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Natural Succession of Nova Scotia's Northern Red Oak *(Quercus rubra)* Forest Communities

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Abstract

An independent review of forestry practices in Nova Scotia identified the need for improvements to current old forest management. The review recommended that research programs focus on the potential inclusion of additional species, including Northern red oak (*Quercus rubra*), to the climax species group. This study was conducted to determine whether red oak is a species that can maintain dominance in a forested stand in the absence of a large-scale disturbance and confirm or revise the current projected successional pathways. From 23 potential stands, the oldest nine stands that contained a high proportion of oak and had similar site productivity were selected to be surveyed. At these sites, red oak was a major component of the stand structure species composition and did not appear to have difficulty regenerating. However, it was evident that red oak had issues being recruited from the regeneration layer and establishing an intermediate cohort. Based on this research, red oak does not meet the definition of climax species as the recruitment issues will prevent it from being a dominant species in the late stages of natural succession. Although red oak is not a climax species on these ecosites, forest stands that are categorized as 'Red oak – White pine/ Teaberry' (SP9) can be climax communities and should be included in future Old Forest Policy targets.

Keywords: Northern red oak, *Quercus rubra*, natural succession, old-growth, climax species

Introduction

In 2017, William Lahey was commissioned by the Province of Nova Scotia to administer an Independent Review of Forest Practices. The review was conducted with the support of a panel of experts, and recommendations were released with the final report in August of 2018. The report concluded that current efforts for protecting and restoring old forests are inadequate and made recommendations for improvements to data collection, Old Forest Policy targets (NSDNR, 2012), and old forest restoration opportunities. From the recommendations, Lahey (2018) identified the need for research programs to focus on including additional species, particularly Northern red oak (*Quercus rubra*; referred to as red oak), in the climax species group (Lahey, 2018). Climax species typically dominate stand composition during the late stages of natural succession, resulting in a climax community (NSDNR, 2012). Climax communities are understood to have the longest period of ecological continuity and typically contain conditions associated with the old-growth stage of development (Jones, 1945). Currently, the Old Forest Policy (NSDNR, 2012) defines 'old-growth' as a forest that 1) contains 30% or more of the basal area in trees 125 years or older; 2) at least half of the basal area is composed of climax species (i.e., white pine (*Pinus strobus*), red spruce (*Picea rubens*), eastern hemlock (*Tsuga canadensis*), sugar maple (*Acer saccharum*), yellow birch (*Betula alleghaniensis*), and American beech (*Fagus grandifolia*)), and 3) total crown closure is a minimum of 30%.

Red oak is the only species of oak that is native to Nova Scotia. Red oak seedlings can be intermediate to moderately shade-tolerant when young, becoming more intolerant of competition and shade as it matures (Burns & Honkala, 1990; Farrar, 1995). Because of the reduction in shade tolerance as red oak matures, it is understood as an early- to mid-successional species that regenerates after large-scale disturbances (Abrams, 1992). In particular, fire perpetuates red oak regeneration because of the thick bark, resistance to rotting after scaring, ability to regenerate in fire-created seedbeds, and deep tap rooted system that allows for coppice growth (Lorimer, 1985; Abrams, 1992). Fire also reduces competition from other less fire-resistant species, such as red maple (*Acer rubrum*), which allows red oak to take advantage of the post-fire landscape (Abrams, 1992). Several studies focusing on red oak forest communities have been conducted in the Northeastern United States. These studies have determined that in the absence of a large-scale disturbance, particularly fire, red oak forests transition to later successional, shade-tolerant species (Nowacki et al., 1990; Aldrich et al., 2005). Although red oak does not typically dominate late successional forests in these areas, these studies have also determined that stable conditions are evident on sites of extreme edaphic (i.e., xeric sites) or climatic conditions and in areas that experience periodic fires (Abrams, 1992; Nowacki & Abrams, 2008). In Maine (Gawler & Cutko, 2018), Ontario (Lee et al., 1998), and Nova Scotia (Neily et al., 2013), a major portion of red oak forest communities persist on dry-fresh moisture and nutrient-poor sites. Because of the poor site productivity, these forests may have the ability to remain stable rather than transitioning to more shade-tolerant species.

In general, it is understood that the frequency of fire influences the amount of red oak on the landscape and the successional development of red oak forests (Abrams, 1992). To understand fire's frequency history in Nova Scotia, a timeline of vegetation history in Nova Scotia has been constructed through charcoal and pollen analyses (Livingston, 1968; Green, 1981). These studies indicate that spruce dominated Nova Scotia's post-glacial landscape (10,500 – 9000 years B.P.), resulting in a frequent fire regime (Green, 1981). As the climate began to warm, less flammable pine and hardwood species began to grow which reduced the fire frequency (Green, 1981). After 4000 B.P., Nova Scotia's climate was cooler and wetter, resulting in a less severe fire regime and a mixed forest structure that is present today (Livingston, 1968; Green, 1981). Although the use of fire by the Mi'kmaq is evident (Drushka, 2003; Joudry, 2016), there was no noticeable impact on the forest composition during this time (Livingston, 1968). After European settlement, human-caused wildfire became more frequent across the province, with return interval estimates of 200 years (Fernow, 1912) and 400 years (Green, 1981). Current fire suppression techniques have resulted in a substantial decrease of forest area burned (Taylor et al., 2020), resulting in a post-fire suppression return interval estimate of 1,000 – 2,500 years (Wein & Moore, 1978). The most recent estimates from Taylor et al. (2020) and MacLean et al. (2021) suggests that the natural fire (i.e., lightning-caused, with no fire suppression) provincial fire return interval is approximately 500 years for Acadian tolerant hardwood and mixedwood forests. Other disturbances on Nova Scotia's landscape, such as hurricanes, are also not frequent, with return intervals of high (> 60% of stand killed), moderate (30-60% of stand killed), and low (< 30% of stand killed) severity hurricanes estimated at 1,250 years, 714 years, and 1,111 years respectively (Taylor et al., 2020; MacLean et al., 2021). High to moderate severity windstorms are even more infrequent, with a return interval of 5,000 years (Taylor et al., 2020). Instead, small-scale low severity windstorms are the prevalent natural disturbance occurring across the province approximately every 71 years (Taylor et al., 2020; MacLean et al., 2021).

Currently, red oak does not comprise a large portion of Nova Scotia's forests. Only 4% of the province's forested area is identified as containing some component of red oak (NSDLF, 2020; Fig. 1). Stands with high percentages of red oak are even more rare, with stands containing greater than 50% oak comprising 0.25% of the forested area in the province. When overlain with Nova Scotia's mapping of natural disturbance regimes (NSDNR, 2015), 82% of the stands containing oak are located within frequent or infrequent disturbance regimes and 18% are in gap-phase disturbance regimes. Most stands with red oak are concentrated in the western part of the province, with 80% of stands containing oak located in the Western ecoregion (NSDNR, 2015; Fig. 1).

