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by

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QUERCUS RUBRA L. REGENERATION FROM PRESCRIBED BURNS: AN IN-DEPTH LOOK INTO MANAGEMENT IN CANADIAN FORESTS, SPECIFICALLY ONTARIO

by

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A CAUTION TO THE READER

This HBScF thesis has been through a semi-formal process of review and comment by at least two faculty members. It is made available for loan by the Faculty of Natural Resources Management for the purpose of advancing the practice of professional and scientific forestry.

The reader should be aware that opinions and conclusions expressed in this document are those of the student and do not necessarily reflect the opinions of the thesis supervisor, the faculty or Lakehead University.

MAJOR ADVISOR COMMENTS

ABSTRACT

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This paper explores the impact that prescribed fires have on red oak (*Quercus rubra* L.) regeneration in Canada and Ontario. Prescribed fires are important to consider the best management techniques that should be used in oak-dominated stands. To increase the success of prescribed burns the oak regeneration should be monitored and additional methods such as thinning, competition control and shelterwood harvesting should be used. Therefore, prescribed burns will have an affect on oak-dominated stands and how they are managed. Prescribed burns should be used when possible to naturally regenerate oak species and increase the fire cycle in areas that it was historically present.

CONTENTS

TABLES

FIGURES

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INTRODUCTION

Oak regeneration from prescribed fires is important to consider the best management techniques that should be used in oak-dominated stands. Proper management techniques are important in high value stands such as oak because of the need for high-quality stock that will provide a profit when selection cut. This thesis will take an in-depth look at the history of oak, the biology of oak, and the processes of oak regeneration. The focus will be on oak regeneration as a result of fires in Canada, with a special focus on Ontario, refer to Figure 1. The research conducted on oak regeneration will be through a compilation of various academic articles.

Figure 1. Map of Canada, Ontario is illustrated in dark blue (Government of Canada 2016).

OBJECTIVE

To determine the impact that fire has on the physical and chemical environment that oak is regenerating and how this affects the characteristics of oak as it matures. I plan to determine this through extensive research into oak management in Canada. Academic articles will be consulted for my thesis.

NULL HYPOTHESIS

Prescribed burns will have no effect on oak-dominated stands and how they are managed.

ALTERNATIVE HYPOTHESIS

Prescribed burns will have an effect on oak-dominated stands and how they are managed.

LITERATURE REVIEW

Oak (*Quercus* L.) is a deciduous hardwood tree species that is native to North America and is a beneficial species to forest ecology, human consumption and visual appeal (Farrar 1995). Oaks have been a dominate tree species in North American forests as a result of anthropogenic influences to the fire cycle and species composition. It is important to consider the events leading to its' current status to make appropriate management decisions.

PRESCRIBED BURN

Prescribed burns to regenerate oak species date back hundreds of years when the Aboriginal Peoples of North America utilized fire to clear patches of land for agricultural purposes (Davies 1994). In this sense, the Aboriginal Peoples were able to grow their desired foods and be self-sustaining. Oak trees were one of those species that was selected for agricultural purposes. Since oak trees are a mast tree, they supply large quantities of nuts seasonally that are a food source for animals and people (Davies 1994). This past manipulation of fire can be studied through palioecological history of fossilized pollen, charcoal and fire scars (Spencer et al. 2017). When the Europeans arrived, they adopted this practice after witnessing the efficiency and effectiveness of fire in clearing land (Dey and Guyette 2000). Suppression of fires began in the 1920s when fire was viewed as a destructive and detrimental to humans (Dey and Guyette 2000). The large quantities of oak species in southern Ontario are as a result of the frequently prescribed fires that occurred before 1920. The newly suppressed fire regime is not allowing oak to regenerate at the same levels as it used to be common. Humans are still having an impact on the present species by indirectly selecting for shade tolerant species that can survive in the understory until a gap dynamic occurs (Dey and Guyette 2000).

The shift from prescribed burning to suppression has selected for red maple (*Acer rubrum* L.) and away from oak species according to Hutchinson et al. (2008). This study looks at the fire record, specifically fire scars to determine the regeneration success of oak and maple after the cessation of the wildfire. The records suggested that immediately following the fires both oak and red maple sprouted in an attempt to regenerate after being top-killed. Sprouts are a type of vegetative regeneration that occurs on certain hardwood species when stressed; developing on young stumps or even seedlings as young as one year (Farrar 1995). The frequency of sprouting depends on several factors, including a decrease in sprouting when the diameter of the tree increases as well as a decrease if the site is ideal for oak species (Johnson et al. 2002). The increase in red maple after the cessation of fires is largely attributed to oak species being out-competed by the red maple. Hutchinson et al. (2008) state that although repeated fire was crucial for the regeneration of oak in the past, that in our current forests prescribed burns are no longer enough to allow for the establishment of oak species. This is due to the high volume of maple trees they are now fire resistant and additional methods would need to be applied to allow for the establishment of oak. It is suggested for a well-timed repeated prescribed burn cycle with the addition of harvesting methods such as selective harvesting to thin the competing maple trees.

