Effects of forest management on Acadian forest structural diversity and species composition

A baseline biodiversity assessment
in the Medway Community Forest Cooperative license area

by

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A Capstone submitted in conformity with the requirements
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Faculty of Forestry
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Effects of forest management on Acadian forest structural diversity and species composition in the Medway Community Forest Cooperative license area

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Abstract: Decades of intensive forest management in Nova Scotia has resulted in younger forests and potentially simplified forest structure. The Medway Community Forest Cooperative (MCFC) acquired a Crown Land Area License in 2015 to pilot alternative forest management on a portion of Crown Lands in Annapolis County, Nova Scotia. This study undertakes a biodiversity assessment for the community forest by analyzing forest structure and composition in order to assess the current state of the forest and provide a baseline against which future efforts to restore the forest to native conditions can be judged. Harvesting effects on the ecosystem are evaluated by examining current forest structure and species occurrences among dominant forest types and stand ages in MCFC, and by comparing coarse woody debris abundances against comparable information from ecological reserves and managed forests in Maine, USA (Kuehne et al. 2018). The study purpose is to quantify the effects of past management on stand structure and population distributions in support of future multi-species management planning in the community forest. Specific objectives are to evaluate forest-type (red spruce, black spruce, white pine, and red maple dominated) and age effects of harvesting on (1) abundance of downed woody debris in various decay classes, (2) snag density, (3) understory vegetation floristic quality, (4) bird species present and (5) mammal composition.

In 2019, 25 plots across a range of forest types and ages were sampled for downed woody debris volume and decay class, snag abundance, and Floristic Quality Assessment of understory vegetation. Additionally, bird communities were sampled in 12 of the plots, and 25 camera-traps were deployed to sample mammal communities. Coarse woody debris volumes were observed as insufficient in intermediate ages stands based on a threshold for natural Acadian forest conditions. Floristic Quality of understory vegetation was diminished, being below natural conditions. Two individual species at risk were observed. The study suggests insufficient habitat suitability and poor forest health conditions as a result of historic forest management. Some regeneration and recovery towards natural conditions are evident based on time since disturbances. Low intensive, uneven-age management is recommended to support the redistribution of age classes to increase overall forest age. Increased coarse woody debris abundance and managing for old growth characteristics are recommended. The study sample size should be increased and resurveyed every five years monitoring effects of management.

Keywords: biodiversity, forest structure, Medway Community Forest Cooperative, forest management, restoration

TABLES OF CONTENTS

LIST OF FIGURES

INTRODUCTION

Historic forest policy and management in Nova Scotia has changed the nature of the province's forests, with resulting threats to species and forest structure upon which wildlife depend (McCurdy & Stewart 2005; Nova Scotia Lands and Forestry 2016; Lahey 2018). The Medway Community Forest Cooperative (MCFC), which is a recently-established community forest in the province, provides a case in point, with a legacy of intensive past logging practices. The exact nature of this legacy is of particular interest given the MCFC's goal of returning the forest back to a more native condition. Forest composition and structural variation among stand types is of particular interest because even-aged management can diminish horizontal and vertical structural complexity (Goodburn & Lorimer 1998; Cyr, Gauthier, Bergeron & Carcaillet 2009; Haughian 2018; Seedre, Felton & Lindbladh 2018). Clearcutting is widely used in Nova Scotia and is heavily criticized due to associated prolonged adverse impacts on biodiversity and habitat (Lahey 2018; Rolek et al. 2018; Seedre, Felton & Lindbladh 2018).

To inform forest management it is essential to quantify the current ecosystem health and assess the effects of past intensive even-age management. Coarse woody debris (CWD) availability and understory plant composition are critical components of ecosystem function and contribute to habitat quality and availability. Forest birds and mammals have varying sensitivities and resiliencies to structural simplification, making them sensitive indicators of good forest health conditions (Ure, Chisholm & Kehler 2012; Staicer & Westwood 2013). Habitat conditions themselves can also be used as indicators of forest health (Edenius & Mikusiński 2006). Specific indicators for forest monitoring are selected for being the most sensitive to predicted impacts – in this case, forest management – and hence to effectively measure changes in conditions beyond natural variability.

Certain forest features are of particular interest in this regard. For example, downed woody debris (DWD) is a critically important feature of forests through its role in water retention, nutrient cycling, as a substrate for regeneration, and habitat for a wealth of organisms (Fraver, Wagner & Day 2002; Parminter 2002). Several of these functions are influenced not only by the amount of DWD, but also variation in the types of DWD, including its size and decay class (Goodburn & Lorimer 1998; Fraver, Wagner & Day 2002). Dead wood levels are dynamic and naturally fluctuate in effect of stand age and species mix, disturbance and decay processes (Vanderwel, Malcolm & Smith 2006). Wood biomass removal in managed forests has a significant effect on DWD dynamics. The literature suggests snag abundance is reduced after harvesting (Stewart et al. 2003; McCurdy & Stewart 2005). Commonly, DWD volume is increased following harvest with a greater proportion in the early decay class, and diminished late decay class (Stewart et al. 2003; McCurdy & Stewart 2005; Kuehne et al. 2018; Rolek et al. 2018).

Similarly, snags (standing dead trees) are a critical component of a forest ecosystems, providing food sources and a substrate for nesting and cavities. Generally, snags and dead wood are abundant following a natural disturbance, then decline in intermediate successional stages, and again increase in quantity and size through stem exclusion and gap dynamics of old growth conditions (Goodburn & Lorimer 1998; Fraver, Wagner & Day 2002; McCurdy & Stewart 2005; Lahey 2018). However, forest management and wood biomass removal can disrupt this natural process (Hansen et al. 1991; Rolek et al. 2018). Even-age management, particularly clearcutting, provides insufficient habitat availability in young forests, with snag density increasing with forest age (Rolek et al. 2018; Seedre, Felton & Lindbladh 2018).

Understory plant communities also provide an example of changes in the biota that may have subsequent ecosystem effects due to dependencies for food, cover, nesting and other requirements. Presence of understory plants have been used to create an assessment of floristic quality determining the degree of disturbance, making it a valuable indicator of forest health. The Universal Floristic Quality Assessment (FQA) tool has been created to facilitate ecological assessment and monitoring and is based on "coefficients of conservatism", or CC value scores assigned to individual species based on tolerances to degradation (e.g., Freyman, Masters & Packard 2016). Land use changes and disturbance are known to restructure the forest floor (Spyreas & Matthews 2006). The mean CC values of intact vegetation compositions generally range from 5-6 (Swink & Wilhelm 1994). The mean CC values for secondary, preserved, and managed hardwood forests in the American Midwest are 3.9, 4.7, and 4.8 respectively (Mabry et al. 2018). Wood biomass removal from managed forests negatively impacts richness and cover of many plant species and reduces floristic quality (Swink & Wilhelm 1994; Haughian 2018).

Among mammalian species, American Marten (*Martes americana*) populations dropped in the 1900s in response to habitat loss of old forest conditions, and over-trapping (Boss 1987; Beazley & Cardinal 2004). Beginning in the 1980s, Marten live-trapped in northern New Brunswick were introduced to Kejimkujik National Park and tracked with radio telemetry equipment (Boss 1987; Ure et al. 2012). The species serves as a good indicator of ecosystem health due to their requirement for old forest conditions, and connectivity (Ure et al 2012). There is insufficient research on the current status of the population of American Marten in southwestern Nova Scotia. The department of Lands and Forestry asks citizens to call and report sightings or accidental trapping of individuals. Several are reported in the region annually, suggesting the population is at least maintaining itself (Beazley & Cardinal 2004; Ure et al. 2012).

Mainland moose (*Alces alces americana*) population estimates are uncertain, though reports and recent aerial data estimates consistently suggest populations are very low, isolated, and in decline (Beazley & Cardinal 2004; NS DNR 2007). Addressing the greatest threats to the species is urgently needed to avoid extirpation. Local scientists describe the status of mainland moose not as a population but as localized remnant groups, threatened by overexploitation, habitat destruction, fragmentation, and reduced access to food exacerbated by climate change (NS DNR 2007; Broders et al. 2012).

