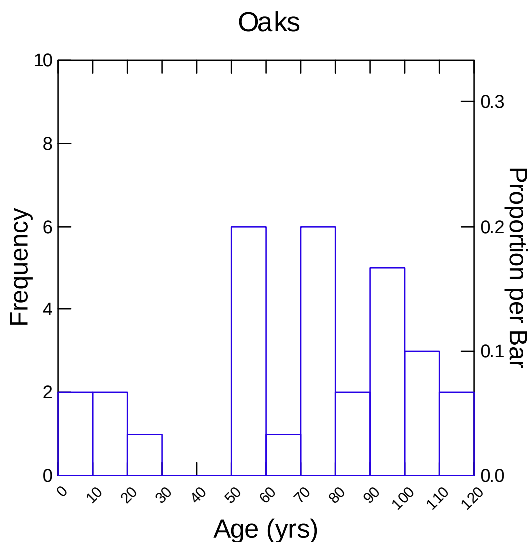
APPENDIX 10B. (continued).

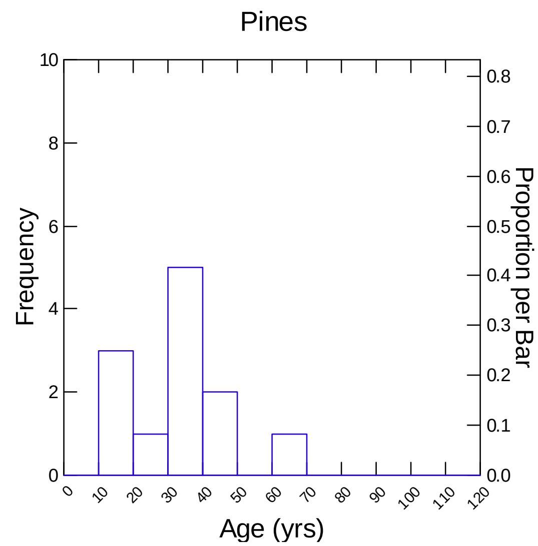
Aggregation of 49 Cut and Cut and Burned Plots

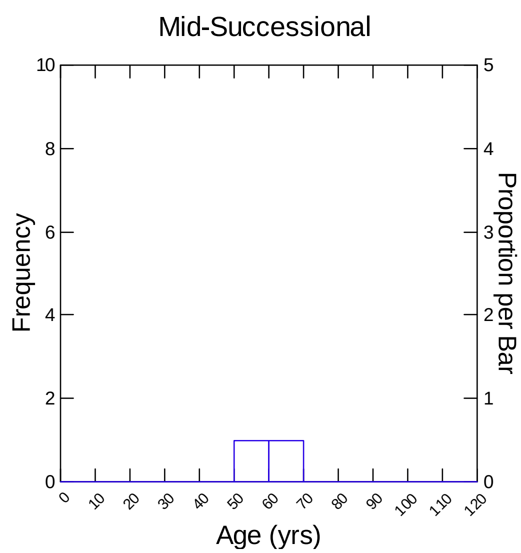


APPENDIX 10B. (continued).

<u>Aggregation of 10 Burned-Only Plots</u>





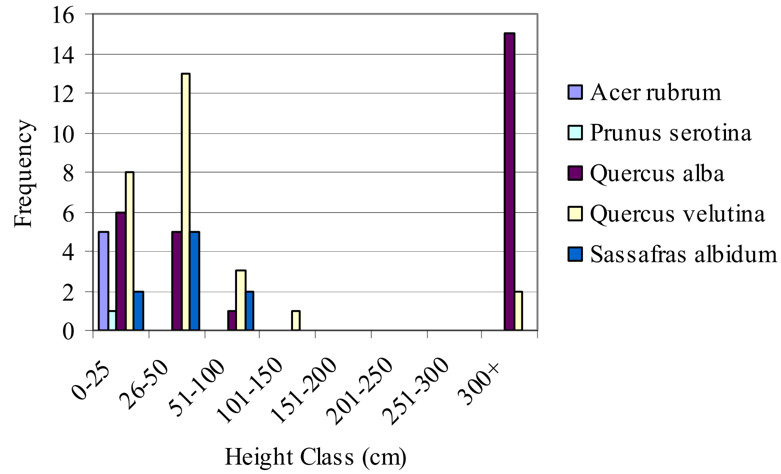


APPENDIX 10C

Height Class Distributions for Seedlings and Saplings of Selected Species among Management Prescriptions:
Case Study – Northern Outwash Sites