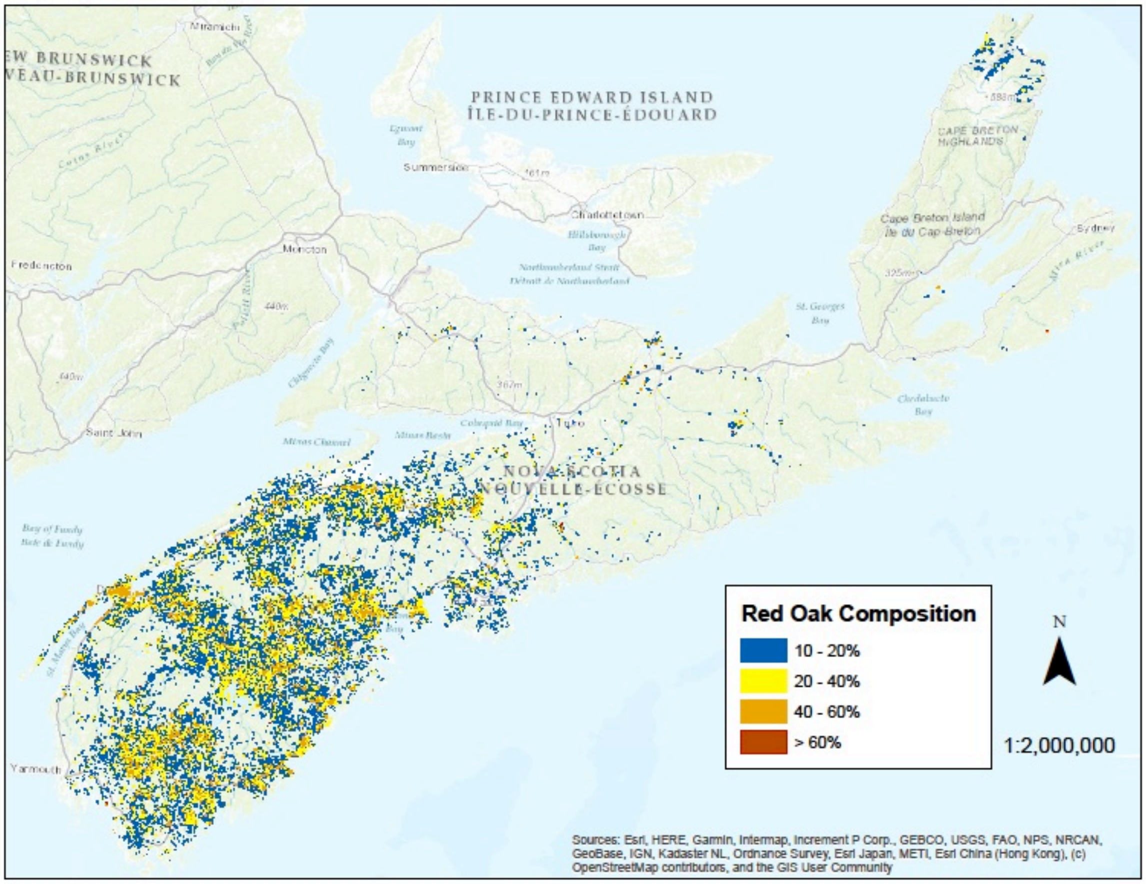


Fig. 1. Distribution and percent of red oak composition across Nova Scotia based on the provincial forest inventory database (NSDLF, 2020).

The Forest Ecosystem Classification (FEC) guide (Neily et al., 2013) suggests potential successional pathways for red oak in the province. Table 1 outlines the early, middle, and late successional vegetation types that are associated with red oak dominance. Through these successional pathways, red oak forests are understood as early- to late-successional. The vegetation types that are both red-oak dominant and late successional are SP9 (Red oak – White pine/Teaberry) and TH6 (Red oak – Yellow birch/Striped maple). However, the FEC guide states that the reoccurrence of low severity, understory fires is essential for stable red oak dominance in the SP9 vegetation type (Neily et al., 2013). In the absence of fire, the successional pathways indicate that stands containing red oak will develop towards other late successional vegetation types.

The goal of this research is to determine whether red oak in Nova Scotia is a species that can maintain dominance of a forest stand in the absence of a large-scale disturbance. To identify if red oak meets this criterion, stands containing red oak will be identified along the projected successional pathway (Table 1) and have the following objectives examined: determine if red oak is able to regenerate in the understory; assess age cohorts to determine if stands exhibit multiple cohorts of oak; and analyze regeneration and cohort data to project the future succession of the red oak vegetation types. We hypothesize that red oak will be able to regenerate in the understory but will not exhibit multiple cohorts of oak, resulting in the species not being able to maintain its dominance in a forested stand indefinitely. We further predict that red oak will have a declining presence as stands succeed, resulting in red oak not dominating stands in the later stages of succession. Our research will confirm or revise the outlined successional pathway (Table 1) and address Lahey's recommendation of determining if red oak is a climax species contributing to a late-successional forest community in these conditions. From this research we will have an increased understanding of how stands containing red oak proceed through natural succession, which will in turn help guide old forest policies and management practices.

Table 1. The successional pathways of the most frequent red-oak vegetation types in the Forest Ecosystem Classification guide (Neily et al. 2013). Late successional vegetation types that identify red oak as a dominating species are bolded.

Vegetation Types	Successional Stage		
	Early	Middle	Late
IH1a: Large-tooth aspen/ Lambkill/ Bracken (Red oak variant)	IH1a: Large-tooth aspen/ Lambkill/ Bracken (Red oak variant) IH2: Red oak – Red Maple / Witch hazel	SP6: Black spruce – Red maple / Bracken / Sarsaparilla	SH4: Red spruce – White pine/ Lambkill/ Bracken **SP9: Red oak – White pine / Teaberry**
IH2: Red oak – Red Maple / Witch hazel	IH1a: Large-tooth aspen/ Lambkill/ Bracken (Red oak variant) IH2: Red oak – Red Maple / Witch hazel	SP4: White pine/ Blueberry / Bracken	SH4: Red spruce – White pine/ Lambkill/ Bracken **SP9: Red oak – White pine / Teaberry**
SP9: Red oak – White pine / Teaberry	IH1a: Large-tooth aspen/ Lambkill/ Bracken (Red oak variant) SP8: Black spruce – Aspen / Bracken – Sarsaparilla	IH2: Red oak – Red Maple / Witch hazel SP4: White pine/ Blueberry / Bracken	**SP9: Red oak – White pine / Teaberry**
TH6: Red oak – Yellow birch / Striped maple	IH3: Large-tooth aspen/ Christmas fern – New York fern IH4: Trembling aspen / Wild raisin / Bunchberry IH6: White birch – Red maple / Sarsaparilla – Bracken	IH7: Red maple/ Hay-scented fern – Wood sorrel	TH1: Sugar maple / Hay-scented fern TH2: Sugar maple / New York fern – Northern beech fern **TH6: Red oak – Yellow birch / Striped maple**

Methods

Site Selection

This study targeted the oldest possible stands containing oak to determine if red oak is contributing to a self-sustaining, climax community. The most frequent stands containing red oak are understood to exist on ecosites classified as an AC6 or AC7. Based on the edatopic grid, these ecosites have nutrient-poor soil with a moisture regime ranging from moist to fresh (Fig. 2) and support vegetation types outlined in Table 1. Queries of the forest inventory database (NSDLF, 2020) and FEC plot database were used to identify stands that met the desired vegetation types (Table 1) and contained a high proportion of oak.

The results of the inventory queries were intersected with a potential old forest layer to isolate prospective old stands. The potential old forest layer ranks stands based on their height relative to other stands occupying similar ecosites. Areas with groupings of several high-ranking stands were further assessed using aerial photography (1928 – 2020) to remove areas that had evidence of a recent stand-replacing disturbance, harvesting, or other anthropogenic alterations.

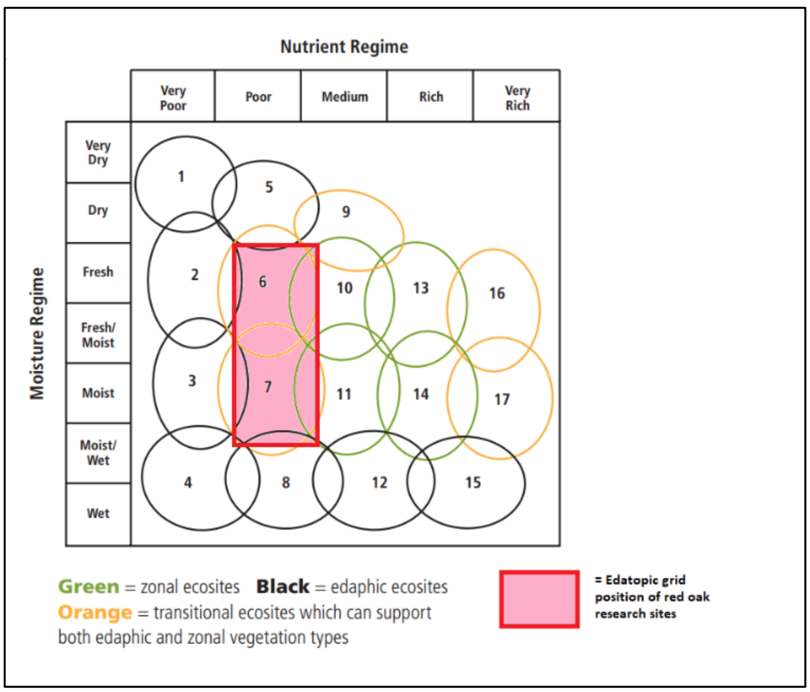


Fig. 2. Edatopic grid outlining the nutrient and moisture regimes for the AC6 and AC7 ecosites.