Landbird species at risk in the region are the Canada Warbler (*Cardellina canadensis*), Olive-sided Flycatcher (*Contopus cooperi*), and Rusty Blackbird (*Euphagus carolinus*). Loss of habitat is the main threat on their breeding grounds. Several studies identify the decline in quality of spruce-fir forest and conifer-associated breeding bird abundances in the Acadian forest region, and a lack of proactive forest management strategies to conserve habitat for birds during the breeding and post-breeding period is reported (Staicer & Westwood 2013; Rolek et al. 2018). Amendments to the provincial policies for the conservation of wildlife habitat for forest management is required. Collaboration between researchers, parks and citizens to identify suitable breeding habitat has been conducted in southwestern Nova Scotia quantifying the vegetation at sites occupied by each (Staicer & Westwood 2013). Staicer and Westwood's (2013) study in southwestern Nova Scotia determined that the majority of Canada Warbler sites were in wet deciduous or wet coniferous. Olive-sided Flycatcher sites were spruce or wet coniferous forest, abundant in black spruce and lambkill, and Rusty Blackbirds were found across a wide range of vegetation types suggesting tree species was less important. Generally, across all plots surveyed where the landbird SARs were present, the study revealed nearly half the trees were live conifers, one-quarter live deciduous, and one-quarter snags (Staicer & Westwood 2013).

My objectives here are to quantify the effects of past harvesting on stand structure and population distributions, with the intent of quantifying current forest conditions as a baseline against which future management can be designed and monitored. Specifically, five forest indicators (DWD, snags, understory plants, birds, and mammals) were analyzed to evaluate the impact of harvest history in various stand types and stand ages. Stands were differentiated by dominant tree species, including red spruce (*Picea rubens*), black spruce (*Picea mariana*), white pine (*Pinus strobus*), and red maple (*Acer rubrum*). In addition to quantifying variation in these various components among the study sites, I also used information in Kuehne et al. (2018) to compare dead wood resources in the MCFC against to those in managed and unmanaged stands of Maine.

BACKGROUND

Nova Scotia's evolving forest policy

Legislation is increasingly backing conservation work in Nova Scotia and recognizing the adverse impacts of even-age forest management, as the department of Lands and Forestry (DLF) underwent an independent review of forest practices in 2018, through 2019 (Lahey 2018). The report recommends the province adopt the ecological triad model to prioritize protecting and enhancing ecosystems and biodiversity (Lahey 2018). Sustainable forest management (SFM) practices have been implemented to varying degrees across the province for decades, but recent enactment of the Biodiversity Act (2019) by the DLF in the province exemplifies steps taken to proliferate ecosystem-based management and serves as a toolkit to do so. Under the Act, ecosystems may be protected as “biodiversity management zones” to support conservation and sustainable use of specified biodiversity values (2019). The community forest fulfills a missing piece in a nested model of land planning in the region, between protected lands and tradition crown land and private land forest management. In their role, experimental and non-traditional multi-age forest management may pilot ecosystem-based management with a stronger focus on biodiversity conservation while also harvesting wood biomass.

Medway Community Forest Cooperative business model

A three-year pilot project was awarded to the MCFC by the Nova Scotia Department of Natural Resources (NSDNR), establishing the province's first community forest in 2013. Through a Forest Utilization License Agreement (FULA) with the NSDNR in January 2015, MCFC acquired a Crown Land Area License to sustainably operate on 15,064 ha of forested land in the Annapolis county in Nova Scotia. The Medway District Management Plan informs operations on the license area based on a 100-year projection of the current forest condition, anticipated forest growth, and management interventions planned over that period (Five-Year Business Plan, 2019). Based on these projections, MCFC has been allocated with an Annual Allowable Cut of 21,600 tonnes for all timber products.

Bowater Mersey Paper Company Ltd. owned the land previously and managed the forest primarily with even-aged harvest practices and silviculture prescriptions to produce softwood pulpwood and sawlogs. They managed 550,000 ha of forest in the province from 1929 to 2012 targeting pulpwood demand, subsequently diminishing available wood supply today. The result was 27% of the productive area to be in the regeneration age class (45-95 years) and 67% of the productive area being below the maturity levels (<35 years) that would normally support harvest consideration (Interim Management Plan 2016-2018, 2016). Management restructured the age distribution of the forest to reduce the overall age. Old forests (100-205 years old) represent nearly 9% of the forest, either having never been harvested or historically harvested once, maintaining much of their original stand characteristics. Intermediate and mature forest stands (40-95 years old) represent approximately 35%, and young forests (0-40 years old) make up nearly 45% of the MCFC forest.

Public campaigning to "Buy Back the Mersey" following the closure of BMPC led to 550,000 hectares of freehold lands being purchased by the province of Nova Scotia in 2012. Management goals in the pilot phase are to generate profits through ecologically appropriate forest management and to provide alternative activities to provide economic benefit to the local community (Interim Management Plan 2016-2018, 2016). Harvesting operations in the community forest aims to balance the goals of both generating economic benefits and promoting restoration of natural Acadian forest conditions. Best practices for transitioning from historical even-aged management to ecosystem-based management is required by the province in the adoption of the triad model, and the DLF will look to the experts of alternative forest management projects, such as the community forest.

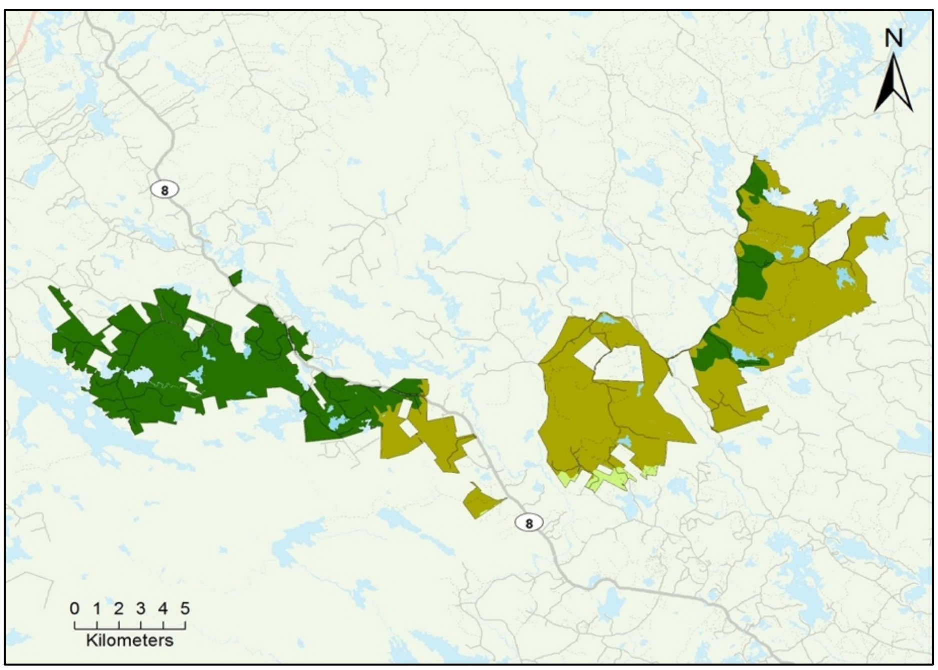
MCFC is a for-profit cooperative facilitating a governance structure based on community decision-making. It is democratically governed by an elected Board of Directors with seats for identified stakeholders and rights holders in the community representing economic, environmental, social/outreach, First Nations, and members-at-large. Anyone may participate through a share-based membership, purchased for a nominal fee, that entitles members to vote or run for the Board of Directors and engage in committee meetings. The MCFC mission is to support local communities through sustainable and ecologically-based, multi-value forest management (Five-Year Business Plan, 2019). Product lines include crown timber harvesting, firewood, value-added lumber, recreation, development of The Nova Scotia Working Woodlands Trust, and Private Land Services. The MCFC management goals are to: (1) increase the average forest age on the license area, (2) increase the proportion of high-value timber, (3) integrate traditional knowledge into forestry practices, (4) increase uneven-aged conditions, and (5) reduce intensive management while promoting natural regeneration (Five-Year Business Plan, 2019).

Managing the forest at the ecosystem level requires baseline data and ongoing monitoring to identify land classification, land capabilities, and species abundances. Combining the strengths from single-species models with an overarching ecosystem model to assess habitat suitability and monitor many species over time provides an effective tool for management (Edenius & Mikusiński 2006; O'Brien 2010; Ure et al. 2012).