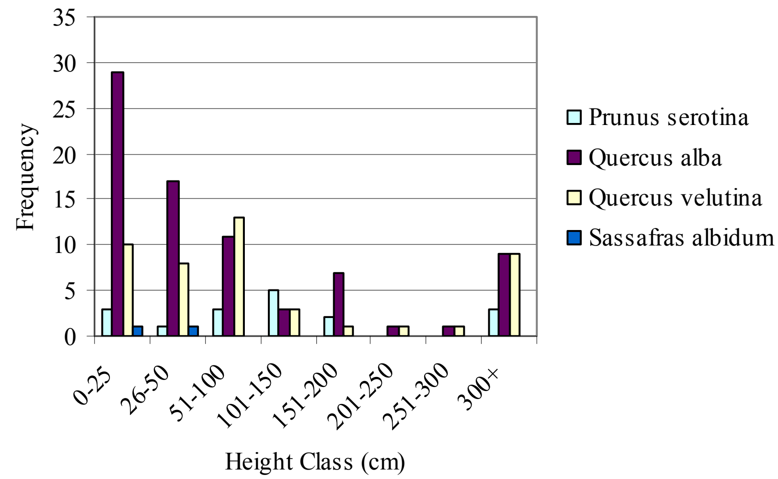
Aggregation of 10 Clearcut Plots

BRAD1B



Aggregation of 10 Shelterwood Plots

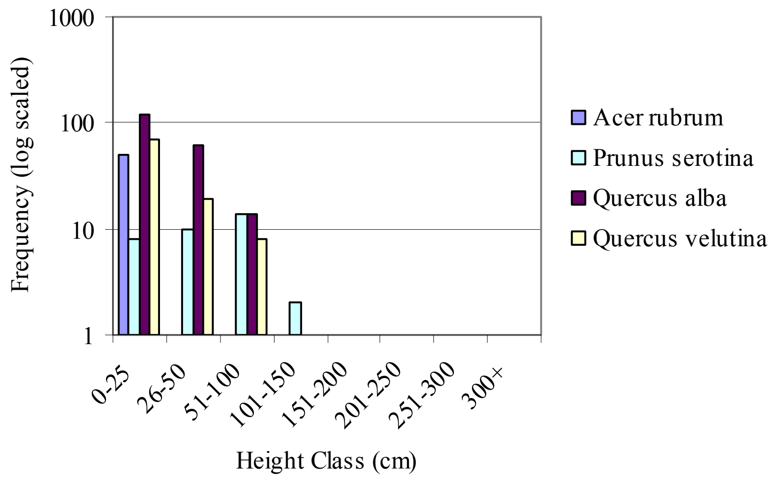
MAN9B



APPENDIX 10C. (continued).