Dey and Guyette (2000) agree with this statement, finding that frequent short fire intervals are beneficial to oak because this allows for the establishment of oak seedlings, specifically *Quercus rubra* L. in south-central Ontario. With the presence of fire in the regime, oak does not have to compete as much with other species for limited resources such as light and nutrients. Dey and Guyette (2000) go on to say that oak is well adapted to frequent fire regimes because they have thick bark that protects their cambium from fire; their ability to vegetatively reproduce if fire has damaged their shoot, and the quantity of well insulated dormant buds that protects them from fire. These factors allow for a high reproduction of oak after a fire as well as resilience to fire.

Abrams (2010) agrees with Dey and Guyette that fire suppression, or the 'Smoky Bear era' as he terms it is the primary cause of decreases in oak populations in their once abundant habitat. Abrams (2010) goes on to say that this shift in the fire frequency has shifted the ecosystem from tall grasses, hickory, and oak savanna to an increased level of shrubs and closed canopy systems. The closed canopy does not allow for a lot of the light to reach the understory and does not encourage oak growth and regeneration.

A study conducted by Hutchinson et al. (2005) looked at how repeated prescribed burns affected the structure, composition and regeneration of oak mixed wood forests. The study sites included a control or unburned area, a forest burned twice and a forest burned four times. It was found that the highest intensity of fire was on the forest with two prescribed burns occurring and this area had a reduction of 31% on small trees ranging in diameter at breast height (DBH) 10-25cm. In contrast, it was found that the study site with four prescribed burns there was a mortality rate of 19% for small trees. In both study sites, there was no noticeable impact on large trees greater than 25cm DBH. Despite the reduction in small trees, since large trees are still present in the stand there were no significant canopy gaps, and therefore oaks were not exposed to a greater quantity of light. Hutchinson et al. (2005) suggested that since there were limited results with just the repeated prescribed burns it would probably be beneficial to also implement partial harvesting to allow for more light to enter the under-story. Further studies were also recommended to see how repeated prescribed burns with natural gap dynamics affect the stand over time and if this would increase in oak species success.

REGENERATION

Oak regeneration is predominately a result of fire either as a prescribed burn or a wildfire; vegetative reproduction; and the planting of seedlings by people, typically referred to as treeplanters. Regeneration from fire results from frequent fires that decrease competition and create ideal conditions for oak establishment and growth.

A study conducted by Wilson et al. (2007) looked at the success of container and bare-root seedling stock of red oak in Ontario. Container stock is stock that was grown in a container and has a soil pod around the roots that provides an element of protection while handling as well as providing nutrients to the seedling. Bare-root stock is seedlings that are not protected by soil and therefore caution needs to be exerted while planting to decrease the amount of damage to the root system. The results of their study concluded that the container stock had better success with establishing and showing an increase in their growth. There was zero mortality in the container stock when accessed after the first growing season and there was a 25% mortality rate for the bare-root stock after the initial growing season, they also showed little to no additional growth. It is suggested to see the effect of future stock improvements has on the success of various stock types.

Dillaway et al. (2007) analyzed the advance regeneration of oak species in the understory. They studied the effect of light in mid and under story undisturbed forest conditions on root and shoot development of oaks. Dillaway et al. (2007) specifically studied white oak (*Quercus alba* L.), and they found that there was an increase in growth of this species when there was an increase to light exposure. When the mid-story was thinned, it allowed for more vigor in both root and basal diameter, seedling height, quantity of carbohydrates, and overall mass. These were all shown to increase mildly for not only mid-story thinning but also in the occurrence of a clear-cut in initial data collection. However, greater increases were shown to occur when data was collected one year after the initial readings. Non-structural carbohydrates were greatest for oak regenerating after the occurrence of a clearcut, for the mid-story thinning the results were intermediate and for the control of a closed canopy there showed low to no improvements (Dillaway et al. 2007). Therefore, it is suggested that for management of oak that clear-cutting is optimal however, any degree of thinning in upper canopies can be a less aggressive but still successful method to increase survival and growth of oak species.

MANAGEMENT OF OAK SPECIES

The management of oak has historically taken different forms, as supported by the literature. Oak species are typically managed in selection cuts because of their high economic value.

