RAPID ASSESSMENT OF MOTHER TREES TO IDENTIFY BIODIVERSITY HOTSPOTS, CREATE A GIS DATABASE, AND DOCUMENT OLD-GROWTH FOREST STANDARDS:
CENTRAL CATCHACOMA EASTERN HEMLOCK FOREST

Research Report No. 46

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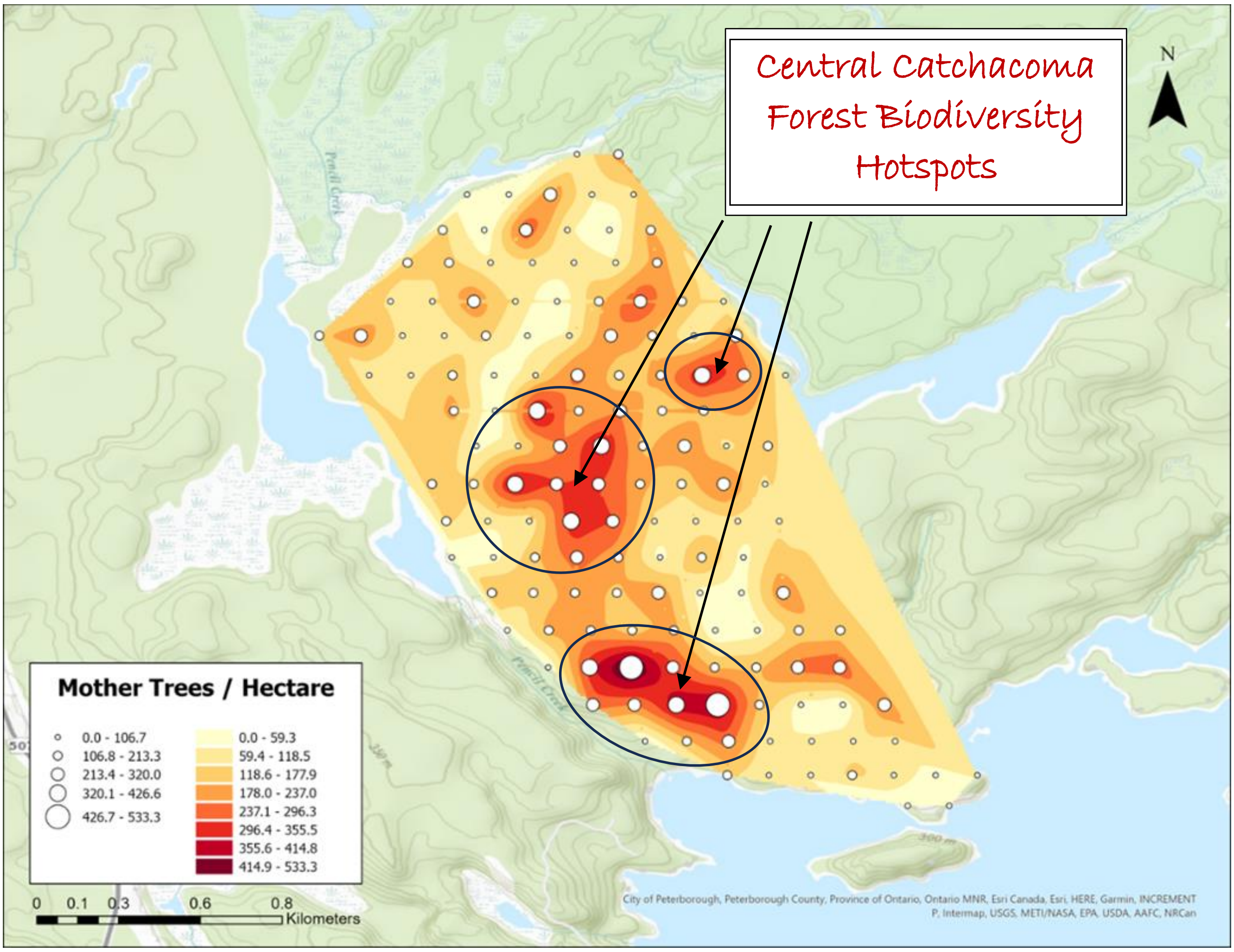