Reconnaissance of Potential Stands

Field reconnaissance was conducted before establishing more detailed research plots to allow for the exclusion of stands that did not meet the desired stand conditions. The reconnaissance of proposed stands took place from April to October 2020 in partnership with Mersey Tobeatic Research Institute (MTRI). Of the stands identified through the GIS process, 23 stands were assessed using the Old Growth Scoring procedure (Stewart et al., 2003). (Appendix A).

Stands that were found to be the oldest and met the FEC ecosite criteria were selected to have more rigorous research plots established. Three research plots were established within each of the selected stands through systematic sampling with a random starts approach. Therefore, the experiment is of a nested design with nine stands (samples) and 27 plots (subsamples) (Fig. 3).

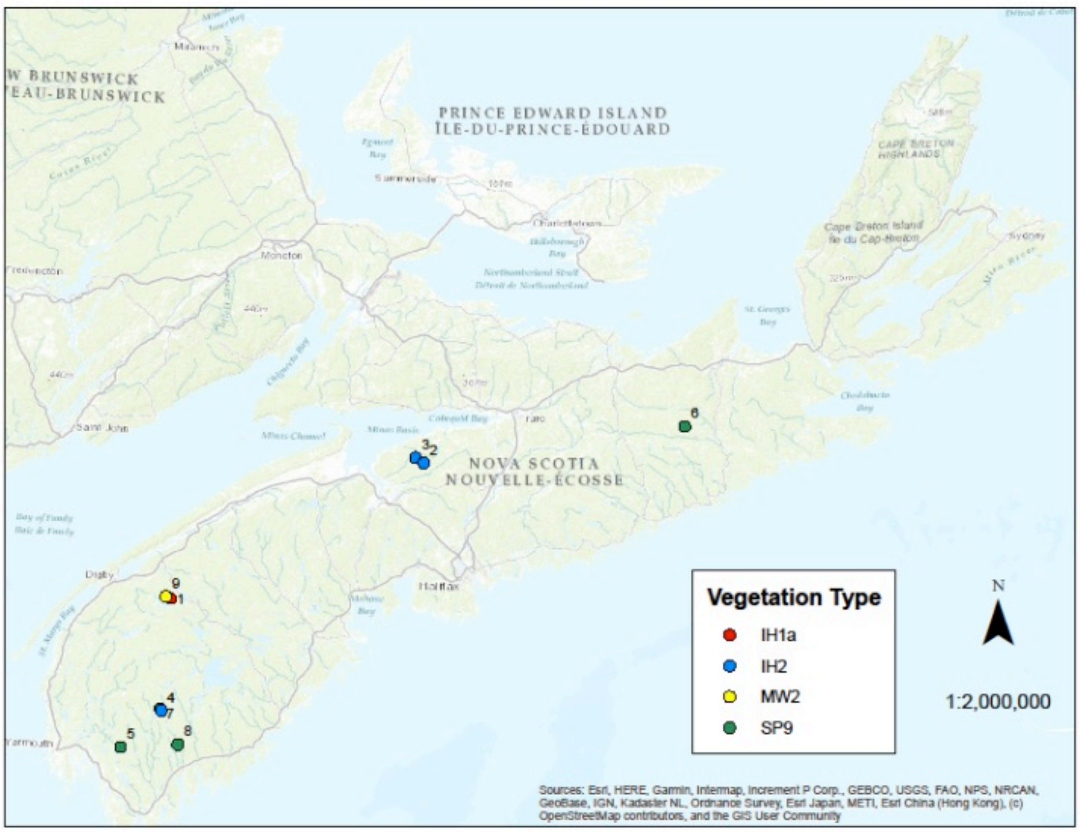


Fig. 3. Location of nine red oak research stands across the province of Nova Scotia. Stand numbers: 1 = Oak Lake; 2 = Stanley; 3 = Pinnacle Hill; 4 = Clamshell Lake 2; 5 = Great Barren Lake; 6 = Indian Man Lake; 7 = Clamshell Lake 1; 8 = Oak Hill; 9 = Mulgrave Lake

Field Methods

To distinguish the FEC ecosite type, the vegetation type and soil type were determined for each of the sampled stands. At each plot centre, a basal-area-factor-2 (BAF 2) prism was used to conduct a variable radius plot sweep to obtain the basal area (m^2/ha) and tree density (#/ha). All live (> 2 cm diameter at breast height (DBH)) and dead standing trees (i.e., snags; > 10 cm DBH) captured in the plot were numbered and had the species and status (live or dead) recorded and the DBH (cm) and height (m) measured to the nearest 0.1 units. Heights were obtained using a sonic Vertex IV hypsometer (Haglof, Sweden). All trees were cored with an increment borer at breast height (1.3 m) to obtain an age. Samples were not collected when the trees were hollow or contained heart rot. For snags captured in the prism sweeps, height and DBH were measured, and the top diameter visually estimated to the nearest 0.1 units.

Any snag > 45° lean from vertical was considered downed and was tallied as downed woody material (DWM). A fixed 90 m triangular transect from plot centre was used to obtain information on DWM (Appendix B). Downed material > 10 cm encountered along the transect had the diameter at point of intersection, species, and decay class recorded. The decay class of each snag was determined according to Stewart et al. (2003) modified decay classes.

Information on the regeneration layer was collected through a 5.16 m radius fixed-area plot. Stems were tallied based on species and separated into classes of 10–30 cm in height or > 30 cm in height. The > 30cm regeneration class included only trees that were less than 2 cm DBH. Additional information, such as browsing and human disturbance, was noted at plot locations when found.

Results

Regeneration

Across all stands, red oak was the most abundant species in the 10 – 30 cm regenerating layer and accounted for 36% of the total regeneration tallied. Red oak/red maple vegetation types (IH2) had the highest proportion (79%) of 10 – 30 cm red oak regeneration. Red oak regeneration in the 10-30 cm layer was less abundant in other vegetation types, accounting for 21%, 17% and 16% in the IH1a, MW2, and SP9 vegetation types, respectively. Red maple was the second most abundant species in the 10-30 cm regeneration layer, comprising 28% of total regeneration across all plots. In SP9 vegetation types, red maple and white pine had the highest average densities (Fig. 4).

In the > 30 cm regeneration layer, red oak contributed to a major portion of the density in the IH2 and SP9 sites but was absent in IH1a (Fig. 5). Particularly in the IH2 sites, red oak was the most abundant species in both height classes. The combination of coniferous species, including black spruce (*Picea mariana*), white pine, and balsam fir (*Abies balsamea*), accounted for 47% of the total > 30 cm regeneration. Black spruce was the second most abundant species in this layer, accounting for 21%, 17%, and 16% in the IH1a, MW2, and SP9 vegetation types respectively. Red maple was present at each of the sites but was only a significant component of the SP9 sites.