Study Site

The Medway Community Forest is located in the Southwestern region of Nova Scotia (44°23'N, 65°03'W) and comprises an area of c. 15,000 ha. The majority (56%) of the forested land is in the South Mountain Ecodistrict, 43% in Fisher Lake Drumlins Ecodistrict, and 1% in the south end in the LaHave Drumlins Ecodistrict (Figure 1). The South Mountain Ecodistrict is characterized by granite outcroppings with a maximum elevation of 250 metres above sea level. Soils are shallow, stony, dry, well-drained sandy loams that developed on granite till (Neily et al. 2005). Large granite boulders restrict harvest operability and the district has limited stocking levels within forest stands. Fisher Lake Drumlins is a productive, predominately mixed-wood ecosystem. LaHave Drumlins Ecodistrict is characterized by shallow, stony till derived from underlying slates. Soils are well-drained, shallow, sandy loams expect those developed on drumlins, which tend to be deeper and less stony (Neily et al. 2005).

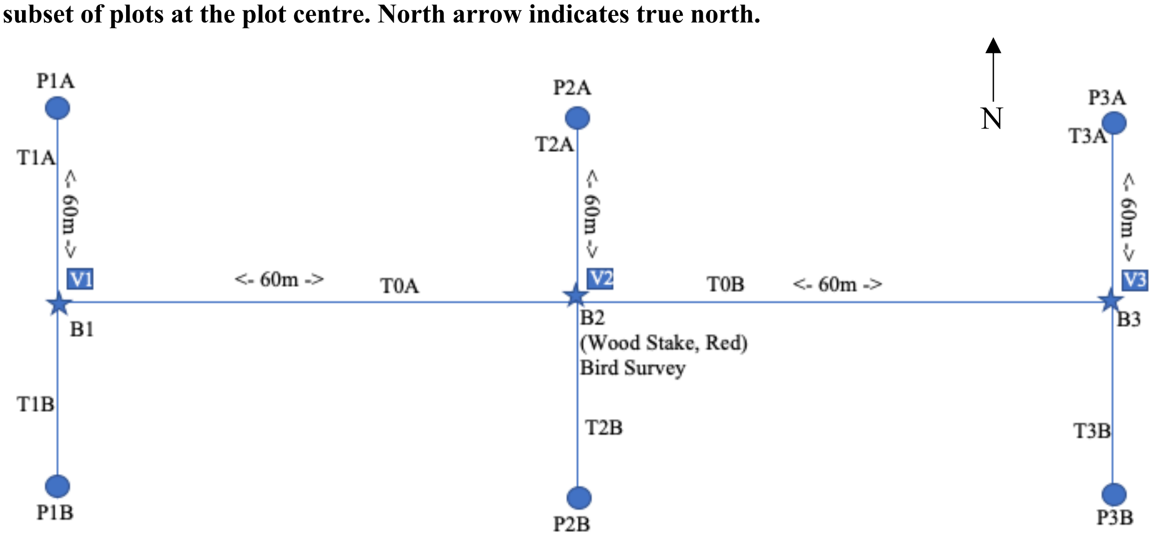
Figure 1. Natural Landscape Classification Map (44°23'N, 65°03'W) of the Medway Community Forest showing the Fisher Lake Drumlins (dark green), South Mountain Rolling Plain (olive green), and LaHave Drumlins (light green) ecodistrics. Areas in the lightest green shade are outside the Medway Community Forest. (Interim Management Plan 2016-2018, 2016). The location of highway 8 is also shown.



Sampling Design

The study was informed by ongoing biodiversity monitoring in Haliburton Forest (O'Brien 2010), Kejimkujik National Park and Historic Site (Keji) (Ure et al. 2012), Baxter State Park (Baxter State Park 2012), and the Nova Scotia Department of Lands and Forestry Permanent Sample Plots (PSPs) (Nova Scotia Department of Natural Resources 2002). In June through August 2019, forest data was collected along 25 line-transect plots. Information on trees, understory vegetation, and forest structure data was collected. Plots were at least 70-m from the road edge, with a minimum of 200-m between the midpoints of each plot. Each plot consisted of a 120-m line, with three 60-m perpendicular lines intersecting at either end and through the middle (Figure 2). Plot location was determined by the main dominant tree species of the MCFC forested land based on the Forest Resource Inventory (Appendix 1). Over 90% of the forest is comprised of stands dominated by red spruce (31.05%), black spruce (28.81%), white pine (15.62%) and red maple (15.53%), hence the study focused on these four stand types (Figure 3). Due to the presence of fire on the landscape, one plot was also included from a three-year-old burn site that had been previously partially harvested. Stands less than 40 years old were omitted from the study, and plots were split evenly between immature (40-70) and relatively mature (71-90) stands (Nova Scotia Department of Natural Resources 2008).

Figure 2. Plot design showing the 300-m of line transect used to sample forest data in the Medway Community Forest Cooperative licence area. Stars indicates prism sweep locations, square indicates understory vegetation quadrats, and circles indicate visual canopy assessment. Bird surveys were undertaken in a subset of plots at the plot centre. North arrow indicates true north.



At each intersecting point (B1, B2, B3; Figure 2) a prism sweep (BA 2) was conducted recording tree species and diameter at breast height ≥ 4 cm (DBH). Five meters northeast from each prism sweep location, a 1 m^2 quadrat were placed on the ground to record understory vegetation species and abundance (V1, V2, V3; Figure 2). Species abundance was categorized by percent of ground cover (1-20, 21-40, 41-60, 61-80, and 81-100%). For each species, a coefficient of conservatism value between 0-10 was assigned from the Maine/New Brunswick Plains and Hills data set on the FQA online tool (Cameron & Faber-Langendoen 2018; see further details below). Downed woody debris (DWD) volume was measured along the transects by measuring diameter and decay class of dead wood ≤ 1 m above the ground, and ≤ 45° angle (Parminter 2002; Vanderwel et al. 2006). For analysis purposes, downed woody debris volume (m^3/ha) following Van Wagner (1968) was calculated for the four combinations of decay class and size (small early decay, small late decay, large early decay, large late decay). DWD volume includes pieces ≥ 8 cm, and large pieces were ≥ 40 cm. Decay class was determined based on Maser et al. 1979 as follows: (1) wood is hard and bark remains intact, (2) wood is hard and bark falls off, (3) wood is soft and no bark is remaining, (4) wood is substantially decayed and pieces are easily removed, inner heartwood is soft but remains intact, and (5) wood is decayed throughout and resembles soil (Parminter 2002). Early decay combined stages 1-2, and late decay combined 3-5. Snag density (≥ 8 cm DBH) was calculated over the whole transect length in each plot using a 2 BAF prism. At six points in each plot % canopy openness and % canopy dieback are visually assessed (P1A, P1B, P2A, P2B, P3A, P3B; Figure 2)

Figure 3. Plot locations in the Medway Community Forest Cooperative by dominant tree species (yellow = red spruce, black = black spruce, white = white pine, red = red maple, and purple = post-burn site).