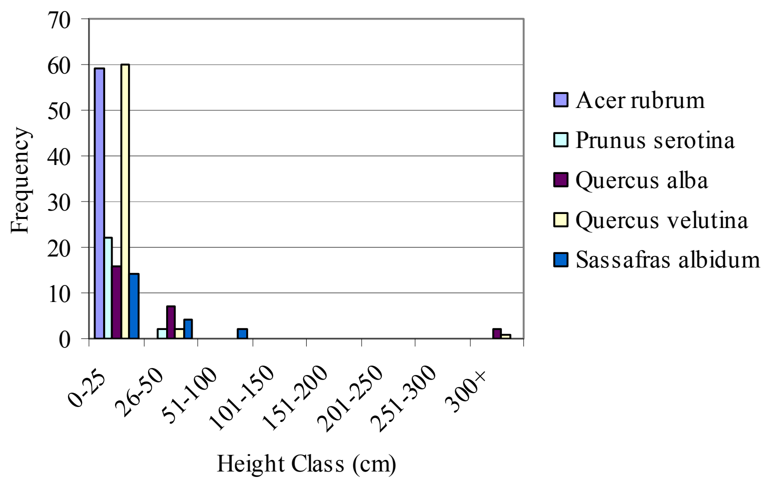
Aggregation of 10 Burned Plots

MAN1B



Aggregation of 10 Unmanaged Plots

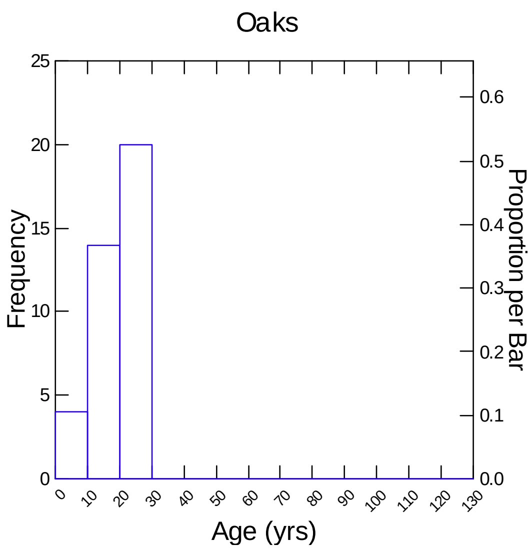
BRAD1

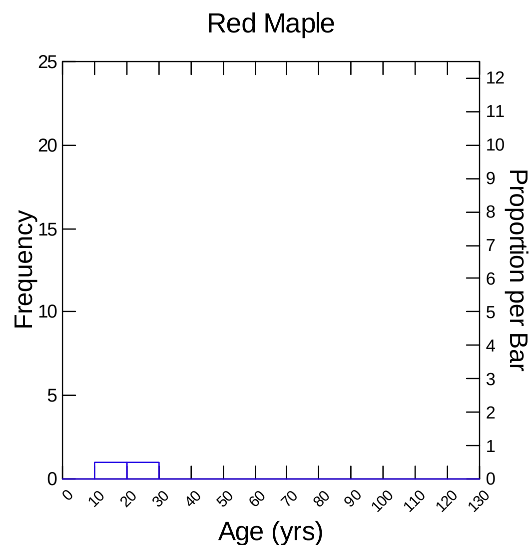


APPENDIX 10D

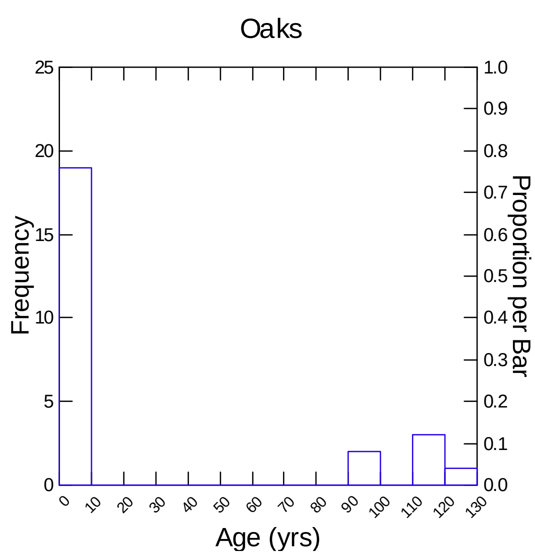
Age Class Distributions for Oak Species and Red Maple among Management Prescriptions: Case Study – Northern Outwash Sites