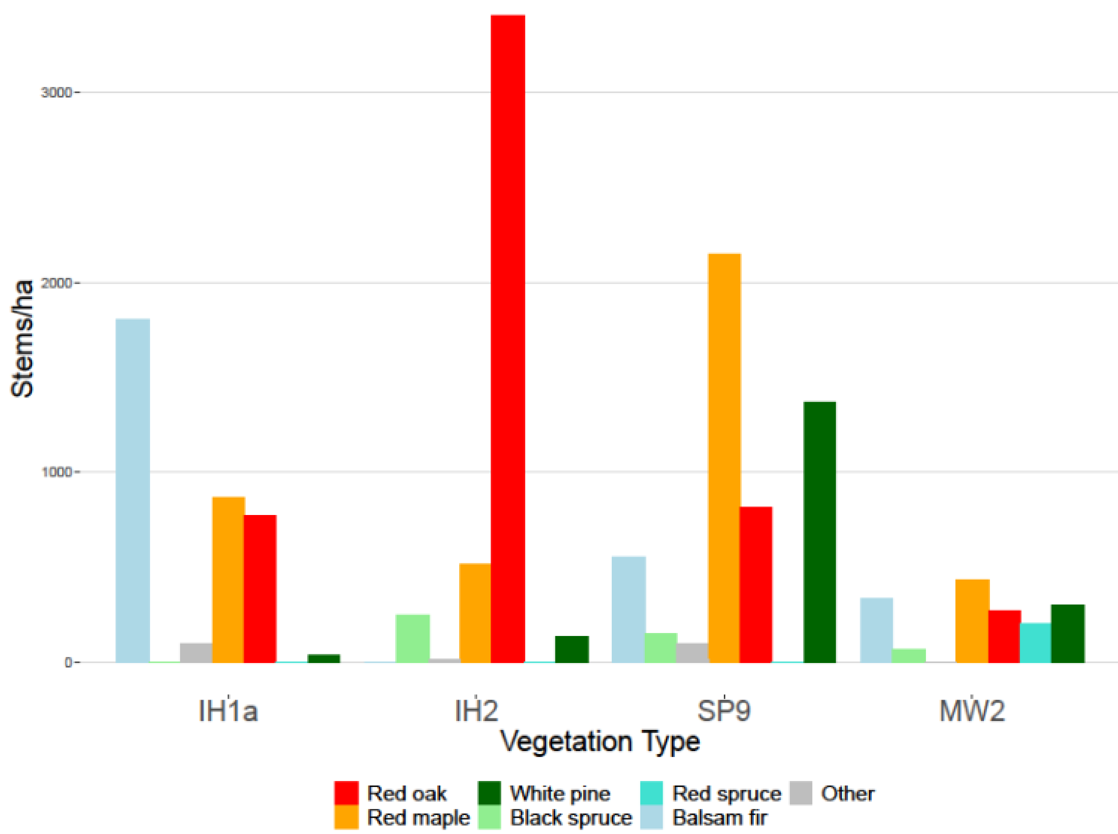


Fig. 4. Species regeneration densities in the 10 – 30 cm height class for each vegetation type.

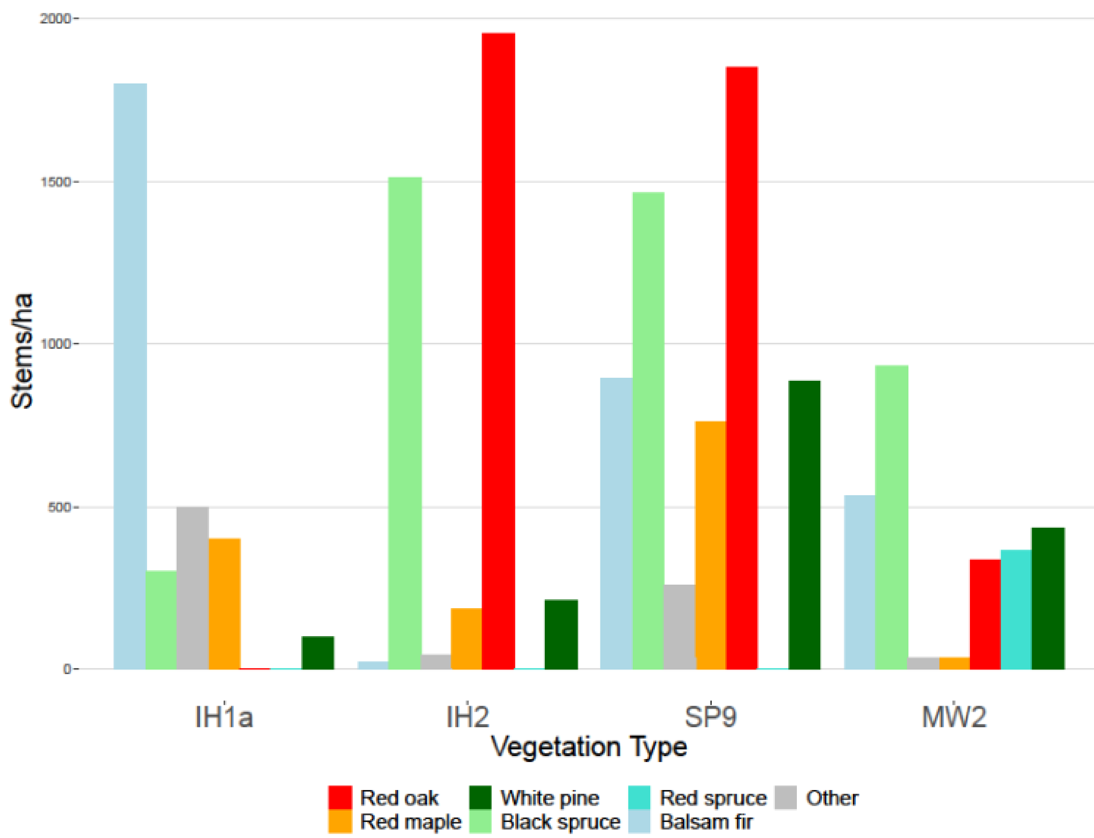


Fig. 5. Species regeneration density in the > 30 cm height and < 2 cm DBH class for each vegetation type.

Cohort Analysis

The maximum ages of red oak for each stand ranged from 121 to 205 years, with the oldest tree being cored at the Oak Hill site in Shelburne County. The old-growth scoring ages for each of the nine research stands were calculated using the old-growth scoring procedures (Table 2). This age is determined by obtaining the age of the tree that represents the minimum diameter of the top 30% of the basal area. Based on Nova Scotia's current definition of old growth, and if red oak is categorized as a climax forest species, two of the nine research stands would be considered old growth.

Table 2. Maximum ages and old growth scoring ages of stands selected for research plots.

#	Stand Name	Vegetation Type	Maximum Age (years)	Old Growth Scoring Age (years)
1	Oak Lake	IH1a	130	119
2	Stanley	IH2	160	120
3	Pinnacle Hill	IH2	156	137
4	Clamshell Lake 2	IH2	121	109
5	Great Barren Lake	SP9	162	114
6	Indian Man Lake	SP9	147	131
7	Clamshell Lake 1	SP9	151	120
8	Oak Hill	SP9	205	107
9	Mulgrave Lake Annapolis	MW2	122	111

Red oak was a major component of the oldest cohort, contributing to the majority of the basal area in seven of the nine stands (Table 3). White pine was the second most frequent tree species, followed by red maple and white birch. For this study, basal area was examined across three 50-year age classes (Table 4). The two lower age classes contain what is considered the 'intermediate' cohorts. The portion of trees in the upper age class (> 100 years) is considered part of the 'oldest cohort'. Although intermediate cohorts are present, red oak does not appear to be a major component of this cohort in eight of the nine stands (Fig. 6). For each of the vegetation types, 86 – 97% of red oak basal area is in the oldest age class (Table 4). The percent of red oak basal area greatly declines in the intermediate age cohorts, with an average of 6% in the 50 – 100 years and 3% in the < 50 year categories (Table 4). Clamshell Lake 1 is the only stand that contained a distinct intermediate cohort of red oak and was identified as an SP9 vegetation type (Fig. 7).

Across all vegetation types sampled, it is evident that red oak is the dominant species in the oldest cohort, comprising approximately 59% of the total basal area in this age class (Fig. 6; Appendix C). The overall presence of red oak-in the lower age categories greatly declines, averaging approximately 13% of the basal area in the 50 – 100-year age class and 9% of the basal area in the < 50-year age class (Fig. 6; Appendix C). White pine is the most abundant species in the 50 – 100-year age class, accounting for 28% of the total basal area, followed by red maple and black spruce at 19% and 16%, respectively (Fig. 6; Appendix C). In the < 50-year age class, white pine is also the most abundant species at 44%, followed by balsam fir (18%), black spruce (14%), and red spruce (14%) (Fig. 6; Appendix C). When assessing the live red oak density for each vegetation type, 42% and 43% of red oak stems are identified in the < 50-year age class of IH2 and SP9 respectively. However, when assessing the overall species composition, red oak still only accounts for 9% of the trees in the < 50-year age category (Appendix D). Species dominance in each age class based on density are similar to values based on basal area (Appendix C; Appendix D).