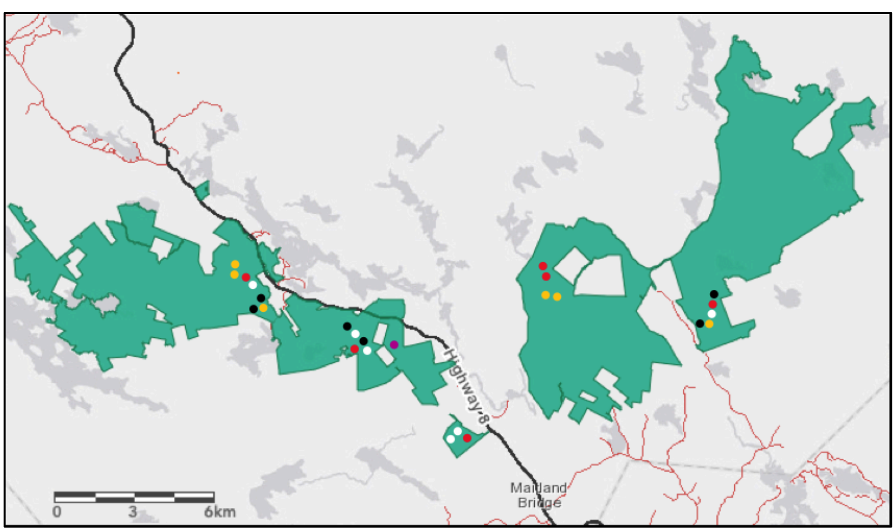
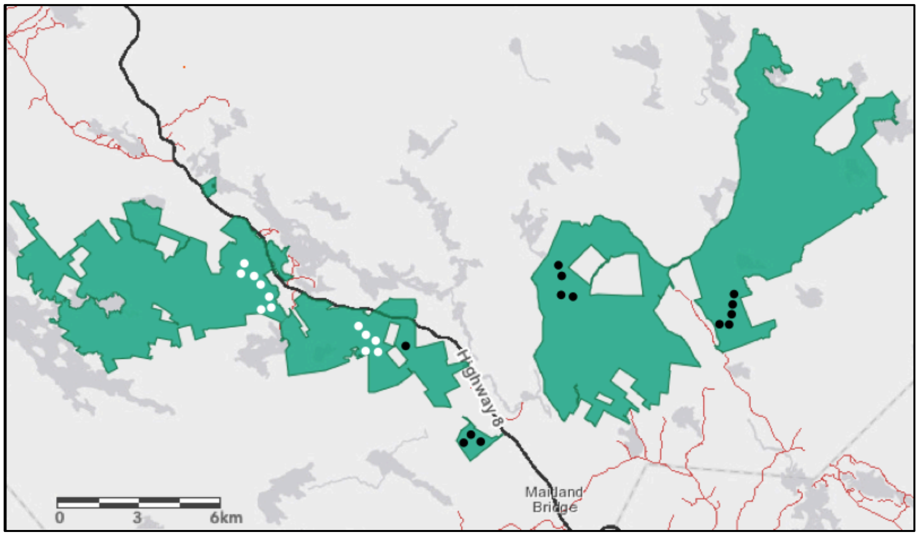


Figure 4. Plot locations in the Medway Community Forest Cooperative in which bird point-count surveys were undertaken (white = surveyed plots, black = unserveyed plots).



The New England – Acadian forest region is relatively small, and records of primary forest or unmanaged old growth stands are limited. Keuhne et al. (2018) was therefore of particular value because they compiled forest data from a relatively large sample of both unmanaged Ecological Reserves (ERM) and managed forestlands from the Forest Inventory and Analysis data (FIA) in Maine, USA. Ecological reserves are defined as *"an area where timber harvesting does not occur and natural disturbance events are allowed to proceed without significant human influence"* (Keuhne et al. 2018). MCFC dead wood resources were compared to the ERM data to assess variability by dominant tree species by effect of harvest. Stands in the reserves showed no evidence of harvest, and thus set a standard for natural Acadian conditions.

Floristic quality was assessed by determining the mean CC value per plot from the Maine/New Brunswick Plains and Hills dataset based on presence of individual species (Cameron & Faber-Langendoen 2018). The assessment excludes mosses and lichens since they had yet to be assigned coefficients of conservatism (CC values). Three species (*Carex spp., Maianthemum dilatatum, and Sorbus spp.)* present in the study did not have CC values assigned. The CC value was determined by the average for the respective genus (Appendix 2).

Forest bird species and abundance were recorded at the center of 12 of the 25 plots using 10-minute point count surveys (Figure 4). Each plot was surveyed twice, with a minimum of seven days apart as per bird monitoring protocols in the end of May and early June (Staicer 2001; Ure et al. 2012). The narrow timeframe for data collection of forest bird in breeding season and the restrictions from a particularly wet and windy spring meant only 12 of the 25 plots were surveyed. This small sample size offers an initial assessment to be further explored.

Forest mammals were observed and baited with game camera traps at the center of each plot (Campark Trail Camera 1080P Hunting Cam 14MP 2.4" Color LCD). Cameras were secured to a tree 1-m from the ground and left for five nights in each plot, taking three photos and five seconds of video when triggered by motion. The cameras were baited with a cow bone and two carrots 0.5-m from the ground, and carrots at the base of the tree. Three cameras were set at the same time, with a minimum distance of 2-km apart and rotated to all 25 plots after 5 nights at each (Cusack et al. 2015; Forrester et al. 2016; Gompper et al. 2016).

Thresholds for five indicators of forest health were set as minimum standards for natural Acadian forest conditions (Oliver et al. 2015; Kuehne et al. 2018). The threshold for downed woody debris (DWD) volume was 40 m^3/ha determined by old growth Acadian forest ecosystems in Nova Scotia (Stewart et al. 2003). Snag density thresholds were determined for each dominant stand type (spruce, white pine, red maple) in the study compared to Ecological Reserve data in Maine (Kuehne et al. 2018). To compare spruce stands between MCFC and ERM data, red spruce and black spruce data were combined and represented as spruce. The Universal Floristic Quality Assessment (FQA) calculator was used to determine the mean C per plot, and the minimum threshold for intact forests in the region is a mean C of 4.5 (Spyreas & Matthews 2006; Mabry et al. 2018). The presence of Species at Risk (SAR) was used to determine threshold for both birds and mammals.

Statistical Analysis

One-way and two-way analysis of variance (ANOVA) were utilized to examine relationships between the various indicators and FRI age class and dominant tree species. Tukey's range test was used for multiple comparisons of means with a 95% family-wise confidence level. Detrended Correspondence Analysis (DCA) and Canonical Correspondence Analysis (CCA) were used to analyze bird species. A permutation test (9,999 iterations) was used to assess understory vegetation by dominant tree species and FRI age classes. Because diameters of snags were not measured, I determined snag density by assuming that snags had the same diameters as the average live tree diameter measured for each plot. The plot radius factor of $1/(2\cdot(BAF)^{0.5})$ = 0.3536 and the length of the line transects was used to determine densities for any given plot.