BRAD1B: Aggregation of 10 Clearcut Plots



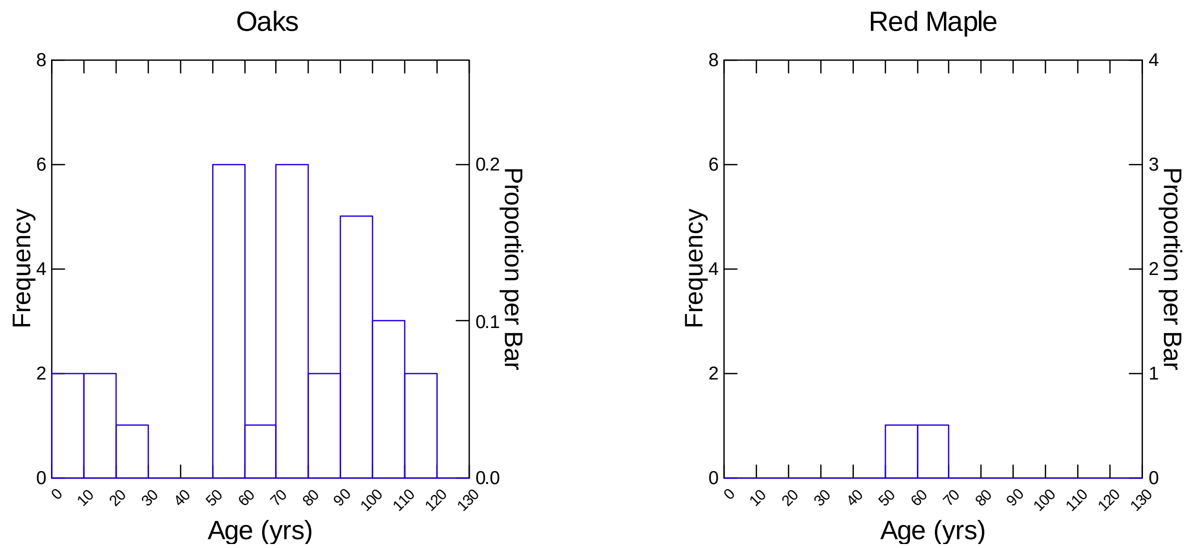


MAN9B: Aggregation of 10 Shelterwood Plots

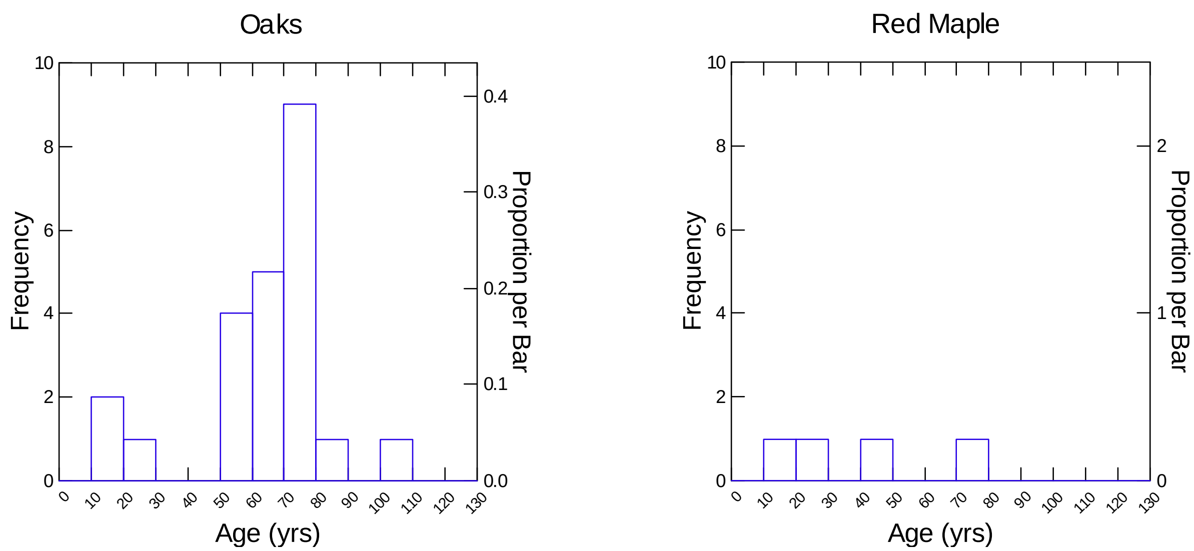


APPENDIX 10D. (continued).

<u>MAN1B: Aggregation of 10 Burned Plots</u>



<u>BRAD1: Aggregation of 10 Unmanaged Plots</u>



APPENDIX 11A

Comparison of Oak and Red Maple Regeneration (Understory Stem Density) and Seedling and Sapling Abundance among Management Prescriptions: Selected Northern Sand Lake Plain Sites[1, 2]