Table 3. Vegetation type, soil type, ecosite, and species composition based on basal area (BAF2) for surveyed stands.

Stand Name	VT	ST	Ecosite	Species Composition (%)[1]								
				rO	wP	rS	rM	bS	wB	wS	lA	bF
Oak Lake	IH1a	ST2	AC6	58	22	0	7	0	0	0	2	9
Stanley	IH2	ST6	AC7	44	2	0	38	16	0	2	0	0
Pinnacle Hill	IH2	ST6	AC7	44	2	0	38	16	0	2	0	0
Clamshell Lake 2	IH2	ST2	AC6	38	46	0	6	6	0	0	0	0
Great Barren Lake	SP9	ST2	AC6	35	20	0	22	8	4	2	2	0
Clamshell Lake 1	SP9	ST2	AC6	34	30	0	11	0	4	0	0	0
Indian Man Lake	SP9	ST2	AC6	34	30	0	11	0	25	0	0	0
Oak Hill	SP9	ST2	AC6	21	63	0	3	10	25	0	0	0
Mulgrave Lake Annapolis	MW2	ST2	AC10	37	0	30	16	3	10	0	2	3

[1] rO = red oak; wP = white pine; rS = red spruce; rM = red maple; bS = black spruce; wB = white birch; wS = white spruce; lA = large-tooth aspen; bF = balsam fir

Table 4. The percentage basal area of red oak across three age categories for each of the vegetation type.

Vegetation Type	Red oak age (years)		
	Intermediate cohorts		Oldest cohort
	< 50	50-100	>100
IH1a	0%	3%	97%
IH2	3%	2%	95%
SP9	6%	8%	86%
MW2	0%	9%	91%

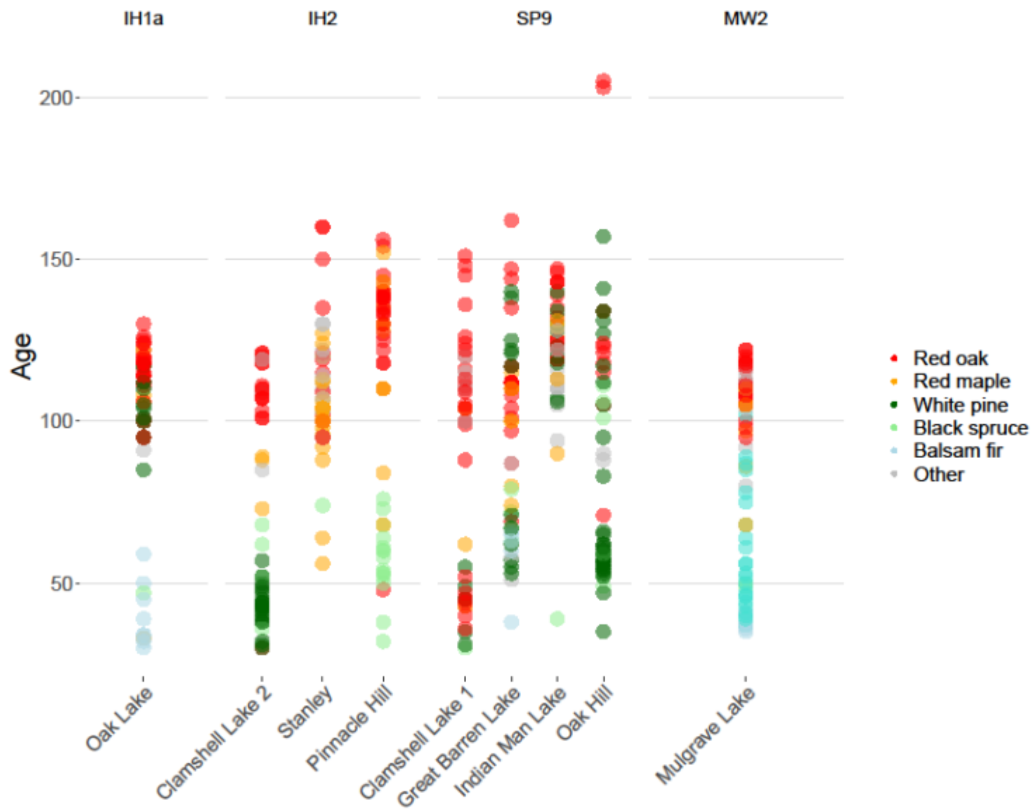


Fig. 6. Age and species of trees measured at each of the nine research stands categorized by respective vegetation types. Species categorized as 'other' species include large-toothed aspen, white birch, white spruce, and eastern hemlock.

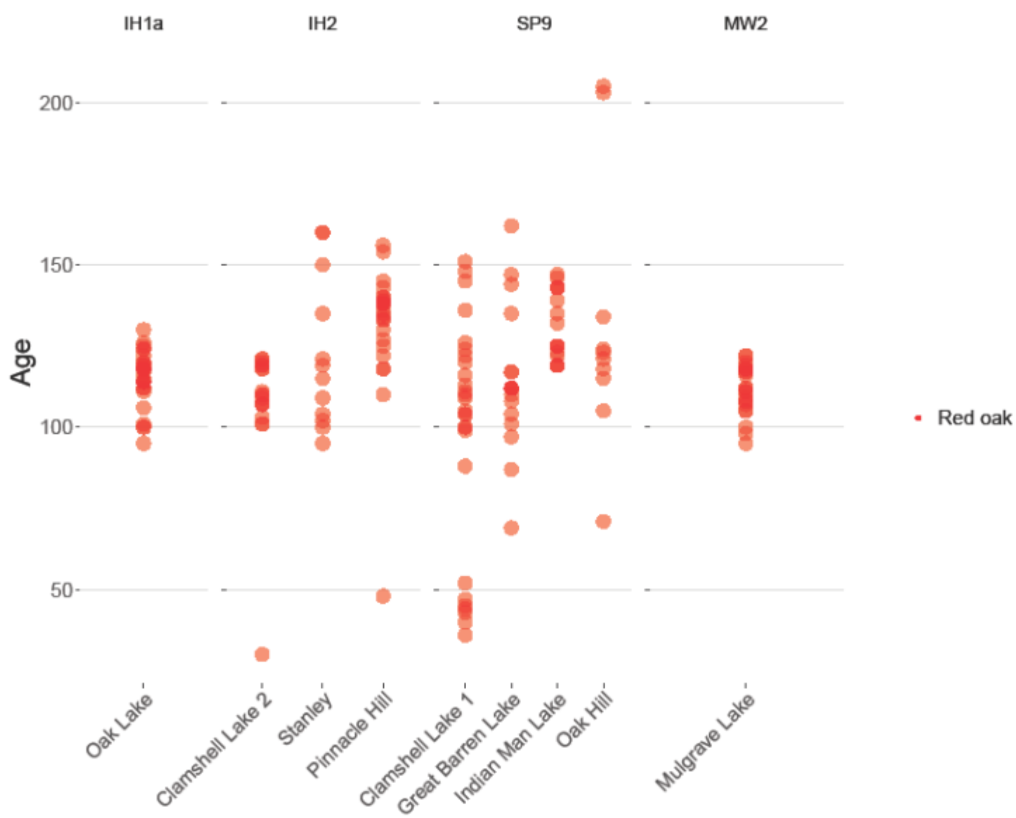


Fig. 7. Age of red oak trees measured at each of the nine research stands categorized by respective vegetation types.