"In the short-term, individual groups and societies might profit from forest destruction. However, with old-growth forest vanishing at an unprecedented pace, mankind as a whole loses the ecosystem services provided by these forests… [including their] spiritual and/or aesthetic nature, genetic resources, non-timber products, habitat for wildlife, the sequestration of carbon, the prevention of floods and erosion, to name only a few... Data on old-growth forests are generally scarce… ***NGOs involved in the protection of old growth or primary forests need fast and efficient survey methods and, given the land-use pressure on the remaining areas, they cannot afford to waste time****."*

(*Old-Growth Forests*, Wirth et al. 2009)

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Summary

1. Three mother tree (MT; or "old-growth tree") hotspots that support the highest MT densities and MT species richness in the study area were identified; two were dominated by eastern hemlock MTs and one was dominated by eastern white pine MTs. Of the three hotspots, the latter has the highest MT densities and richness.

2. One cut stump was found mid-way along the western boundary of the *Central Portion* of the *Catchacoma Forest* during this survey for a density of 0.006 cut stumps/ha across the 181 ha (456 ac.) area. This low disturbance density is among the top few forested landscapes in southern Ontario with the highest level of ecological integrity.

3. Eastern hemlock MTs were by far the most common MT species in the study area at 70% relative abundance. The second-most abundant MT species was eastern white pine at 59% relative abundance, which was 41% higher than the third most abundant MT species, red maple, at 18%. The relative abundance of each of the remaining MT species was less than 12% including red oak (11%), white oak (9%), sugar maple (5%), red pine (5%), yellow birch (4%), large-tooth aspen (4%), northern white cedar (3%), and white birch (1%).

4. The study area as a unit is composed of an eastern hemlock (70%)-eastern white pine (59%)-red maple (18%) upland forest ecosystem, which is likely a rare forest type. Within the study area we found four MT forest types from most to least abundant: (1) eastern hemlock-dominant (47%), (2) white pine-dominant (26%), (3) other MT species dominants (9%), and (4) eastern hemlock-white pine co-dominants (8%). MTs were absent from roughly 10% of the study area.

5. The two hotspots with the highest MT density and richness (*A* and *B*) appear to also have the highest diversity of slope-aspects (indicator of temperature), which is at least partially facilitating high MT richness.

6. Studies that include MT data for temperate coniferous forests are rare. Compared to five other studied forests with MT data, highest MT densities were found in the eastern hemlock-dominated *Catchacoma Forest* (123-194/ha). The second highest MT density is associated with an eastern hemlock-dominated forest in *Connecticut*, USA (125/ha). All four of the stands with the lowest MT densities were dominated by pine forest.

7. At least three studies, one by the *Ontario* government and two by AFER including this one, have identified the carbon component of the *Catchacoma Forest* as significant at the provincial level.

8. Unlike the *USA* and the *European Union* where federal and multi-federal action, respectively, are leading the effort to develop comprehensive standards for the assessment, identification, mapping, and protection of old-growth and primary forests, the *Canadian* federal government has not yet initiated a national effort to develop such standards. The most significant achievement towards this effort in *Ontario* has been the classification of old-growth forest types and the determination of the age-of-onset for each of these forest types. Densities and biomass standards for MTs, snags, logs, and integrity (human disturbance) as well as a rapid and effective field protocol have yet to be developed in *Ontario*.

9. To conduct field surveys for the detection and characterization of old-growth forests in *Ontario*, we recommend rapid assessment of primary old-growth features (MTs, snags, logs, cut stumps). Rapid assessment is required since all eastern hemlock-dominated forests in *Ontario* could be gone by 2075 given current trends. We used systematic rectangular plot (6x30 m alternating at 50 m intervals) placement along evenly spaced transects at a 2% minimum sampling intensity with coverage of the entire 181 ha stand. This methodology facilitates (1) more efficient coverage (by 15X) of larger areas compared to assessing randomly placed and intensively sampled large plots (400 – 500 m^2) typically used for long-term ecological studies, and (2) seamless integration into a GIS database that can be used for mapping and analysis and will serve as the foundation for future long-term ecological studies.