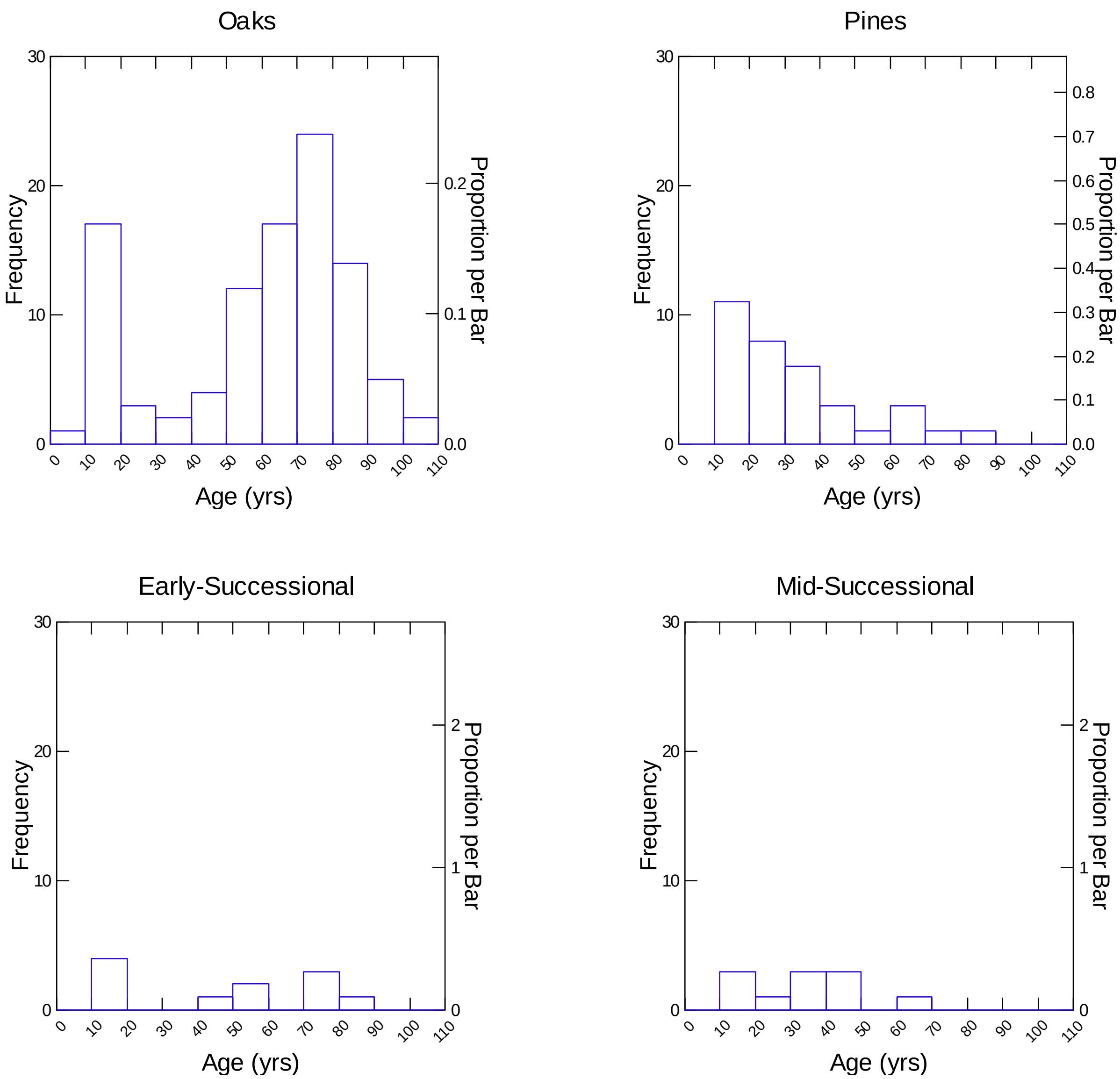
	Management Prescription			
	Unmanaged	Shelterwood	Clearcut	Cut and Burned
Understory Stem Density (stems ha^{-1})				
All Oak Species	155.00	20.00	820.00	320.00
White Oak	75.00	20.00	40.00	0.00
Black Oak-Northern Pin Oak[3]	80.00	0.00	780.00	320.00
Northern Red Oak	0.00	0.00	0.00	0.00
Red Maple	40.00	266.67	0.00	0.00
Seedling and Sapling Abundance[4]				
All Oak Species Seedlings	10.05	16.20	2.90	7.00
All Oak Species Saplings	0.25	0.20	0.10	0.00
Red Maple Seedlings	1.73	7.33	0.00	0.00
Red Maple Saplings	0.00	0.03	0.00	0.00

[1] For each variable, means are shown.
[2] For all variables: Unmanaged (n = 4), Shelterwood (n = 3), Clearcut (n = 1), Cut and Burned (n = 1).
[3] Stems of black oak and northern pin oak are aggregated due to difficulties with field identification between these closely related species.
[4] Units are numbers per 4 m^2 plot for All Oak Species and Red Maple Seedlings/Saplings.