Deadwood

Total deadwood (DWM and snag) volume was highest in the IH1a vegetation type, which averaged a total of 183.0 m^3/ha. Large-tooth aspen (*Populus grandidentata*) accounted for the largest portion (59%) of deadwood. Red oak was the second most common, contributing 22% of the total (Fig. 8). Stands classified as IH2 had an average deadwood volume of 70.0 m^3/ha. Red oak accounted for the highest proportion of this deadwood volume at 29%, with large-tooth aspen and red maple comprising 15% and 13%, respectively. The deadwood volume in SP9 vegetation types averaged 46.4 m^3/ha. White pine comprised most volume (41%), with red oak accounting for just 4% of total deadwood. The one stand classified as MW2 contained the least amount of deadwood volume, averaging 32.3 m^3/ha. Of this deadwood volume, white birch and red spruce were the biggest contributors at 32% and 18% respectively, with red oak contributing only 9%.

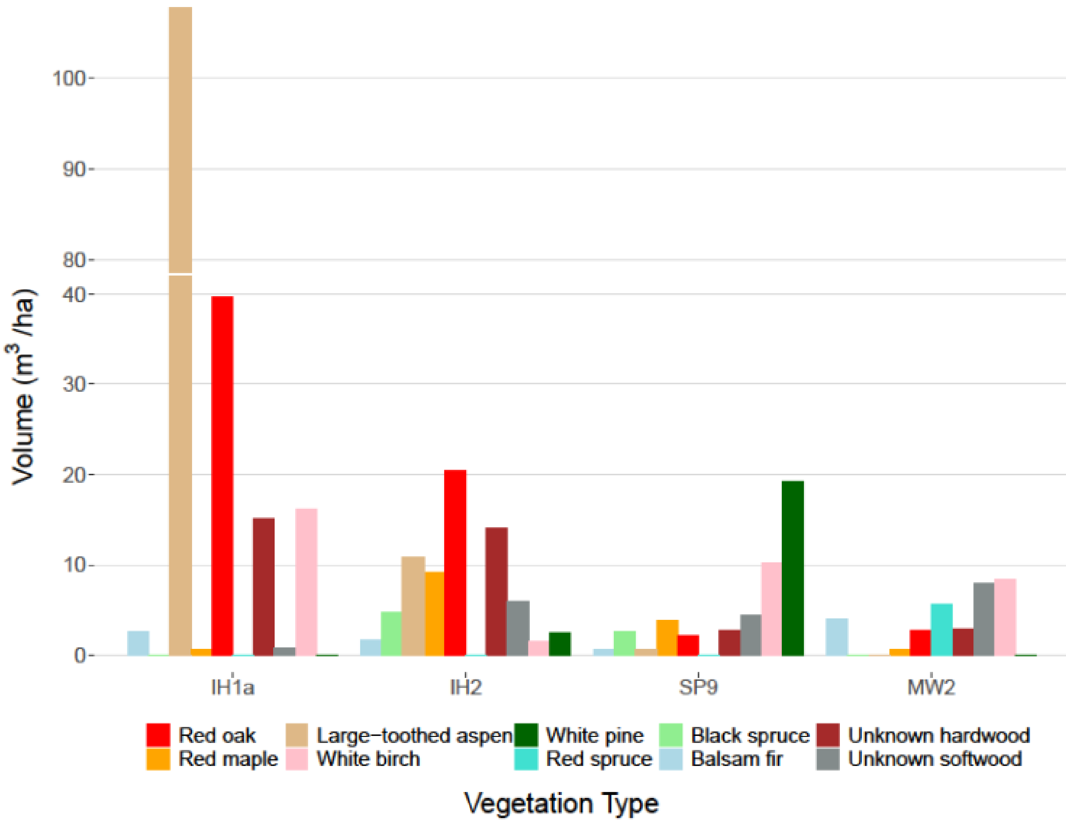


Fig. 8. Average species deadwood volume (downed woody material and snags) for each of the vegetation types.

Discussion

Recruitment Issues

All stands included in this study contained red oak regeneration. In most cases, red oak was the most abundant species in both the 10 – 30 cm and > 30 cm regeneration height classes. However, the abundance of red oak regeneration varied greatly by stand and in some cases, minimal red oak regeneration was observed (Fig. 5). At sites where red oak regeneration was in abundance, there was evidence of browsing by mammals, resulting in some coppice growth and an increase in the number of stems counted.

Although red oak has an older cohort and established seedlings in the regeneration layer, it is apparent that stands lack a prominent intermediate cohort of red oak. This is evidenced from the lower proportion of red oak in the younger age classes across all the vegetation types (Fig. 6). The species composition of younger cohorts in this study suggests that red oak is being replaced by a variety of other species depending on the site. Although red oak had the greatest accumulation of regeneration, its apparent inability to compete for resources, combined with the potential effects of browsing and seed collection by mammals, has resulted in other species being promoted from the regeneration layer. Therefore, red oak does not appear to be moving from the regeneration layer to the understory in the same abundance as the older cohort.

A noteworthy observation from the tree-ring aging analysis was that during the growth process, red oaks from the older cohort seem to have had steady increment growth into the later years. This minimal evidence of suppressed growth suggests that most of the older red oaks did not live through a period of stress or suppression.

Successional Dynamics

Only one stand surveyed in this study was found to be the early-successional vegetation type, IH1a. This vegetation type was distinct because of the significant presence of large-tooth aspen. Large-tooth aspen is understood to be a very shade-intolerant species (Burns & Honkala, 1990; Farrar, 1995). Its presence in the canopy suggests this stand originated from a large-scale disturbance. Although still a dominant species in the stand, large-tooth aspen is dying and becoming less abundant in the canopy because of its short life span (Burns & Honkala, 1990; Farrer, 1995), resulting in a large amount of deadwood. Because of the decline in large-toothed aspen, it appears that red maple and white pine will replace the aspen in the canopy, allowing for the stand to transition into an IH2 vegetation type. Data at the IH1a site showed the regeneration layer to be dominated primarily by balsam fir and red maple (Fig. 4). Red oak is present in the 10 – 30 cm regeneration layer but is absent in the > 30 cm regeneration layer and in the intermediate cohorts. The presence of black spruce, white pine, and balsam fir in the > 30 cm regeneration layer suggests a likely transition to a spruce/pine-dominant vegetation type such as SP9. Therefore, our research supports the pathway identified in the FEC, with IH1a as an early successional forest community that can transition to IH2 through the loss of mature aspen and continue towards later successional vegetation types.

Red oak/red maple stands (IH2) are understood to be an early to mid-successional vegetation type. These stands are understood to originate from large-scale disturbances, particularly fire, or transition to this state from another early successional vegetation type such as IH1a (Neily et al. 2013). Red oak was the largest contributor to deadwood in IH2 vegetation types, followed by large-tooth aspen and red maple (Fig. 8). Red oak regeneration densities accounted for the majority of stems in the 10 – 30 cm regeneration layer and in the > 30 cm layer but was absent in the intermediate cohort (Fig. 7). Instead, red maple, black spruce, and white pine occupied the intermediate cohort (Fig. 6). Although red oak may persist as part of the overall stand structure, its dominance of overall species composition is expected to decline because it is not being recruited into the intermediate and older cohorts. Instead, white pine and other coniferous species are establishing, resulting in IH2 transitioning towards an SP9 or SH4 vegetation type.

Overall, the SP9 stands appeared to have more-dispersed red oak ages in the oldest cohort, which may be attributable to different external disturbances influencing the succession of these stands. Among the four surveyed SP9 stands, two had evidence of significant non-stand replacing disturbances. The Oak Hill site, located at the southern end of a drumlin, appeared to have been subjected to a small-scale disturbance, likely a wind event. At the site, white pine was dominant in the regeneration layer and had an established presence in the intermediate cohorts. In contrast, sparse to no red oak was observed in the intermediate cohorts (Fig. 7). At the Indian Man Lake stand, there were no red oaks tallied in the intermediate cohort; however, evidence of a previous understory fire resulted in the abundance of red oak in the regeneration layer. Based on historical aerial photography (1927) and in-person observation, the Great Barren Lake stand did not have evidence of a previous stand-replacing fire. However, the range of ages in the oldest cohort suggests that a stand-replacing disturbance did occur approximately 150 years ago. Clamshell Lake 1 was the only stand surveyed that had distinct cohorts of red oak, with an older cohort and one in the < 50-year age class.