Brose and Van Lear (1998) did a study similar to those suggested by Hutchinson et al. in their 2005 study regarding looking at the combination of prescribed burns with forest management techniques. Seasonal prescribed fires in oak-dominated shelterwood systems were studied. The three study sites analyzed were divided into a control, a spring burn, a summer burn and a winter burn using shelterwood harvesting techniques. It was found that the spring and summer had a greater mortality rate than in winter burns. Brose and Van Lear (1998) also found that the majority of all regeneration was top killed in the fires and sprouted as a result. The most vigorous sprouts occurred on the oak and hickory (*Carya* spp. Nutt.) with red maple not as successful at sprouting as the frequency of fires increases. It was also determined that with the higher quantity of fires the better stem form and stimulated height growth was observed on oak. Therefore, the literature suggests that, shelterwood harvesting with prescribed burns is a good way to manage oak stands and promote regeneration. The regeneration for two seasons can be viewed in Table 1 below.

Table 1. Adjusted declines in stem density and changes in height growth (mean + SE) for two growing seasons (GS) after seasonal prescribed fires in shelterwood stands (Brose and Van Lear 1998).

		Height growth	
Treatment	Density (stems/ha)	First GS (cm/year)	Second GS (cm/year)
	Hickory		
Control	76±8*e*	19±3*f*	18±5*d*
Winter burn	643±55*d*	52±3*d*	61±4*a*
Spring burn	662±50*d*	39±3*e*	58±4*a*
Summer burn	1105±62*c*	31±5*e*	31±5*c*
	Oak		
Control	79±7*e*	17±2*f*	22±2*d*
Winter burn	531±48*d*	71±4*c*	48±3*b*
Spring burn	543±64*d*	57±3*d*	40±3*c*
Summer burn	1124±78*c*	40±5*e*	36±3*c*
	Red maple		
Control	82±6*e*	34±4*e*	44±4*b*
Winter burn	541±71*d*	140±14*a*	43±4*b*
Spring burn	1425±181*c*	94±9*b*	44±6*b*
Summer burn	1475±158*c*	60±5*c*	30±4*c*
	Yellow-poplar		
Control	70±8*e*	40±5*e*	50±3*b*
Winter burn	2801±197*b*	137±12*a*	47±6*b*
Spring burn	4169±335*a*	101±17*b*	48±9*b*
Summer burn	4231±387*a*	51±9*de*	32±4*c*

Source: Can. J. For. Res.

Another study analyzed oak regeneration with the addition of sunlight to the understory using the shelterwood harvesting method found similar results (Brose 2011). Brose (2011) suggests using shelterwood to open portions of the canopy while also using herbicides or prescribed burns to control competing vegetation.

In comparison, Laliberte et al. (2016) studied the impact selection harvests had on red oak and how this impacts their harvesting cycle. A study was conducted on numerous northern Canadian hardwood stands evaluated low vigour harvesting on these stands and its effects on red oak. It was found that red oak showed a decrease in vigour with an increase in DBH. When oak trees surpass a DBH of 34-46 cm they should be marked and subsequently harvested to ensure that the quality of the wood is not lost in later years (Laliberte et al. 2016). For trees that fall below this DBH stems that should remain to include those that have a high grade of stem structure. Also trees should be monitored for growth as well as regeneration.

In a study conducted by Raymond et al. (2003) to assess a mixed wood forest containing eastern white pine (*Pinus strobus* L.), red oak, yellow birch (*Betula alleghaniensis* Britton) and paper birch (*Betula papyrifera* Marsh.) for response to harvesting methods single and group selection. The results found that the scarification had a negative impact on red oak. It was found in the study that the scarification methods killed previously established oak that was in advance regeneration. Sander (1990) suggests that the best red oak germination success occurs when the acorns are either buried in or in contact with mineral soil. It is likely that to have success with oak regeneration, oak must be either the primary or only species that is being managed for in the stand.

RELEVANCE

I am interested in conducting a literature review on the success of oak regeneration from prescribed burns in Canada, specifically Ontario because it is an opportunity to determine potential management techniques that could increase the survival of seedling in Ontario forests. Fires has been suppressed until recently in Ontario and has resulted in an increase of the intervals between fires. Therefore, it will be interesting to see the effect that reintroducing fire, as prescribed burns will have on the regeneration of oak. This is especially relevant when consulting the literature on the conversion from oak savannas to maple forests in Southern Ontario. Prescribed fire will allow light exposure to enter the canopy and regenerate oak species if conducted regularly. I am interested to see if this does allow for appropriate regeneration of oak and conversion to oak savanna or if and what additional methods are required to reach the desired result.