APPENDIX 11B

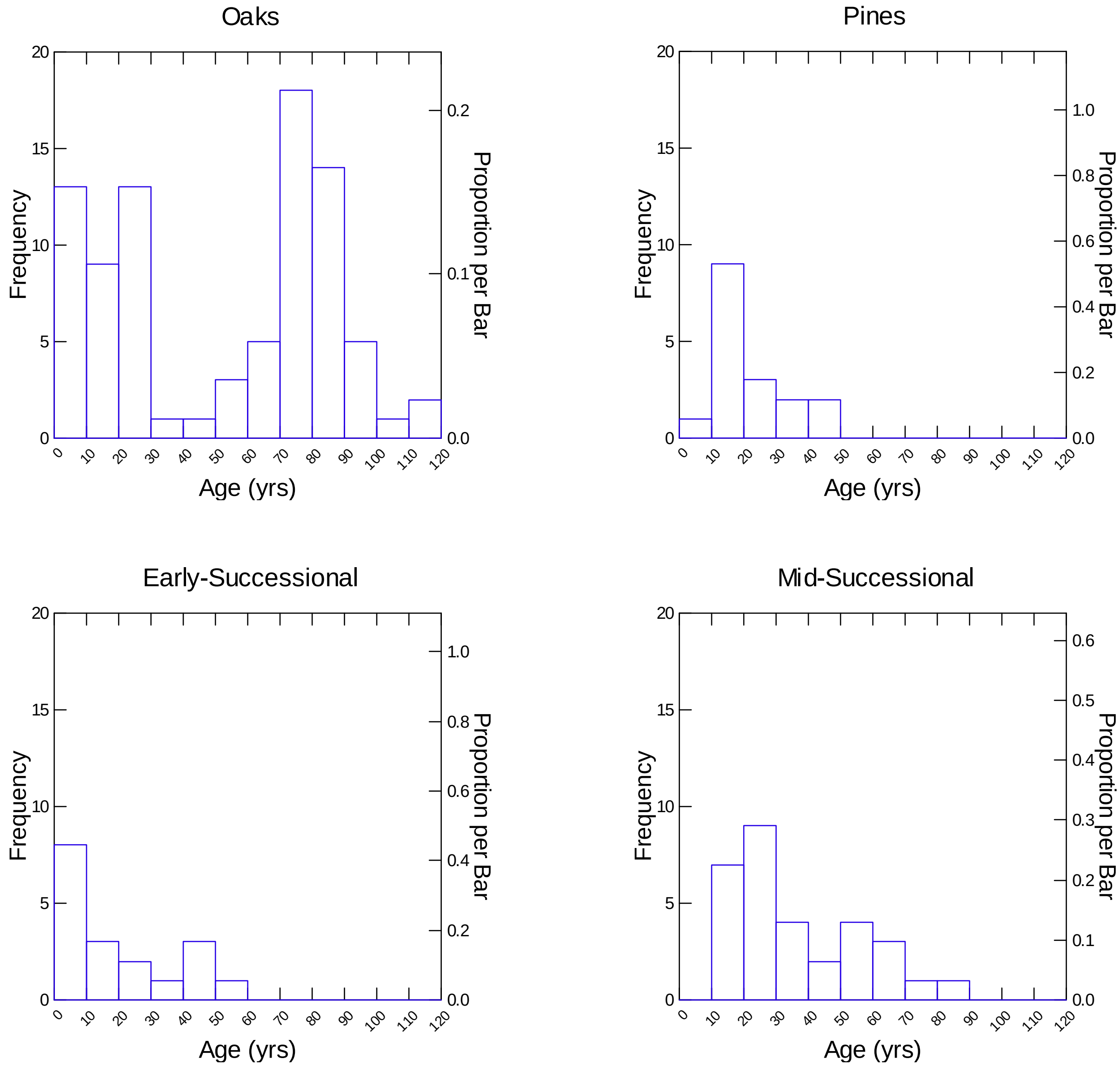
Age Class Distributions for Species Groups among Management Prescriptions: Selected Northern Sand Lake Plain Sites

<u>Aggregation of 40 Unmanaged Plots</u>



APPENDIX 11B. (continued).

<u>Aggregation of 50 Cut and Cut and Burned Plots</u>

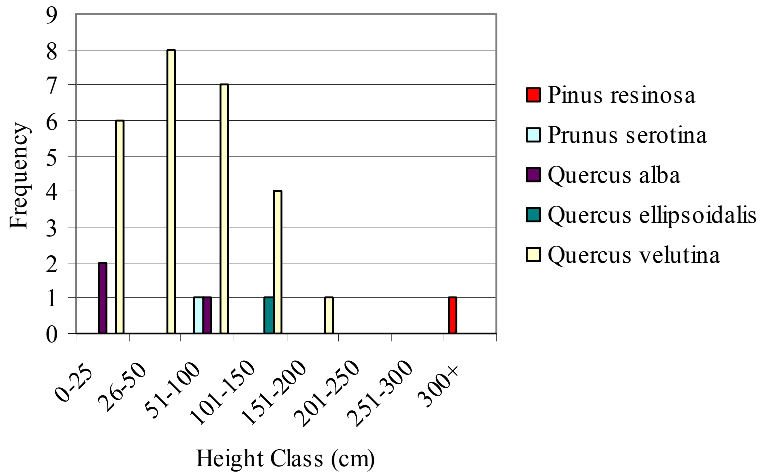


APPENDIX 11C

**Height Class Distributions for Seedlings and Saplings of Selected Species among Management Prescriptions:
Case Study – Northern Sand Lake Plain Sites**