Red oak regeneration was abundant at the SP9 sites but appeared to have the same recruitment issues observed in the other vegetation types. This was evident as 85% of the red oak basal area was over 100 years old. Although the density of each age class suggests a much higher abundance (43%) of stems in the < 50-year age category, it is apparent that red oak is still only a minor component of the overall regenerating species composition. This significant increase in younger stems can also be attributed to larger values increasing the overall vegetation type density. This is evident in the SP9 sites, with only one of the four stands having trees in the < 50-year age category, resulting in a higher stems/ha value (1,150 stems/ha) increasing the overall average to 288 stems/ha (Fig. 7). Red oak deadwood volume was not as abundant relative to the other vegetation types, which suggests that red oak was either not dying as frequently, was less frequent in the stand structure, and/or the deadwood material was smaller in size. The continued classification of these stands as SP9 will depend on whether scattered (10%) oak is recruited from the regeneration layer.

The stand identified as a MW2 vegetation type is an example of red oak growing in a richer, zonal forest type. Red oak and red spruce dominated the oldest cohort. It appeared that these species originated from the same stand-replacing disturbance, as trees within the oldest cohort were relatively the same age (110 years) and had low standard deviation (6 years). Although red oak dominated the canopy, the intermediate cohort suggests that this stand will progress towards being red spruce dominant. This observation was also supported by the regeneration data, with the largest portion of regeneration identified as red spruce with minimal red oak establishing. Therefore, red spruce appeared to thrive on the richer site and out-compete red oak, resulting in a progression towards an SH4 vegetation type.

Old Forest Management Implications

None of the red oak stands surveyed in this study would meet the current policy definition of old growth. This is because red oak is not currently considered a climax species and in seven of the nine stands, the old-growth scoring age does not meet the 125-year age threshold. This study confirms that IH1a and IH2 stands are early to mid-successional and therefore are not considered eligible under the Old Forest Policy (NSDNR, 2012). The SP9 sites are suspected to have longer periods of ecological continuity as the high maximum ages suggest that more time has passed since a stand-replacing disturbance. From the cohort and regeneration data, it was apparent that SP9 will not always be self-perpetuating. A natural disturbance that creates conditions favourable for red oak recruitment, particularly fire, is needed to maintain a scattered to abundant (10 – 50%) presence of red oak in the stand's species composition. Therefore, the presence of red oak should not impede stands from being considered 'old-growth'. Based on this research, the SP9 vegetation type can be considered an edaphic climax forest community and should be included in future Old Forest Policy targets.

Recommendations

Effects of Browsing by Mammals

It became apparent that browsing by mammals was occurring to some degree in most stands where oak regeneration was present. Red oak is somewhat adapted to withstand browsing as its tap root system allows it to establish new coppice growth (Burns & Honkala, 1990). However, it is likely that browsing allows other species to overtop red oak in the regenerating layer, thus giving them a competitive advantage upon gap creation. Furthermore, red oak acorns are a primary food source for numerous wildlife, including deer, squirrels, and other forest mammals (Lee et al., 1998). To address these difficulties with seedling establishment and regeneration growth, future studies should look at the correlation between animal populations and oak regeneration success.

Gap Disturbance

It is apparent that red oak has difficulty establishing an intermediate cohort because of its inability to survive through long periods of suppression and stress. The creation of appropriately sized gaps could be considered in stands where oak regeneration is desired. Future studies may include a canopy gap analysis and how it relates to the frequency and height of red oak regeneration. An analysis of this nature will help guide future management decisions and increase understanding of whether red oak will be able to continue to exist through small-scale natural disturbances other than fire.

Oak on Other Edaphic Sites

This study of red oak forests in Nova Scotia was generally limited to nutrient-poor ecosites with fresh to moist moisture regimes (ecosites AC6 and AC7). Previous research (Neily et al., 2013) confirms that red oak can exist on ecosites that are both richer and poorer than the sites in this study. It is also known that red oak is found in riparian ecosystems in various parts of Nova Scotia, including in northern and eastern ecoregions where red oak is less common. Future studies should focus on other ecosystem types that support red oak, which may exhibit other successional processes and development responses related to site productivity and species silvics.

Tolerant Hardwood (TH) forest types were generally not assessed in this study. The main reason for the exclusion is because of the infrequency of TH6 on the landscape. The site conditions for these forest types are slightly richer, with nutrient and moisture regimes classifying the productivity between AC9 – AC14 ecosites (Fig. 2). Future research should focus on conducting similar analyses to understand the successional development of these unique forests.

Conclusion

In the surveyed stands, red oak accounted for a significant component of the overall species composition and regenerating layer. From examining the cohort data, it appeared red oak had difficulty competing in the understory and establishing an intermediate cohort. Further, core samples provided no evidence of red oak living through periods of suppression. Instead, it appears the strategy for red oak is to establish an abundance of regeneration and wait for a disturbance, particularly fire, to create space in the canopy and reduce competition from other species. From the data collected for this report, IH1a and IH2 were confirmed as early to mid-successional vegetation types that will transition towards an SP9 vegetation type. For SP9 vegetation types to remain stable, the influence of natural disturbances such as low severity fires or the creation of appropriate gaps (i.e., potentially mid-scale to large wind events) is required. Without external disturbance agents, SP9 vegetation types will transition to another late-successional forest community. Based on this research, red oak does not meet the definition of climax species in these ecosites as the recruitment issues prevent it from being a dominant species in the late stages of natural succession. Instead, red oak will have a decreasing presence as stands progress through gap-phase dynamic processes, resulting in red oak becoming a minor component in a later-successional, climax community. Stands that are currently SP9 will likely continue to be dominated by black spruce and white pine over time without the aid of a fire or mid-scale disturbance event. Although red oak is not a climax species, forest stands that are categorized as an SP9 vegetation type can be climax communities and should be considered in future Old Forest Policies. Further research is needed to understand the effects of animal populations on red oak regeneration, appropriate gap sizes needed to encourage red oak recruitment to the intermediate layer, and analyses of red oak on other ecosites.

References

Abrams M.D. (1992). Fire and the development of oak forests. *BioScience, 42*(4), 346-353.

Aldrich, P.R., Glaubitz, J.C., Parker, G.R., Rhodes Jr., O.E., & Michler, C.H. (2005). Genetic structure and a declining red oak community in old-growth forests. *Journal of Heredity, 96*(6), 627-634.

Burns R.M., & Honkala B.H. (1990). *Silvics of North America: Volume 2 hardwoods*. Washington, DC: United States Department of Agriculture (USDA), Forest Service. Agriculture Handbook 654.

Drushka, K**.** (2003). *Canada's forests: A history*. Montreal, QC: McGill-Queen's University Press.

Farrar, J.L. (1995). *Trees in Canada*. Markham, ON: Fitzhenry & Whiteside Limited.

Fernow, B.E. (1912). *Forest conditions of Nova Scotia*. Ottawa, ON: Commission of Conservation Canada.

Gawler, S., & Cutko, A. (2018). *Natural landscape of Maine: A guide to natural communities and ecosystems*. Augusta, ME: Department of Agriculture, Conservation and Forestry. Maine Natural Areas Program.

Green, D.G. (1981). Time series and postglacial forest ecology. *Quaternary Research*, 15(3), 265-277.

Jones, E.P. (1945). The structure and reproduction of the virgin forest of the North Temperate zone. *New Phytologist, 44,* 130-148.

Joudry, S. (2016). *Puktewei: Learning from fire in Mi'kma'ki (Mi'kmaq territory)*. Unpublished MES Thesis. Halifax, NS: Dalhousie University.

Lahey, W. (2018). *An independent review of forest practices in Nova Scotia*. Halifax, NS: Nova Scotia Department of Natural Resources.