10. The data describing MT densities for the four eastern hemlock forest types (123 - 194 MT/ha) found in the *Central Portion of the Catchacoma Forest* represents a first step towards establishing old-growth forest standards for the old-growth eastern hemlock forests found throughout *Ontario's Great Lakes-St. Lawrence Forest*. However, many more of these old-growth ecosystems need to be sampled for primary old-growth features to ensure representation of all eastern hemlock forest habitat types. Given the continuing decline of old-growth forests, standards should also be developed for the many other forest types that are found in the *Ontario Great Lakes-St. Lawrence Forest*.

11. The *Global Safety Net* (GSN) calls for nature conservation and stewardship at a planetary scale by expanding terrestrial protected areas globally from 15% (currently) to 50% of the land surface through action at the grassroots level. Recent research shows that *Ontario's* most unique and valuable contribution to the GSN is the large extent of roadless areas and the high carbon storage in terrestrial ecosystems. The *Catchacoma Forest*, with its roadless area and its documented high carbon content is precisely the type of unprotected landscape sought for protection by the GSN.

Introduction

Value and Decline of Old Growth Primary Forests

Old-growth forests are exceptionally valuable ecosystems. They represent some of the largest terrestrial carbon stores on the planet (Luyssarert et al. 2008; Moomaw et al. 2019; DellaSala et al. 2022), harbor the highest levels of biodiversity including rare and endemic species (Keith et al. 2009; Morales-Hidalgo et al. 2015; Messick and Davis 2022), provide abundant ecological services such as air and water purification, nutrient cycling, erosion control, and pollinator habitat (Watson et al. 2018; Lindenmayer and Bowd 2022) and provide benefits to human health as well as recreation, education, and research opportunities (Watson et al. 2018; Cannon et al. 2022; Gilhen-Baker et al 2022).

Despite the numerous values of primary (includes old growth) forests, their spatial extent and integrity are declining rapidly across the globe (Fig. 1; Watson et al. 2018; McDowell et al. 2020). *Canada*, in particular, is facing a significant decline of old-growth—between 2000 and 2014, *Canada* lost the greatest amount of primary forest of all countries, representing 20% of global primary deforestation during that time (Beaudry 2019). Primary forest decline is mainly due to factors including industrial logging, land conversion for agriculture, fire, insects, disease, and climate change (Potapov et al. 2017; Lindenmayer and Bowd 2022). A better understanding the components of old-growth primary forests that foster resilience in the face of these threats is critical for the wise management of these unique and rare ecosystems.

Without collecting any on-the-ground, ecological field data to better understand the landscape, both the *Ontario Government* and the *Bancroft Minden Forest Company* have determined that the *Catchacoma Forest* (662 ha) is a redundant landscape element that is adequately represented in protected areas elsewhere in *Ontario*, and therefore, does not require protection as part of *Ontario's* parks and reserves system (MECP 2020, BMFC 2021). This decision contradicts the known decline of primary forests from local to global levels as well as the decline of eastern hemlock-dominated forests in *Ontario* (Fig. 2; Quinby 2023), which will likely result in the loss of these hemlock stands by ~2075, about 50 years from now. Some have called for the immediate protection of all remaining old-growth forests (Dinerstein et al. 2019).

This precipitous, potentially catastrophic decline of eastern hemlock-dominated forests should be a conservation wake-up call for all who consider this forest type integral to *Ontario's* and *Canada's* current and future natural heritage. These forests are critically endangered and require immediate attention particularly since the hemlock woolly adelgid that attacks eastern hemlock has been observed only 120 km south of the *Catchacoma Forest* and continues moving northward.