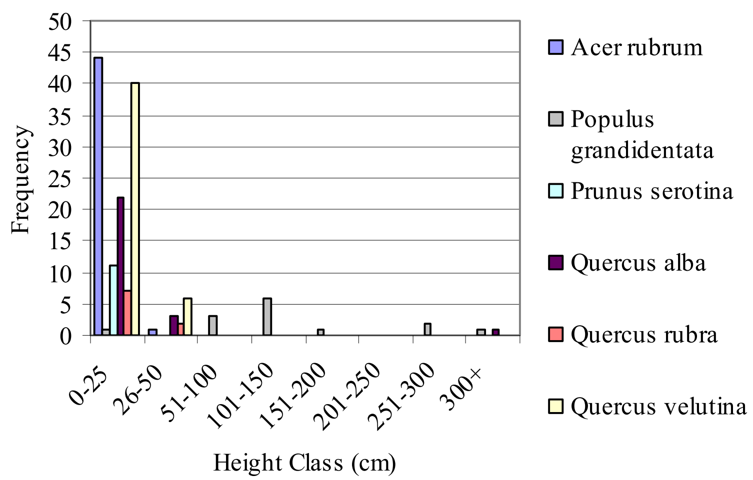
Aggregation of 10 Clearcut Plots

GLA1C



Aggregation of 10 Shelterwood Plots

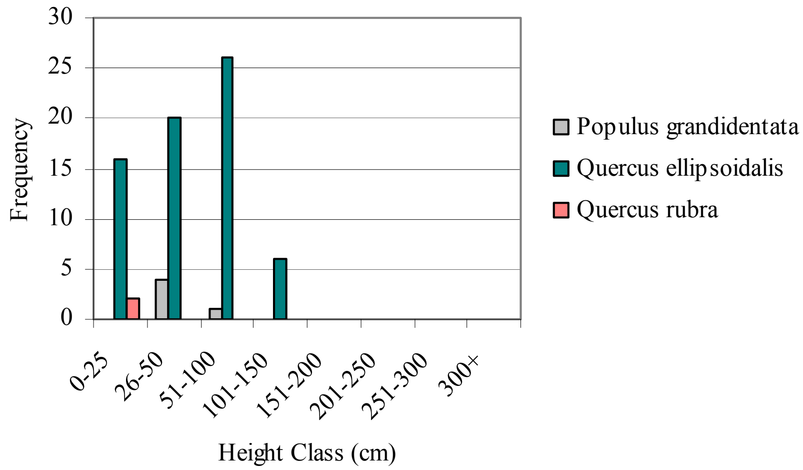
GLA3B



APPENDIX 11C. (continued).