METHODS AND MATERIALS

Literature collected related to the use of prescribed burning on *Quercus rubra* L. stands and the effect this has on their regeneration in Ontario. The information collected will relate to the effects on the environment after a prescribed burn is conducted and the quantity of oak sprouting occurring or new oak seedlings. This data will allow for the interpretation of the success of prescribed burning in relation to increases in the oak population in the area that the burn was conducted.

Other data that can be gathered include competition within the stand, the presence of other site preparation (scarification) and if control measures are going to be used after the prescribed burn.

RESULTS

ONTARIO'S FOREST REGIONS

Ontario has four main forest regions which are the Hudson Bay Lowlands, the boreal forest, the Great Lakes-St. Lawrence forest, and the deciduous forest (Government of Ontario 2015). A forest region is defined as a major geographic belt or zone that is characterized by a broad uniformity in the composition of broad tree species and physiography (Bourchier and Stanton 2015). Ontario has diverse forest regions because of the variation in climate and temperature between northern and southern Ontario. This variation allows for a large selection of species and diversity in plants and animals native to each region.

Oak is present in the hardwood-dominated forest regions Great Lakes-St. Lawrence forest, and the deciduous forest (Government of Ontario 2015). Oak pollen has been commonly found in this location. However, oak pollen can disperse long distances by wind, and this dispersal infrequently produces the growth of a tree in this region (Farley-Gill 1980). Red oak is also present in the boreal forest but not abundantly.

Oak is a dominate tree species in multiple forest regions in Ontario. Therefore, the management and continued presence of oak are important to maintain the success, biodiversity and economic income associated with oak in these regions.

ANTHROPOGENIC FIRE HISTORY IN ONTARIO

The historical fire cycle is important to compare against the current cycle to determine differences in these cycles and why they have changed. A burn suppression has decreased the historic fire cycle and affected the present composition of tree species in their native habitats (Ward et al. 2001).

Ontario is divided into multiple fire management zones to assess suppression strategies, and the role of fire in different sections of Ontario dependent on social, economic and environmental considerations. A paper by Ward et al. (2001) examines the effects of fire suppression in the boreal forest of Ontario. There are three intensities for fire management in Ontario, these intensities can be viewed by referring below to Figure 2. The extensive fire management zone is a disturbance regime similar to pre-suppression, and the fire follows a let-burn cycle unless communities are at risk as a result of the fire (Ward et al. 2001). The intensive management zone is in central Ontario and commercial timber areas. The intension of this zone is to detect the fire before it reaches a substantial size and the fire is extinguished to reduce the economic losses to urban areas and the forestry industry (Ward et al. 2001). The measured management zone follows between the two previous zones; detection of fire is used however if initial suppression is not successful then the fire is reassessed and may be allowed to burn until the fire is extinguished naturally (Ward et al. 2001).

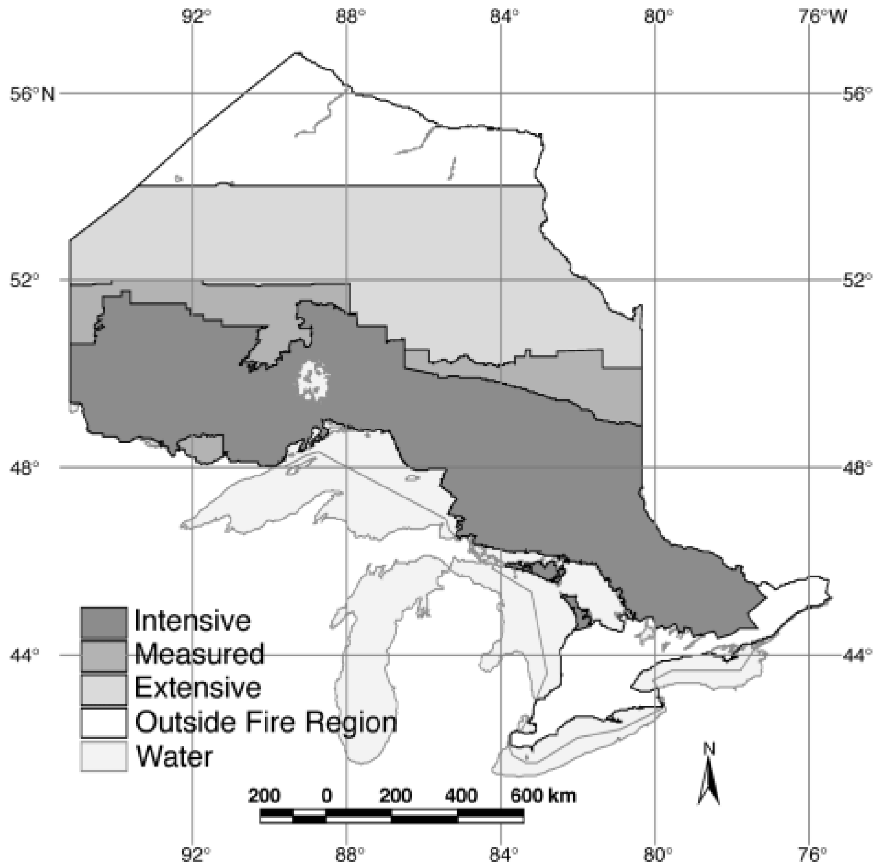

Figure 2. Fire management zones in Ontario (Ward et al. 2001).