Figure 1. The Global Decline of Primary Forest and Non-Forest Ecosystems (Green) and Increase of Atmospheric CO_2 (Blue) from 1850-2020 (Makarieva et al. 2023)

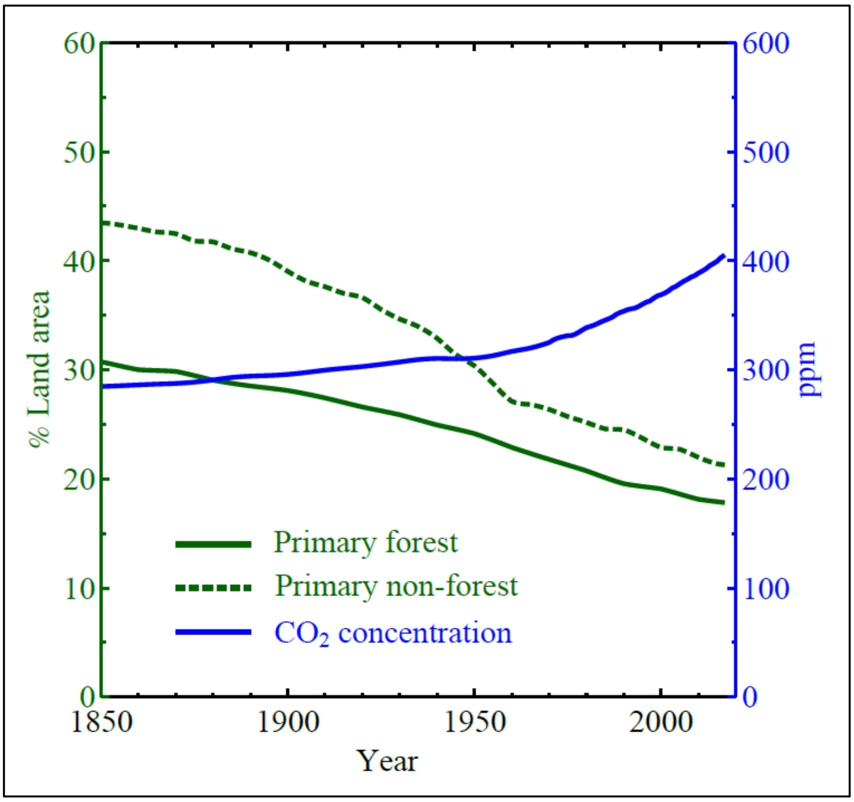
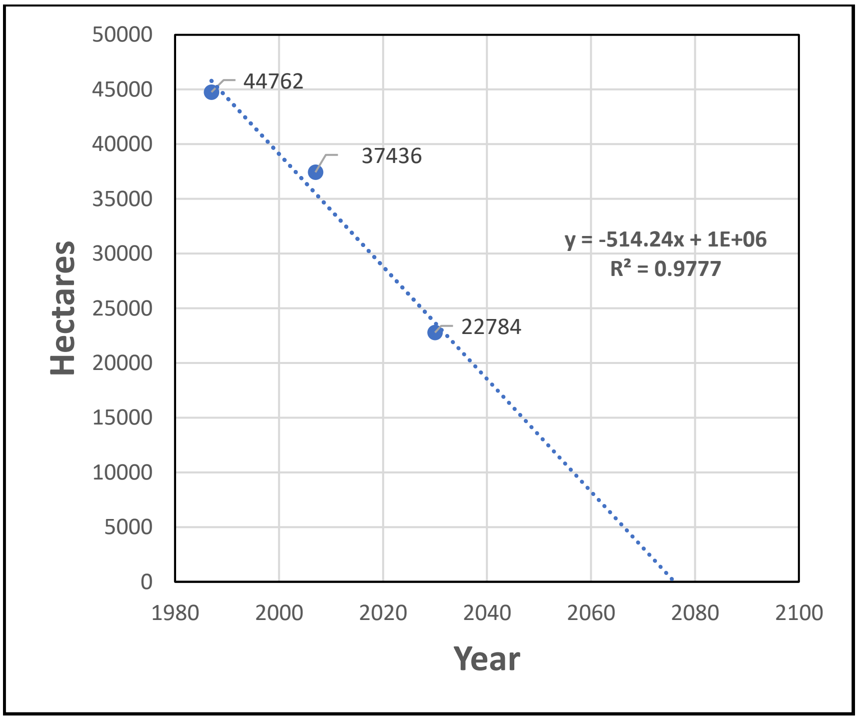