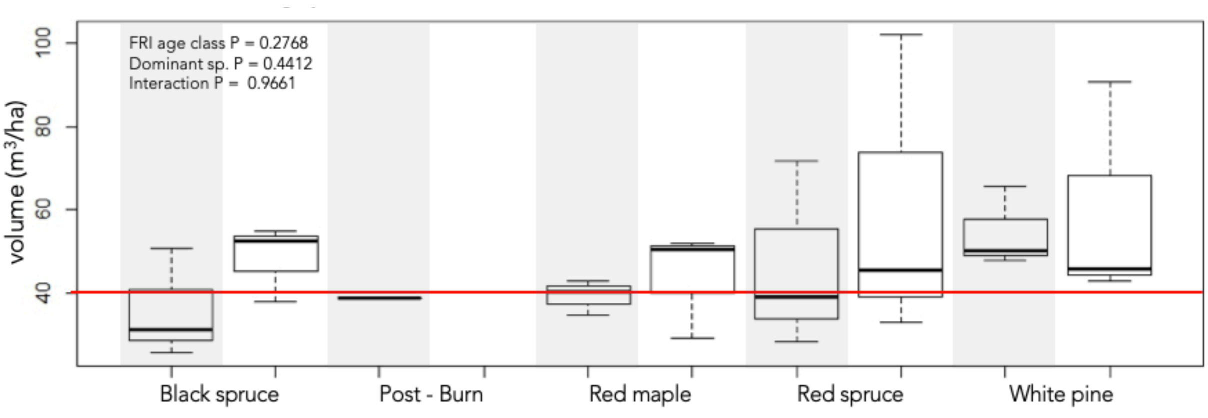
RESULTS

Indicator # 1: Downed Woody Debris

DWD volume in MCFC

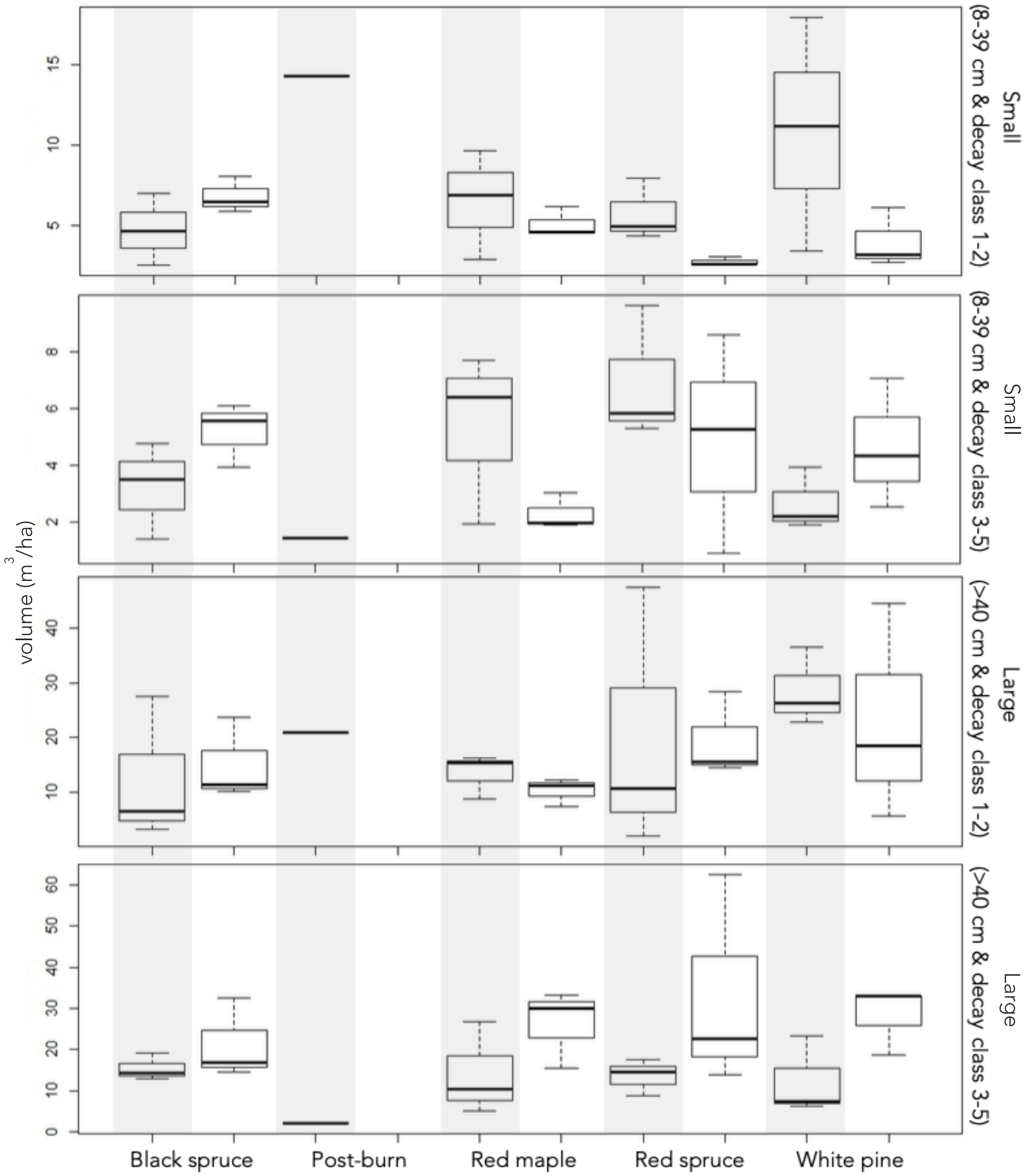
There was no significant effect of FRI age class (intermediate/mature) on total volume (Figure 5), volume of small pieces (<40cm) in decay class 1-2, volume of small pieces (<40cm) in decay class 3-5, or volume of large pieces (>40cm) in decay class 1-2 (ps > 0.20). Stands the mature age class met the threshold volume of 40 m^3/ha determined by old growth Acadian forest ecosystems in Nova Scotia, and intermediate stands were below, with the exception of intermediate white pine stands.

Figure 5. DWD total volume in the Medway Community Forest Cooperative by dominant tree species and FRI age class. (grey = 40-70 years of age, white = 71-90 years of age). A threshold of 40 m^3/ha is indicated in red.



There was a significant effect (p = 0.0021) of FRI age class on large CWD pieces (>40) in the decay class 3-5, with higher volumes in the older forests (Figure 6).

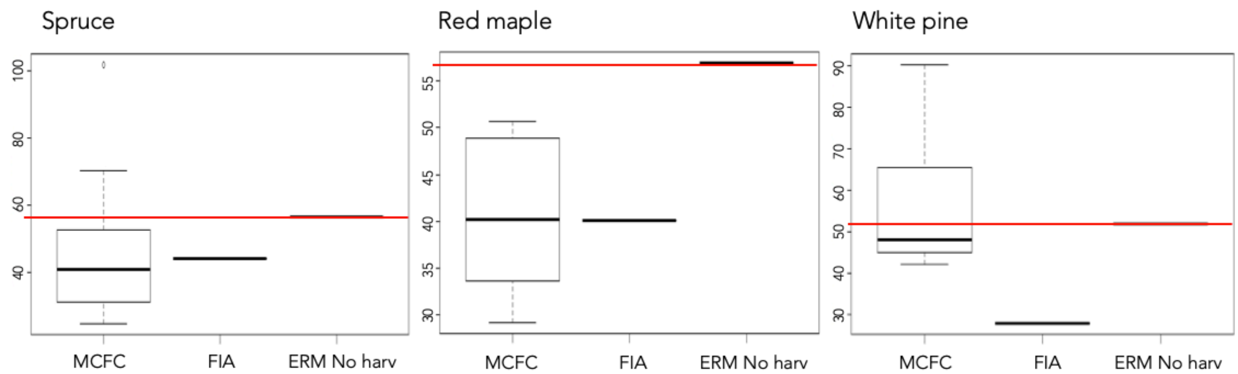
Figure 6. DWD volume by size and decay class by dominant tree species in the Medway Community Forest licence area.



DWD volume in MCFC compared to managed and unmanaged stands in Maine

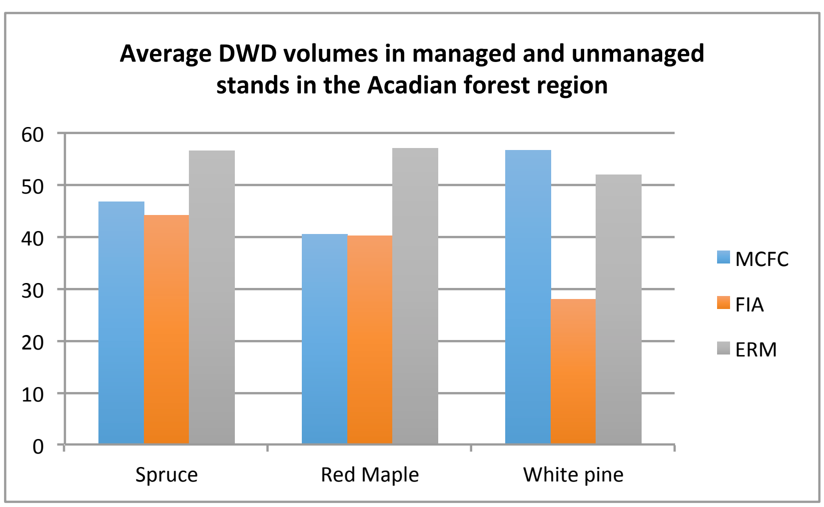
There was a significant effect of harvest history and dominant tree species on the volume of DWD for pieces >8 cm in red maple stands and white pine, but not in spruce, in that the means for the two Maine data sets (harvest and no-harvest) were within the 95% confidence intervals from the MFCF data (Figure 7). Spruce, red maple, and white pine in MCFC all fell below the minimum threshold.

Figure 7. DWD volumes (>8 cm) in the Medway Community Forest Cooperative and in managed (MCFC & FIA) and unmanaged stands (ERM) in Maine by dominant tree species. Threshold (unmanaged stands in Maine) indicated in red.