The management and suppression of certain fires have caused a reduction of large fires, as the small-scale fires are extinguished, this decreases the average annual area burned in the intensive and measured management zones (Ward et al. 2001). Within the last 200 years, fire has been influenced by suppression, fragmentation, past and present forest disturbances, and the changing climate (Ward et al. 2001). The effect that suppression has had on areas burned can be viewed in Table 2.

Table 2. Comparison of pre-suppression and current fire regime for the intensive and measured fire management zones in Ontario (1976-2000 data) (Ward et al. 2001).

	Estimated pre-suppression era	Current era (1976-2000)
Total area (ha)	49 280 000	49 280 000
Fire return interval (years)	65	604
Mean area burned annually (ha)	739 200	81 544
Mean annual burned fraction	1.5%	0.166%

PRESCRIBED BURNING IN PARKS

The presence of fire is increasing in Ontario's Provincial Parks. In these cases, the prescribed burns serve two purposes the primary to regenerate the stand and open the understory and the second being public education to the use of fire in management. Examples of this include Quetico Provincial Park, Iroquois Shoreline Woods Park, Wasaga Beach and the urban settings of High Park and Lambton Park in Toronto.

The use of prescribed burns in Ontario Provincial Parks comply with numerous provincial requirements including the Forest Fire Management Strategy (OMNRa 2004) for Ontario which provides direction to the management of fire on Crown and private land; and the Forest Fire Management Policy (OMNRb 2004). The purposes of these were to prevent injury and property loss as well as be used as an educational tool for the role fire plays in the ecosystem and the benefits associated with fire. Parks are further managed with a Fire Management Policy for Provincial Parks and Conservation Reserves (OMNRc 2004) and a Class Environmental Assessment for Provincial Parks and Conservation Reserves (OMNRd 2004).

Scoular (2008) conducted a study on the fire frequency in Quetico Provincial Park and the spatial and temporal variability of stand-replacing fires. This study found that the stand-replacing fire occurred in the late 1800s to early 1900s and the park uses a 100-year fire cycle in their management (Scoular 2008).

The use of prescribed burns in provincial parks is also being used to regenerate red oak. Two provincial parks that are using this method to regenerate oak species, including red oak is Wasaga Beach and Iroquois Shoreline Woods Park. The prescribed burn held at Wasaga Beach is being conducted to restore red oak woodlands and savannah habitat (Wasaga Sun 2012). Likewise, Iroquois Shoreline Woods Park conducted a prescribed burn after the recent decline of red and white oaks (Williams et al. 2013). The park conducts frequent prescribed burns along with oak management and regeneration to improve the health of the trees and decrease risk to the public associated with oak decline (Williams et al. 2013). Following the prescribed burns, a shelterwood treatment is to be implemented, and when natural regeneration is not successful, the park is going to plant oak seedlings that have been grown in nurseries and greenhouses from acorns collected onsite (Williams et al. 2013).

High Park in Toronto also implemented prescribed fires to regenerate their black oak savannah, red oak is also present in this park (Ubbens 2000). The frequent burning of this park began after a study was conducted that concluded that the park had reduced in size when the surrounding facilities were built up (Ubbens 2000). The burns are conducted to reduce the buildup of dead material and open the soil to increase the success of oak regeneration.

These opportunities allow the public to learn about the benefits of fire in a familiar setting. The parks provided numerous newspaper articles prior to the prescribed burns to bring awareness to the public and educate the public to the benefits of these fires.

EFFECT OF CHANGING TEMPERATURES ON OAK FORESTS

With the increasing temperatures, it is important to access the impact that climate change and global warming will have on various species, including red oak. An understanding of historical fire regimes allows for an idea of how they are currently changing or will be changing as a result of global warming (Ter-Mikaelian et al. 2009). The increased temperatures in North America, in particular, the northwestern Ontario boreal forest and how fire has been influenced within the last thirty to forty years (Scoular 2008). It is important to factor in climate change to determine sites that red oak would be successful and the frequency that prescribed burns can be utilized.