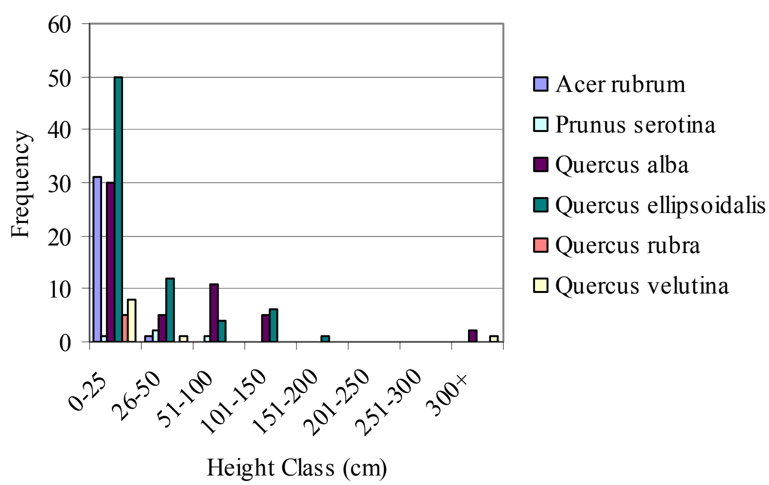
Aggregation of 10 Cut and Burned Plots

HUR3C



Aggregation of 10 Unmanaged Plots

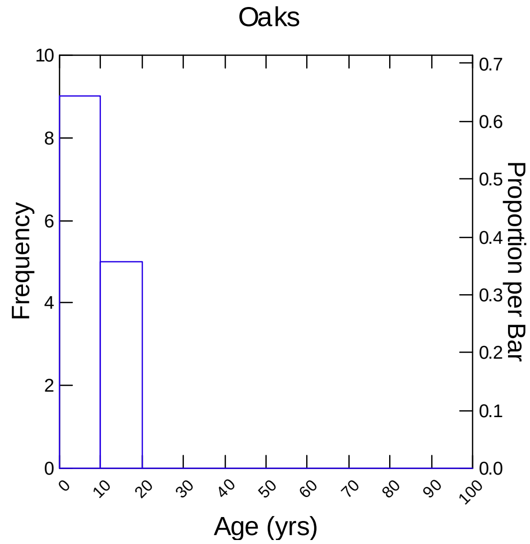
GLA8



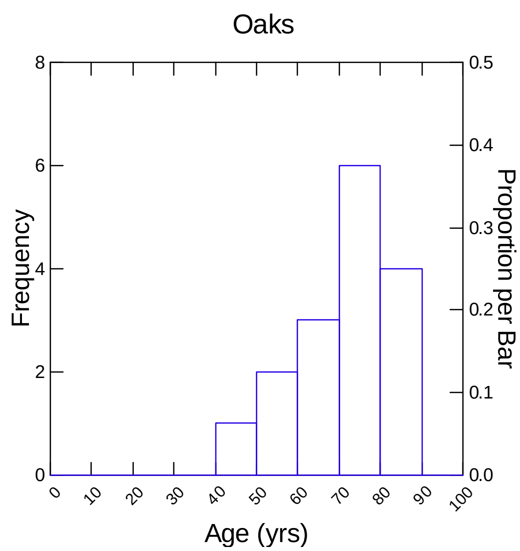
APPENDIX 11D

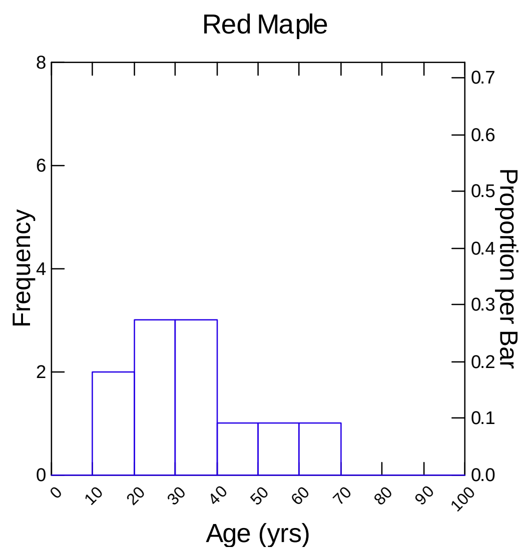
Age Class Distributions for Oak Species and Red Maple among Management Prescriptions: Case Study – Northern Sand Lake Plain Sites

GLA1C: Aggregation of 10 Clearcut Plots



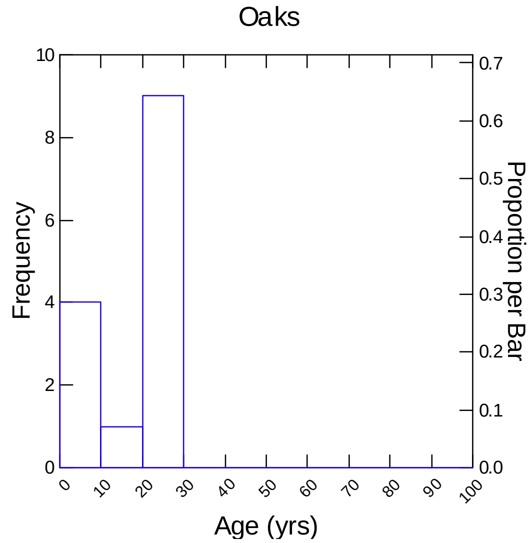
GLA3B: Aggregation of 10 Shelterwood Plots





APPENDIX 11D. (continued).

HUR3C: Aggregation of 10 Cut and Burned Plots



GLA8: Aggregation of 10 Unmanaged Plots