Figure 2. Decline of Eastern Hemlock Dominated Forest in Ontario's Area of Industrial Logging from 1987 to ~2075 (from Quinby 2023; FRI data)



Mother Trees are Keystone Ecological Structures

Mother trees (MTs) are the largest and oldest trees on a landscape and can act as central biodiversity hubs or keystone ecological structures (Liu et al. 2019). As the key component of an old-growth forest, old-growth trees can also be considered MTs, however, not all MTs are old-growth trees. For example, large old trees in urban-suburban areas and on agricultural lands can act as keystone ecological structures providing unique habitat value to insect, bird, and small mammal species despite the absence of old-growth forest conditions (Lindenmayer and Laurance 2017, Liu et al. 2019).

Due to their large size, both above- and below-ground, and to their prolonged lifespans relative to other forest organisms, MTs often have significant influence on hydrological regimes, nutrient cycles, and other ecological processes as well as on the distribution and abundance of many plant and animal species (Nilsson et al. 2003, Lindenmayer and Laurance 2017, Asbeck et al. 2021). MTs use underground mycorrhizal networks to share excess carbon and nitrogen with surrounding trees, particularly those in distress, which increases the health, regeneration, recruitment, and overall resiliency of the surrounding forest (Beiler et al. 2009, Teste et al. 2009, Beresford-Kroeger 2010, Simard 2017, Schiffman 2021, Pardos et al. 2022). Through soil fungi, one MT can be connected to hundreds of individual trees (The Mother Tree Project 2024).

Zahawi et al. (2021) found that the presence of a MT within 100 m of a restoration plot resulted in a 10-fold increase in tree seedling recruitment within the plot indicating that the effect of MT abundance on recruitment density is significant but does have its spatial limits. Further, high MT age and density in a pine forest was found to improve seedling growth and survival (Mao et al. 2014). MT complexes also maintain a tremendous amount of biodiversity, particularly within the soil ecosystem, which increases the forest's ability to tolerate stress. Finally, they often have unique genetic variations that help the population withstand disturbance, stress, extreme climate, and competition with other species, making them valuable gene pools for maintaining resiliency in forest ecosystems (Struve and McKeand 1994, Frelich and Reich 2003, Cannon et al. 2022).

Eastern Hemlock is a Foundation Species

"*Foundation species create, define, and maintain entire ecological systems*" (Foster 2014). As a foundation species, eastern hemlock-dominated forests embody the four features that characterize this designation (Foster 2014): (1) they account for most of the biomass in these stands, (2) they occupy the base of the food web, (3) they are well-connected to many other species, particularly through underground mycorrhizal fungi, and (4) it is a cherished, iconic, long-lived tree species that is highly prized by society for its multiple values. "*The loss of a foundation species from an ecosystem can have dramatic, cascading effects on other species in the system; on ecosystem stability, resilience, and functioning; and can change our perception of the landscape itself*" (Ellison et al. 2015).

The short flat needles of eastern hemlock trees produce a dense canopy that shuts out solar radiation creating a unique understory microclimate of high humidity and lower temperatures during the warm seasons (HCNS 2024). These dense canopies can reduce temperatures at the soil surface by as much as 20 deg C, can keep stream temperatures low supporting benthic invertebrates and fish species such as brook trout, and their canopies provide habitat for diverse communities of spiders that are absent or rare in nearby hardwood forests (Foster 2014). They can also grow in very low light levels (tolerant of shade) allowing their seedlings to establish and regenerate on the same sites for thousands of years. During the cold seasons, the insulating capacity of eastern hemlock canopies and their ability to intercept snow and freezing rains provides valuable shelter to white-tailed deer, moose, and other wildlife species. A review of the value of eastern hemlock forests to birds, small mammals, and forest carnivores is provided by Yamasaki et al. (1999). In summary, the unique ecological role and function of eastern hemlock cannot be replaced by any other tree (HCNS 2024).