A study was conducted looking at the radial growth of white and red oak to climatic responses at their northern limit (Tardif et al. 2006). The purpose of this study was to determine the growth and distribution of these oak species and use this data to estimate the effects of climate change on species distribution (Tardif et al. 2006). The relationship between climate and growth was determined by collecting data on tree-ring measurements and analyzing the growth between the rings for each species (Tardif et al. 2006). The study found that the radial growth data for each species when compared had similar ring width, despite white oak being at its northern distribution limit (Tardif et al.

2006). However, Tardif et al. (2006) did suggest that stands growing in southern aspects may have a higher likelihood to experience wildfires and droughts. Tardif et al. (2006) suggested that further studies could be conducted looking at dendroecological and ecophysiological factors that could provide useful information pertaining to the impact climate has on tree species distributions.

A similar study was conducted by LeBlanc and Terrell (2011) on the climate and growth relationship between white and red oak. LeBlanc and Terrell (2011) study evaluated tree-ring and climate data that was collected at a total of 81 sites, 51 of these sites which had both species present. The study showed that the strongest climate growth associations occur when the tree rings are forming in the early growing season of May through July. LeBlanc and Terrell (2011) suggested that this study allows for guidance in selecting climate variables that strongly relate to radial growth within species; however, in terms of determining tree mortality based on climate influenced radial growth is more species-specific.

The effect of climate on the forest structure and biodiversity is further looked at in a study by Tremblay et al. (2018) which looked at the interaction between harvest and climate change and how this will affect the future habitat quality for focal species in eastern Canada's boreal forest. The study used a forest landscape model stimulator, LANDIS-II to see the effects that different harvest intensities and climate would have on the landscape (Tremblay et al. 2018). The study suggests that strong climate-induced changes could occur in temperate deciduous species such as maple, red oak, and beech (Tremblay et al. 2018). The study suggested that with the increase in temperatures there would be a higher quantity of fire activity promoting the regeneration of deciduous stands (Tremblay et al. 2018). In areas that are not mainly hardwood species than management measures should be conducted to minimize the impact, this climate shift will have on the species and harvest (Tremblay et al. 2018).

Trugman et al. (2016) looked at the impacts of climate on forest composition when conducting a study on climate, soil organic layer and nitrogen in the North American boreal zone following a fire. The study uses the ED2 model to simulate the effect on forests after a fire disturbance and analyze tree recruitment, forest growth and impact to soil levels (Trugman et al. 2016). With the increased fire intensity in the boreal forest, the mean organic layer depth is likely to decrease in Ontario, and will result in the increased survival of aspen seedlings and a lower mean forest age (Trugman et al. 2016). Additional shifts will occur in the Ontario Clay Belt in scenarios up to 2100; a warmer climate will make low severity fires common which will generate stands that have low probability of burning at high severity due to thick organic soil layers (Trugman et al. 2016).

UNDERSTORY

The understory is an important consideration in oak regeneration because the level of light at this stage determines the success of the seedling. Prescribed burns are a useful method to decrease coarse woody debris and competition and allow for an optimal location for oak seedlings.

A study conducted by Dech et al. (2008) evaluated the response to the understory and natural regeneration of red oak following three different partial harvest treatments. The study analyzed how red oak is being out-competed by shade-tolerant competitors and what the competition and regeneration rate was for each treatment in the Great Lakes-St. Lawrence region. The study was conducted two years post-harvest and collected data for 70% and 50% crown closure uniform shelterwood, uncut upper and lower slope and group selection sites (Dech et al. 2008). Each plot was 2m x 2m and measured the height of the seedling, density, mean diameter for red oak, red maple, and sugar maple in the understory (height <1m) (Dech et al. 2008). The study found that both species of maple, reached high cover in all the treatments evaluated; in addition to competition from maple there was a high density of grass (*Carex*) species present in the 50% crown closure uniform shelterwood treatment sites (Dech et al. 2008). Dech et al. (2008) suggested that these increased light levels are of no benefit to red oak if there is a likelihood of advanced regeneration of other species and abundant shrub cover.

Seed banks in the deciduous forest are typically dominated by grass species that are fast growing and have high levels of colonization success (Dech et al. 2008). Therefore, when managing the regeneration of oak, it is important to consider the differences in competition between shade-tolerant environments and increased sun exposure in order to manage for both.

IMPACT ON SEEDBANK

The seedbank is important for the natural regeneration of oak after the occurrence of fires because it supplies a combination of seeds and vegetative sources that can establish (Lee 2004). Therefore, it is critical to determine the impact that prescribed burns have on the seedbank and how these impacts will affect the regeneration of oak.