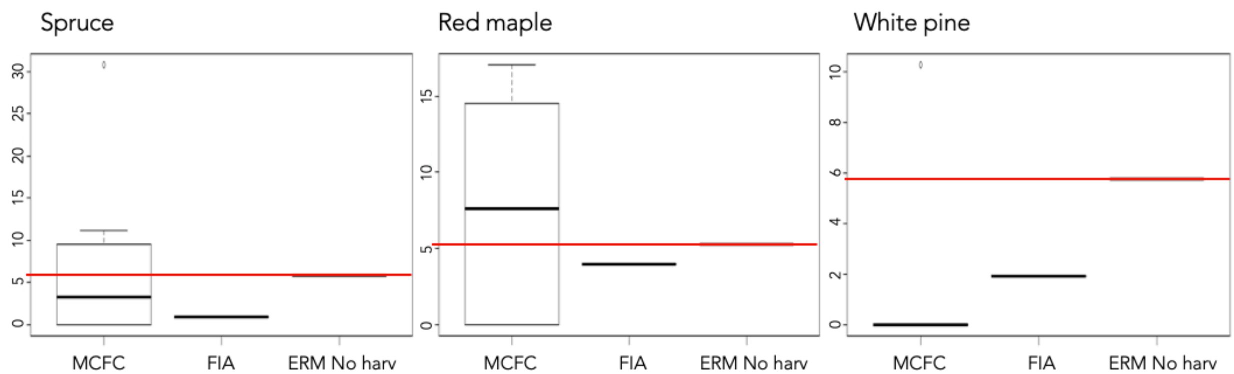
The average volume of DWD by harvest history in Nova Scotia and Maine by dominant tree species (Figure 8) suggests that white pine stands on average in the Medway Community Forest Cooperative meet the minimum threshold for natural Acadian conditions, when compared to Maine. Spruce and red maple stands do not meet the threshold for natural conditions.

Figure 8. Average DWD total volume (>8 cm) in managed (MCFC & FIA) and unmanaged (ERM) stands in the Medway Community Forest Cooperative and Maine by dominant tree species.



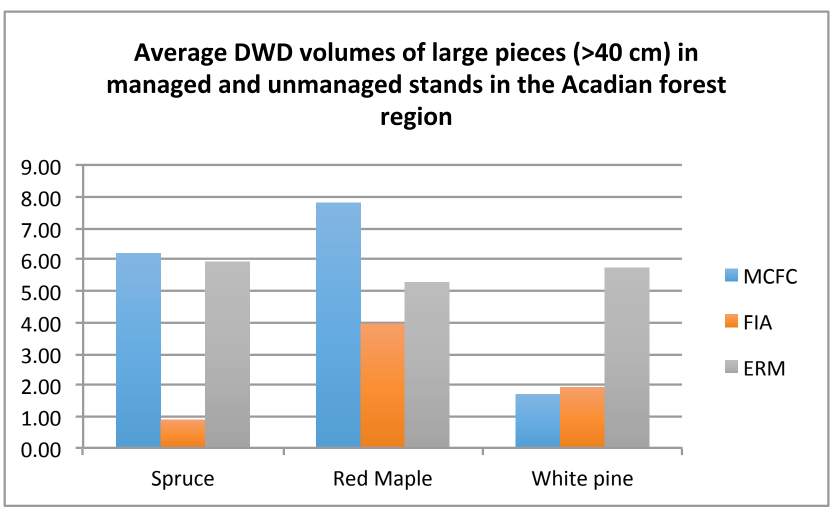
There was a significant effect of harvest history and dominant tree species on the volume of DWD for pieces >40 cm in white pine stands, and no significant effect in spruce or red maple as the means for the two Maine data sets (harvest and no-harvest) were within the 95% confidence intervals from the MFCF data (Figure 9). Red maple in MCFC exceeded the minimum threshold, meeting natural Acadian conditions while spruce and white pine fell below the threshold.

Figure 9. DWD volumes of large pieces (>40 cm) in managed and unmanaged stands by dominant tree species. Threshold indicated in red. FIA = managed forest in Maine, ERM = unmanaged forests in Maine.



The average volume of large (>40 cm) pieces of DWD by harvest history in Nova Scotia and Maine by dominant tree species (Figure 10) suggests that spruce and red maple stands on average in the Medway Community Forest Coop meet the minimum threshold for natural Acadian conditions, when compared to Maine. White pine stands do not meet the threshold for natural conditions (Figure 10).

Figure 10. Average DWD volume of large pieces (>40 cm) in managed and unmanaged stands in MCFC and Maine by dominant tree species.

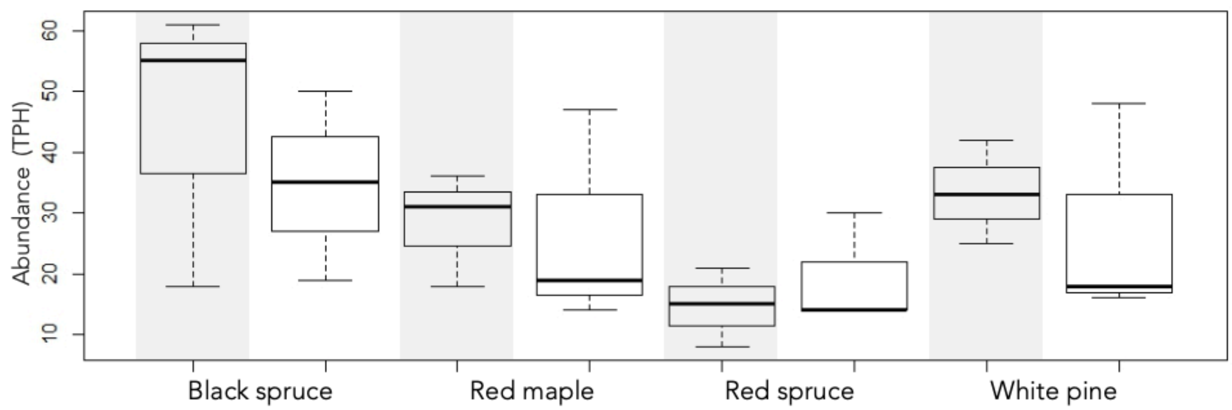


Indicator # 2: Snag Density

Snag density in MCFC

There was no significant (ps > 0.10) effect of dominant tree species and FRI age class on the abundance of snags in the Medway Community Forest Cooperative. Intermediate age stands had a greater abundance of snags than mature stands in all forest types (Figure 11). Red spruce stands had the lowest abundance, and black spruce had the greatest abundance of snags in MCFC.

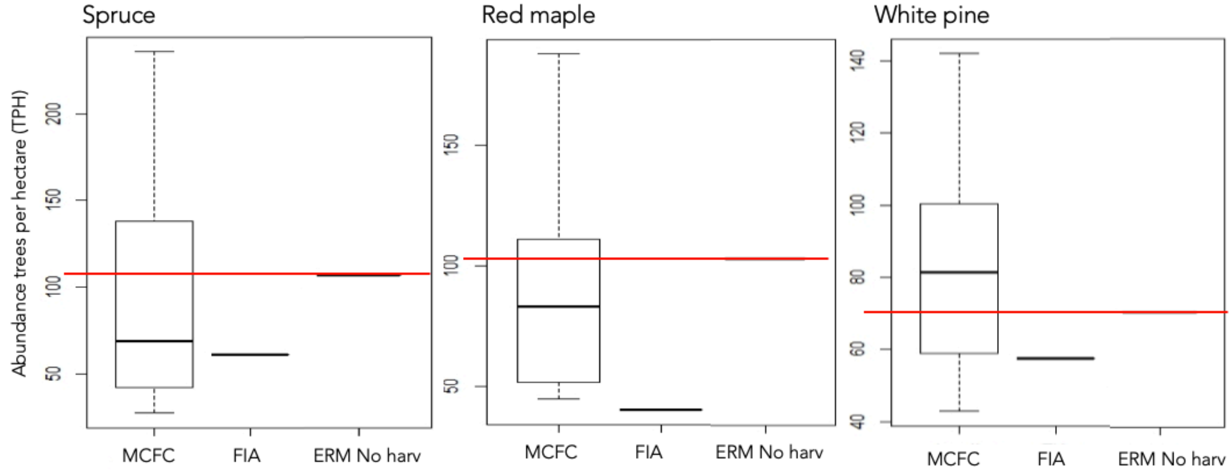
Figure 11. Snag (≥ 8 cm) density (TPH) in managed and unmanaged stands by dominant tree species in effect of dominant tree species and FRI age class in MCFC. Grey = 40-70, white = 71-90.



Snag density in MCFC compared to managed and unmanaged stands in Maine

Abundance of snags was represented by stems per hectare in MCFC, managed stands in Maine (FIA), and unmanaged stands in Maine (ERM). There was significant effect of harvest history and dominant tree species on the snag density in red maple (Figure 12), and no significant effect in spruce, and white pine stands as the means for the two Maine data sets (harvest and no-harvest) were within the 95% confidence intervals from the MFCF data. White pine in MCFC exceeded the threshold, meeting natural Acadian conditions while spruce and red maple fell below the threshold.