Lee, H., Bakowsky, W., Riley, J. Bowles, J., Puddister, M., Uhlig, P., & McMurry, S. (1998). *Ecological land classification for southern Ontario* (Field Guide FG-02). North Bay, ON: Ontario Ministry of Natural Resources.

Livingston, D.A. (1968). Some interstadial and postglacial pollen diagrams from Eastern Canada. *Ecological Monographs* 38(2), 87-125.

Lorimer, C.G. (1985). Methodological considerations in the analysis of forest disturbance history. *Canadian Journal of Forest Research, 15*, 200-213.

MacLean, D., Taylor A.R., Neily, P.D, Steenberg, J.W.N., Basquill, S.P, Quigley, E., Boone, C.K., Oikle, M., Bush, P., & Stewart, B. (2021). Natural disturbance regimes for implementation of ecological forestry: a review and case study from Nova Scotia, Canada. *Environmental Reviews, 00*, 1-31.

Neily, P., Basquill, S., Quigley, E., Stewart, B., & Keys, K. (2013). *Forest ecosystem classification for Nova Scotia* (Report FOR 2013-1). Halifax, NS: Nova Scotia Department of Natural Resources.

Nova Scotia Department of Natural Resources (NSDNR). (2012). *Nova Scotia's old forest policy* (Report FOR 2012-4). Halifax, NS: Nova Scotia Department of Natural Resources.

Nova Scotia Department of Natura Resources (NSDNR). (2015). *Ecological land classification*. [database]. Retrieved from January 28, 2022, from https://novascotia.ca/natr/forestry/ecological/ecolandclass.asp.

Nova Scotia Department of Lands and Forestry (NSDLF). (2020). *Forest inventory – geographic information systems*. [database]. Retrieved from January 28, 2022, from https://novascotia.ca/natr/forestry/gis/downloads.asp.

Nowacki, G.J., Abrams, M.D., Lorimer, & C.G**.** (1990). Composition, structure, and historical development of northern red oak stands along an edaphic gradient in north-central Wisconsin, *Forest Science, 36,* 276-292.

Nowacki, G.J., & Abrams, M.D. (2008). The demise of fire and "mesophication" of forests in the Eastern United States, *BioScience, 58(2)*, 123-138.

Stewart, B.J., Neily, P.D., Quigley, E.J., Duke, A.P., & Benjamin, L.K. (2003). Selected Nova Scotia old-growth forests: Age, ecology, structure, scoring. *Forestry Chronicle, 79*(3), 632-644.

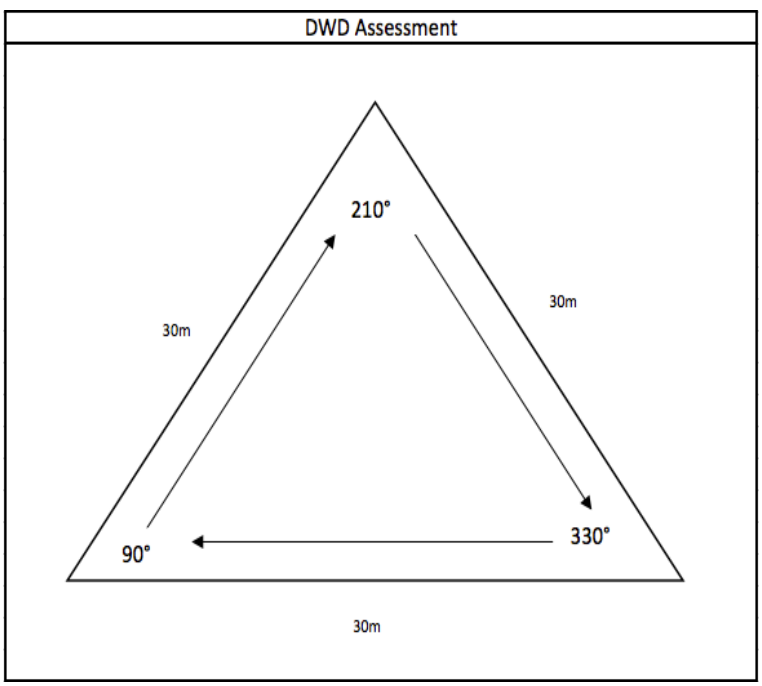
Taylor, A.R., MacLean, D.A., Neily, P.D., Stewart, B., Quigley, E., Basquill, S.P., Boone, C.K., Gilby, D., & Pulsifer, M**.** (2020). A review of natural disturbances to inform implementation of ecological forestry in Nova Scotia, Canada. *Environmental Reviews, 28*(4), 387-414.

Wein, R.W., & Moore, J.M. (1978). Fire history and recent fire rotation periods in the Nova Scotia Acadian forest. *Canadian Journal of Forest Research, 9,* 166-178.

APPENDIX A: Results of Old Growth Scoring completed as reconnaissance before establishing research plots.

Stand #	Species Composition	Oak Percentage	Basal Area	Density	Age of Top 30% BA	Max Age
F150-01164	TA34RS29RM20BF11WB04WP01RO01	1	38	1879	107	125
F152-03476	RO44RM38RS11BS05WS02	44	41	1902	128	138
F152-04709	RM61RO19TA17BS02WS02	19	36	1392	109	135
J116-01439	RO37RS30RM16WB10BF03BS03PO02	37	42	2511	63	92
J116-01529	RM29RO25WB17BF17YB08SM04	25	24	1863	105	142
J116-01843	RO61WB17WP09RS09RM04	61	23	1160	122	122
L109-03457	TA43WP19RO10RM17WB05	10	28	1509	91	104
L110-02256	WP88RO07RM05	7	38	1161	55	64
L110-02589	WP75RM14RM04WB04RO02RS02	2	34	867	84	93
L110-02603	WP84RO06WB05RM05	6	41	828	82	113
L110-02604	WP89RM03WB03PO02RO02	2	43	809	78	112
L112-03290	RM41YB22WA19RS06SM06BF03RO03	3	21	832	127	146
L112-04206	WP18RM18	0	22	1179	132	132
L112-04627	RO33WP33RM17BF08RS08	33	24	1157	114	116
L112-04641	RO56WP33WB11	56	18	815	124	124
L112-05296	RM43WP30RO25BF02	25	42	2576	82	102
L114-02296	RO30WP19BF14RM08RS08WB06YB06	30	24	1782	90	115
P123-01019	RO35RM22WP20BF10RS08WB04WS02	35	34	508	120	144
R122-02792	RM49RO43WP06TA02	43	24	1641	94	114
R122-02822	RO81RM19	81	24	1202	80	93
R122-03586	RO51RM25WB12EH08RS03	51	34	1554	102	115
R122-03610	RO40WP29RM14RS09WB05TA02BF02	40	29	1002	101	113
			36	1367	90	110
W010-03698	RO34WP30WB25RM11	34	37	1241	140	143
J116-01530	RO58WP22BF09RM07TA02	58	35	1543	112	118
R118-04847	WP63RO21RS10RM03WB01	63	38	1106	96	112

APPENDIX B: Downed woody material (DWM) fixed linear transect. The degrees are the compass bearings used to traverse the equilateral triangle.



APPENDIX C: Percent species composition by age class and basal area (m^2/ha) for all study sites.

	Species Composition (%)		
Species	0-50 Years	50-100 Years	100+ Years
Balsam fir	18	4	0
Black spruce	14	16	1
Eastern Hemlock	0	1	0
Large-toothed Aspen	0	4	9
Red Maple	3	19	16
Red oak	9	13	59
Red Spruce	14	11	1
White birch	0	2	8
White Pine	44	28	12
White Spruce	0	2	0
Total	100	100	100

APPENDIX D: Percent species composition by age class and density (stems/ha) for all study sites.

	Species Composition (%)		
Species	0-50 Years	50-100 Years	100+ Years
Balsam fir	28	4	0
Black spruce	43	44	1
Eastern Hemlock	0	0	0
Large-toothed Aspen	0	1	2
Red Maple	5	21	29
Red oak	9	5	46
Red Spruce	4	6	1
White birch	0	2	15
White Pine	11	14	5
White Spruce	0	3	0
Total	100	100	100