A study was conducted by Lee (2004) on the impact that burn intensity has on vegetative and seed banks and emergent understory. Data that was collected for the study included propagule banks immediately after the fire, and the understory was surveyed two years after the fire’s occurrence (Lee 2004). The emergence of seedlings and shoots indicted the abundance and diversity within the seedbank (Lee 2004). After the fires the seed and vegetative banks were assessed for three options, unburned, lightly burned and intensely burned (Lee 2004). Significant differences were present between the burn intensities and emergent vegetation, and between vegetative banks unburned and burned patches (Lee 2004). Lee (2004) conducted this study on an aspen-dominated stand, however, this study can be applied to oak regeneration to understand the fire intensity that will allow for natural regeneration. If the intensity exceeds to an intensely burned seed bank, then additional methods including the planting of seedlings may be required to regenerate the stand.

ROLE OF FIRE

Fires play a role in the composition of species that are selected for in the forest. Frequent fires select for species that are resistant to fires or have serotinous cones and can take advantage of the exposed understory and soil properties after the occurrence of fire. Examples of fire resistance include increased bark thickness, historical tree species composition and sprouting after the occurrence of a fire (VanderWeide and Hartnett 2011). Oak's adaption to fire is that they aggressively sprout after the occurrence of fire (Williams et al. 2013). Red oak utilizes prescribed burns for site preparation and competition reduction (Williams et al. 2013).

The most influential driver of forest composition is fire in the boreal forest (Boucher et al. 2017). It was determined that historically these natural disturbances have had a greater impact on the boreal's composition than logging (Boucher et al. 2017).

One of the benefits of prescribed burns is that they increase the amount of light that is received by the understory. A study was conducted by Rebbeck et al. (2012) which determined the response to light treatments on seedlings of chestnut (*Quercus prinus* L.), white and red oak. The study measured the amounts of gas exchange and chlorophyll present in each of the three oak species at 25%, 18% and 6% sunlight exposure over two summers in one of two native forest soil mixes (Rebbeck et al. 2012). The red oak photosynthesis at saturating light (Amax, mass) increased by 23%–36% when light levels increased from 6% to 25% of full sun (Rebbeck et al. 2012). However, it was shown that chlorophyll content increased with the decrease in sunlight exposure (Rebbeck et al. 2012). The study concluded that there are no benefits to increased light exposure above the level received in a shelterwood cut as long as competition is managed (Rebbeck et al. 2012).

There are three types of fires that can occur in the forest. These types of fires are surface, crown and ground fires (Government of Canada 2016). Ground fires occur beneath the ground and burn the humus, peat and other substrates; has the potential to deplete the seed bank (Government of Canada 2016). Crown fires burn the length of the tree and surface fires burn the surface and litter layer (Government of Canada 2016). Due to the different properties of the fires and the differing substrates they will have varying effects on the regeneration of oak. The type of fire that could be a prescribed burn to promote oak regeneration is a surface fire as it would clear the understory and juvenile trees, allowing for the sun to reach the understory. Oak benefits from allocating carbohydrates to root growth and dormant buds, since these are in the soil they are insulated from the heat (Dey and Schweitzer 2015). Oak stems that are below 4 inches DBH are vulnerable to top-kill, however stems that are larger have a high likelihood of sprouting after the fire (Dey and Schweitzer 2015). After a surface fire the oak would be able to sprout and vegetatively reproduce.

SILVICULTURAL TREATMENTS

Silvicultural treatments are important to consider with the application of prescribed burns to increase the success of oak seedlings and limit competition. Numerous treatments can be beneficial to red oak such as thinning, use of a shelterwood treatment, etc.

A study conducted by Cogliastro and Paquette (2012) evaluated the effect of thinning on the light regime and the growth of underplanted red oak and black cherry. The purpose of the study was to determine the intensity of thinning to be employed to get the desired quantity of stems of each species (Cogliastro and Paquette 2012). A comparison between partial thinning at the 3rd and 7th growing season and a single thinning at the 7th year; each thinning respectively increased the light exposure to 20-30% in the understory (Cogliastro and Paquette 2012). It was found that the red oak that were partially thinned twice had a height double that of their counterparts in the single thinned section (Cogliastro and Paquette 2012). The black cherry did not benefit as much as the red oak did from the thinning treatments however, the authors suggested that an additional thinning could occur at the 15-year mark that would be beneficial to clear favourable trees from those that are currently overtopping them (Cogliastro and Paquette 2012).