Figure 12. Snag (≥ 8 cm) density (TPH) in managed and unmanaged stands by dominant tree species. Threshold indicated in red. FIA = managed forest in Maine, ERM = unmanaged forests in Maine.



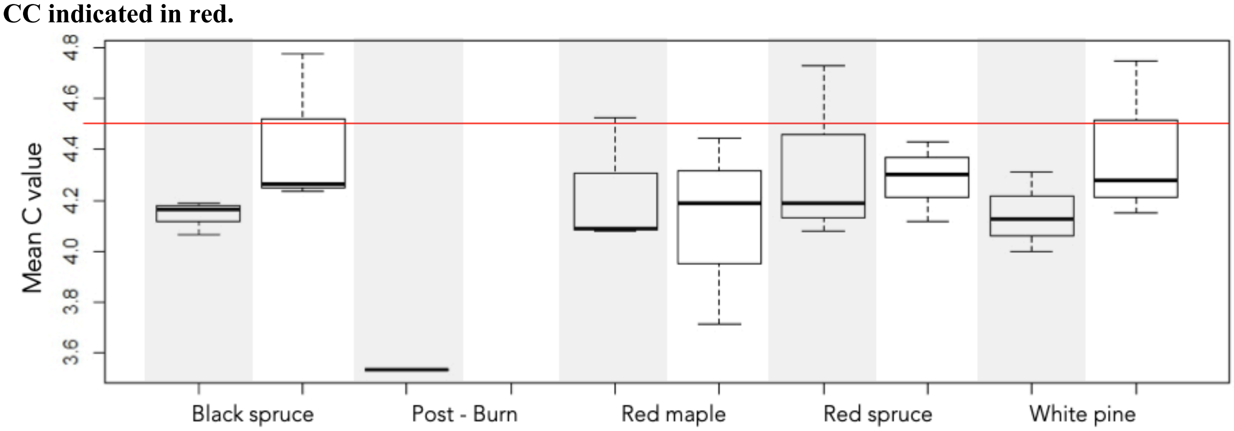
The average snag density was greater in intermediate age stands in black spruce, white pine, and red maple stands in MCFC, and the opposite trend was visible in red spruce stands.

Indicator # 3: Understory Vegetation Floristic Quality

FQA Mean C by FRI age class and dominant tree species

There was no significant effect of dominant species or FRI age class on CC values in the Floristic Quality Assessment (ps > 0.40). Intermediate aged stands had lower floristic quality than mature stands in all four dominant tree species, and the post-burn site was considerably lower than the rest (Figure 13). The results align with the literature that suggests time-since-disturbance correlates with higher Floristic Quality values. The minimum threshold of mean C 4.5 was not met in any plot.

Figure 13. Floristic Quality Mean CC by dominant tree species. Grey = 40-70, white = 71-90. Threshold 4.5 CC indicated in red.

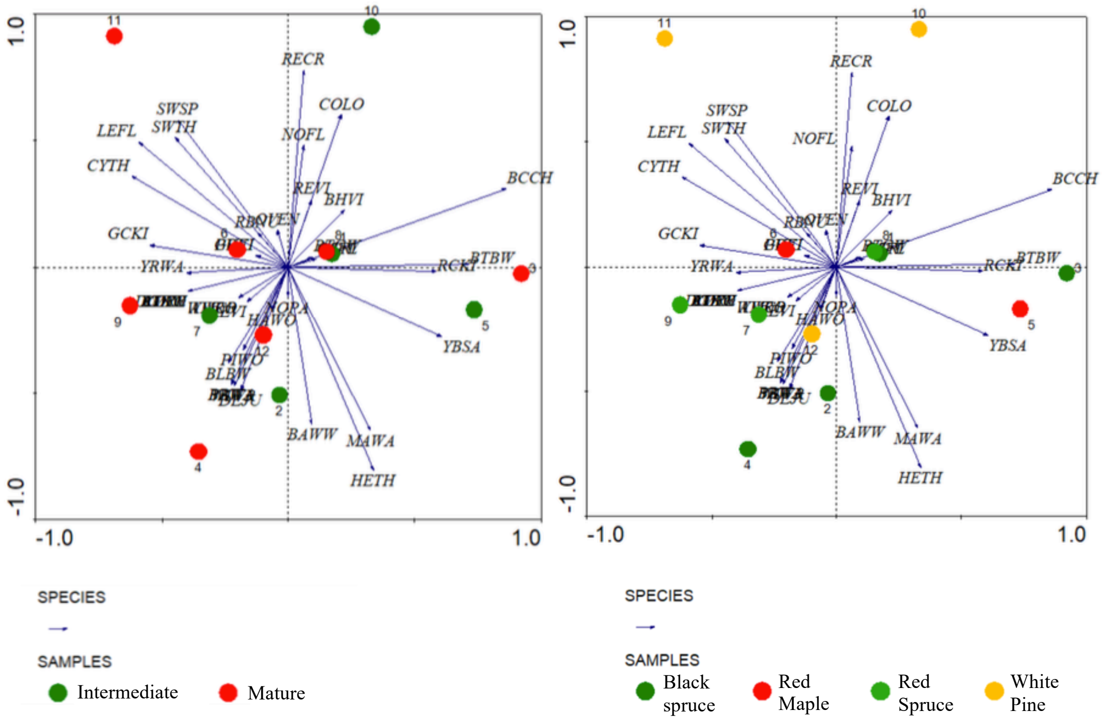


Indicator # 4: Bird Species Composition

Species distribution by dominant tree species and assessment of landbird SAR

Canonical correspondence analysis (CCA) of bird species abundance and composition were not significantly affected by dominant tree species or FRI age class (ps > 0.30). There is a fairly even scatter evident among the 12 plots in the DCA (Figure 14).

Figure 14. Detrended correspondence analysis (DCA) of bird species abundance and composition by FRI age class and by dominant tree species in the Medway Community Forest Cooperative



Observations of bird species of interest was the Red Crossbill (*Loxia curvirostra; RECR*) present in white pine dominated stands (Figure 14). The other species are relatively scattered with no strong trends. Of the three landbird SAR, one individual Olive-sided flycatcher (*Contopus cooperi*) was observed in an intermediate age black spruce stand.

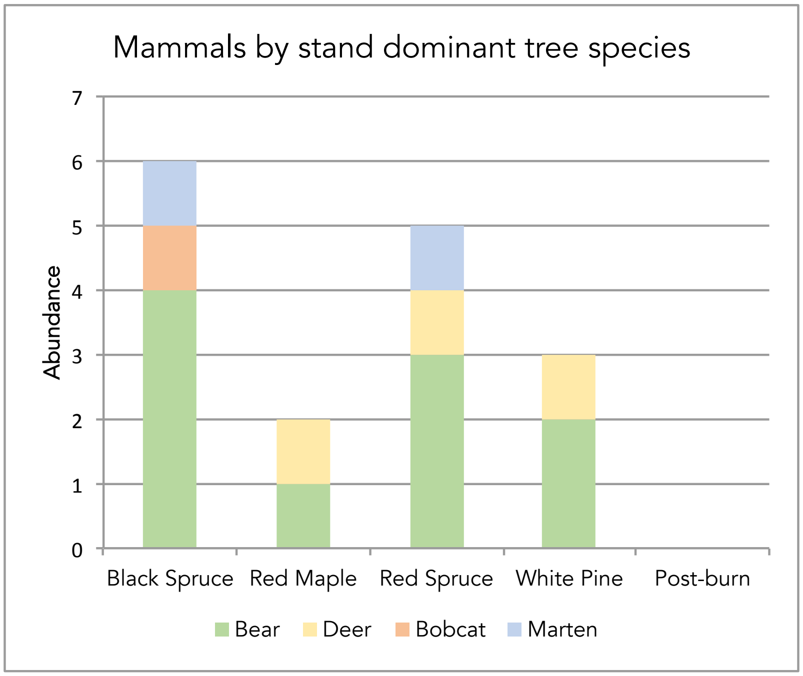
Indicator # 5: Mammal Species Composition

Species distribution by dominant tree species and assessment of SAR

Game camera footage captured images of ten American black bears (*Ursus americanus*), three white-tailed deer *(Odocoileus virginianus)*, one bobcat (*Lynx rufus*), and one American marten

(*Martes americana*) (Figure 15). Based on coat characteristics, it appeared that the same marten was observed in the two plots. There was one individual mammal species at risk observed, American marten.

Figure 15. Mammal species observed in Medway Community Forest Cooperative by dominant tree species



Cumulative Results: 5 Indicators
Forest health assessment by minimum thresholds for natural Acadian forest condition

The forest health assessment is summarized in table 1, which summarizes the metrics and whether they met or failed to meet the determined minimum threshold for natural Acadian forest conditions. The results suggest the forest health is in poor condition given that only 10 of 47 metrics met the minimum threshold, exhibiting a 21.28% passing score. DWD volumes in mature stands in MCFC were generally sufficient (Table 1), although CWD metrics compared between Nova Scotia and Maine in managed and unmanaged stands had 2 of the 12 conditions meet the thresholds, exhibiting a 16.67% passing score. Floristic quality failed across conditions, and 3 of 17 metrics observed species at risk, exhibiting a 17.65% passing score.

Table 1. Forest health assessment matrix: Five forest health indicators exceeding minimum threshold for natural Acadian forest conditions. (green check = exceeded threshold, red ex = below threshold).

Indicator		Intermediate (40-70)				Mature (71-90)			
	Post-burn	Black spruce	Red maple	Red spruce	White pine	Black spruce	Red maple	Red spruce	White pine
MCFC									
DWD total volume ≥ 40 m^3/ha	✗	✗	✗	✗	✓	✓	✓	✓	✓
MCFC vs. Ecological Reserves in Maine (Kuehne et al. 2018)						* (intermediate & mature combined)			
DWD total volume ≥ ERM	-	-	-	-	-	✗	✗	✗	✗
DWD > 40 cm volume ≥ ERM	-	-	-	-	-	✗	✓	✗	✗
Snag TPH ≥ ERM	-	-	-	-	-	✗	✗	✗	✓
MCFC									
FQA Mean C ≥ 4.5	✗	✗	✗	✗	✗	✗	✗	✗	✗
Birds – SAR present	-	✓	✗	✗	✗	✗	✗	✗	✗
Mammals – SAR present	✗	✓	✗	✓	✗	✗	✗	✗	✗

DISCUSSION

Here, I compiled various indicators of forest health to provide a summary of the current state of Medway Community Forest Cooperative. Through comparisons of harvest history in managed and unmanaged stands in Nova Scotia and Maine, the prolonged effects from harvesting are evident. Harvesting effects on ecosystem structure and composition are exposed through varying metrics in intermediate and mature aged stands. The time since disturbance, whether harvesting or fire, correlates with greater coarse woody debris abundance, higher floristic quality and species diversity. The Medway Community Forest Cooperative licence area shows signs of regeneration and recovery of natural Acadian forest conditions, yet the study suggests the forest is in poor condition given less than 22% of the metrics met minimum threshold standards. These results are tentative given the study size and timeframe from one year of assessment that provides an initial assessment. Sample size should be increased to include at least 50 sample plots and reassessed every five years for ongoing monitoring. Such monitoring will be especially valuable if it focuses on the effects of alternative management regimes designed to improve biodiversity conservation.

It is evident that coarse woody debris volumes are reduced through harvesting activities, as supported by the literature (Stewart et al. 2003; McCurdy & Stewart 2005). It is generally observed that snag abundance increases following disturbance and diminishes in the regeneration phase, until old growth dynamics initiate when CWD volumes rebound to natural conditions (Stewart et al. 2003; McCurdy & Stewart 2005; Rolek et al. 2018). Intermediate-aged stands in the study largely present greater CWD volumes than mature stands, suggesting time since disturbance is a contributing factor in the decline in mature stands. CWD dynamics are evidently disrupted, and the effect of forest age reduction across the license area, largely related to historical even-age management, has reduced habitat availability and presumably ecosystem function.

Regional landbird SAR habitat consists of nearly 25% snag composition, commonly in black spruce and balsam fir dominated stands (Staicer & Westwood 2013). Older stands dominated by black spruce or balsam fir, that are in or nearing old growth conditions on the license area, should be designated as valuable bird habitat and management objectives should include increasing snag density and lessening disturbance. Snag density can be promoted through girdling, and by retaining mature trees marked as ecologically valuable, similarly to wildlife and seed trees. Management should determine potential habitat viability due to visible cavity or decay, by designating trees for retention to invest in habitat restoration. Managing snag composition in a given stand should consider a diversity of snag size, height, decay class, location and quantity, and aim for clumps of snags which are beneficial for wildlife (Gardner 2010).

Floristic quality of understory vegetation is shown to rebound overtime, but the persisting impacts are not entirely known (Freyman et al. 2016; Mabry et al. 2018). Rare, endangered, and sensitive species are easily removed from the landscape following disturbance, and the natural recovery is uncertain (Hansen et al. 1991; Haughian 2018). Simplification of the forest floor is likely to have a rippling effect through the ecosystem with adverse impacts on biodiversity.

The study suggests Acadian forest conditions have been simplified through reduced downed woody debris, snags, and floristic quality, resulting in loss of suitable habitat putting more species at risk of extirpation. Few SAR are observed in the initial bird and mammal surveys in the study, and it is necessary to expand monitoring efforts. Surveying a larger area of the license area to identify SAR presence and suitable habitat will better inform management and indicate regions to designate as habitat reserves, free from disturbance.

Uneven-age management and extending the harvest rotation are suggested to support forest restoration and increase more natural conditions (Lahey et al. 2018; Rolek et al. 2018). Specific stands displaying canopy transition should be identified and managed with low intensity to allow for natural gap dynamics to develop with time. Efforts made to restore the age distribution of the forest will support long-term balancing of objectives to maintain biodiversity, ecosystem services and wood biomass removal. Although lessening harvesting disturbance and allowing the forest to mature, and hence restoring multi-age conditions will take decades, it is critical that during this restoration time harvesting be low in intensity and selective. The Medway Community Forest Cooperative operates as a multi-value forest, and the continued development of diverse revenue streams that have lesser impact on the landscape than harvesting will be advantageous to restoring Acadian forest conditions.

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Appendices

Appendix 1. Forest Resource Inventory dominant tree species stand composition for Medway Community Forest Coopertive license area

MCFC FRI stand data	
Dominant tree species	% of stands
Red spruce	31.05
Black Spruce	23.81
White pine	15.62
Red maple	15.53
Balsam fir	3.48
Sugar maple	3.15
Red oak	2.18
White birch	1.62
Eastern hemlock	1.58
Aspen	0.61
Beech	0.32
Red pine	0.32
Eastern larch	0.28
White spruce	0.28
Yellow birch	0.12
Black cherry	0.04

Appendix 2. Understory vegetation FQA CC values

Species	CC value	Species	CC value
Abies balsamea	3	Lycopodium annotinum	5
Acer pensylvanicum	5	Lycopodium obscurum	5
Acer rubrum	3	Maianthemum canadense	3
Acer saccharum	5	Maianthemum dilatatum	5
Aralia hispida	5	Maianthemum racemosum	5
Aralia nudicaulis	4	Melampyrum lineare	6
Betula papyrifera	3	Mitchella repens	5
Betula populifolia	2	Oclemena acuminata	4
Carex spp.	5	Osmundastrum cinnamomea	4
Chimaphila umbellata	6	Picea mariana	6
Clintonia borealis	5	Pinus strobus	3
Coptis trifolia	6	Pteridium aquilinum	3
Cornus canadensis	5	Pyrola americana	6
Dalibarda repens	5	Quercus rubra	4
Dennstaedtia punctilobula	2	Rubus pubescens	6
Erechtites hieraciifolius	2	Sorbus spp.	6
Gaultheria hispidula	6	Spiraea tomentosa	4
Gaultheria procumbens	4	Toxicodendron radicans	3
Gaylussacia sp.	6.5	Trientalis borealis	4
Hamamelis virginiana	5	Trillium undulatum	6
Ilex mucronata	6	Tsuga canadensis	4
Kalmia angustifolia	4	Vaccinium angustifolium	3
Linnaea borealis	5	Vaccinium myrtilloides	5