A study conducted by Gordon et al. (1995) analyzed the seedling success of red oaks that were planted beneath a shelterwood managed hardwood stand in southern Ontario. The growth of the red oak was monitored for six years and benefited from the application of glyphosate, and two burns that had a separation of three years, to decrease competition (Gordon et al. 1995). Different designs were tested that included stock type, competition control and clipping two years after planting. The study concluded that underplanting red oak while shelterwood harvesting on sites that are historically prominent is a successful method of oak re-establishment (Gordon et al. 1995). However, some recommendations were made for future planting using this method that would increase the success and growth of red oak. These recommendations included not employing competition methods if deer browsing is high, taking into consideration the soil type and weather if clipping (Gordon et al. 1995).

DISCUSSION

APPLICATION IN ONTARIO

Prescribed burns are an important prescription for Ontario red oak regeneration. Red oak has become less prevalent on the landscape as the natural fire regime has shifted and oak is not being selected for in the forest ecosystem. With consideration on increased temperatures, the fire regime, and additional silvicultural practices oak regeneration can be managed appropriately and successfully and reach numbers that are closer to the historical population in Ontario.

The increased temperatures will have an affect on the fire regime (Ter-Mikaelian et al. 2009). Considerations for the temperature will have to be applied to prescribed burns and the effect the temperatures will have on the natural fire cycle. The fire frequency, burn extent and mean temperatures are expected to increase across the North American boreal forest over the next century as a result of increased temperatures (Girardin et al., 2013; Hinzman et al., 2013; Kasischke and Turetsky, 2006). An understanding of the fire regime is important in predicting future conditions in the forest and allows for a well-constructed management plan (Ter-Mikaelian et al. 2009). The occurrence of fires has been made difficult to predict because of Ontario's past suppression of fires. Determining the fire interval is typically made more difficult in managed forests because of alternated age dynamics, fire suppression and area burned (Ter-Mikaelian et al. 2009).

Future forest conditions can be used to help estimate the current fire cycles. Ward et al. (2001) used Ontario forest fire records from 1976-2000; these records were used to estimate the forest fire return interval. It was determined that without suppression the fires ranged 190 years and with suppression, the interval is approximately 600 years (Ward et al. 2001). The fire cycle allows for the production of healthy stands and regeneration, with an understanding of its frequency the plan can account for natural disturbances. Therefore, frequent prescribed burns should be implemented to mimic the natural occurrence of fire and historic species compositions in fire burned areas. This practice would eventually increase the presence of red oak in Ontario forests.

Perhaps provenance tests can be conducted on various oak species to determine the suitability of species to different climates and ranges. Similar studies to the studies conducted by LeBlanc and Terrell (2011) and Ter-Mikaelian et al. (2009) could be completed which compared multiple species of oak to see the similarities and differences in adaptation to climate and northern limits of a species.

Prescribed burns are used to mimic those of the natural fire regime because the natural fire regime had a fire frequency that selected for red oak. After fire suppression in Ontario, and Canada, species that were selected for were shade-tolerant. A study by Jin et al. (2018) suggests that the combination of harvesting and prescribed burns can create an environment that selects for species that were historically present. The effect of harvesting and prescribed burns were modeled and comparison were analyzed for a control, burn only, harvest only and a combination of harvest and prescribed burns with different fire intervals (Jin et al. 2018). Ontario should conduct a similar approach to red oak regeneration and determine the interval that prescribed burning should be implemented for maximized success of regeneration.

The different methods of regeneration of oak are prescribed burns, shelterwood harvesting, and scarification (site preparation). These processes can be used individually or combined depending on desired outcome and landscape. Prescribed burns attempt to imitate the natural processes that select for oak. Fire clears the forest floor and exposes the understory to increased levels of sunlight. The silvicultural treatments of scarification and shelterwood harvesting allow for the same benefits to the understory. Scarification prepares the soil for oak regeneration whereas shelterwood harvesting allows for gaps of sunlight to be received by the understory (Brose and Van Lear 1998). Using silvicultural methods and prescriptions, the land will be site prepped to maximize the success of oak regeneration.

The use of prescribed burning of oak is a useful prescriptive method to regenerate red oak as the tree has become less prevalent in Ontario forests. Through the consideration of the increasing temperatures, the fire regime and silvicultural treatments that can be used to aid prescribed burns, red oak should increase in Ontario forests.

CONCLUSION

Oak regeneration has become more difficult as a result of the changing climate and suppression of fires within the province. To allow for the regeneration of oak species in natural settings methods such as prescribed burns, shelterwood harvesting, and site preparation should be implemented. After the oak seedlings emerge, they should be monitored to see if additional management such as thinning, competition reduction and herbicides should be applied. Therefore, prescribed burns will have an affect on oak-dominated stands and how they are managed. Prescribed burns should be used when possible to naturally regenerate oaks and increase the fire cycle in areas that it was historically present.

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