Purpose

Currently, little is known about MT density and richness patterns and dynamics within forest ecosystems including in eastern temperate forests of *Canada* and the *USA*. To address this, AFER surveyed MTs in the *Central Portion of the Catchacoma Forest* located in northern *Peterborough County, Ontario*, which is the largest documented old-growth eastern hemlock stand in *Canada* (Quinby 2019). This unique and valuable stand remains unprotected. The objectives of this study were: (1) to create a MT GIS database, (2) to create heat maps of MTs as a group and by species, (3) to characterize MT forest types, (4) to initiate the development of old-growth forest standards by quantifying the density of MTs and cut stumps, and by demonstrating an effective and efficient protocol, and (5) to explore the relationship between MT density and slope-aspect (temperature). Objective (5) was addressed qualitatively and requires further analysis using quantitative methods. Results of this work will provide a better understanding of the ecology of the *Catchacoma Forest* and can be applied directly or modified to develop standards and field assessment protocols for identifying and characterizing old-growth forests at the highest level (MTs and cut stumps), particularly in the *Great Lakes-St. Lawrence Forest* region.

Study Area and Methods

For this study, we defined MTs as trees that met the minimum old-growth diameters (OMNR 2003, Quinby 2020) shown in Table 1. Using these minimum diameters, we surveyed for MTs in the *Central Portion of the Catchacoma Forest* (study area; Fig. 3) in October and November of 2022. The Forest is located in northern *Peterborough County* about 50 km north of *Peterborough, Ontario* between *Highway 507* and *Kawartha Highlands Provincial Park* at the north end of *Catchacoma Lake*. Prior to data collection in the field, *Google Earth* was used to: (1) determine the number and location of transects and plots that were needed to sample 2% of the study area (Table 2) and (2) determine the size of the study area (181 ha).

Dennsmore et al. (2009) state that sampling intensity varies depending on conditions including available resources (largely staff time and access dollars), presence of rough terrain, high species diversity, and remote access. Intensity of sampling also depends on how the data will be used, the uniformity of the stand, and its size. Sampling percentages can range from as low as 0.2 percent using fixed-radius regeneration plots in homogeneous stands to 20% for variable-radius plots in small diverse forests. As acreage increases, inventory intensity typically decreases (NRCS 2018). When using a 314 m^2 randomly placed plot, Dennsmore et al. (2009) state that a 2 - 3% sample of natural forest habitat is usually adequate, which lines up closely with our use of 300 m^2 plots at a 2% sampling intensity. To meet the 2% sample requirement, we assessed 141, 300 m^2 plots along 19 transects (Fig. 3).

Table 1. Minimum Diameters for Mother Trees in Central Catchacoma Forest (Quinby 2020)

Species	Minimum Old-growth Age (yrs)	Minimum Diameter (DBH, cm)
Eastern Hemlock (*Tsuga canadensis*)	140	40
Eastern White Pine (*Pinus strobus*)	120	50
Large-toothed Aspen (*Populus grandidentata*)	90	40
Red Maple (*Acer rubrum*)	90	35
Red Oak (*Quercus rubra*)	120	50
Red Pine (*Pinus resinosa*)	120	40
Sugar Maple (*Acer saccharum*)	120	35
White Birch (*Betula payrifera*)	100	35
White Cedar (*Thuja occidentalis*)	110	30
White Oak (*Quercus alba*)	120	40
Yellow Birch (*Betula alleghaniensis*)	140	45

The 19 evenly spaced east-west transects allowed for 141 plots to be sampled, which is a higher number than the minimum needed to achieve a 2% sample. Transects were drawn onto a live *Google Earth* map of the study area and were saved as a *Google Earth Project* for later use in the field when the *Google Earth Project* was opened on a mobile device to provide a live map overlain with the transects to be sampled. This allowed field techs to view their moving location relative to the transects in real time during sampling.

Figure 3. The Western, Central, and Eastern Portions of the Catchacoma Forest, and the 19 Transects Sampled in Central Catchacoma Forest, Ontario
(parallel yellow lines = transects)

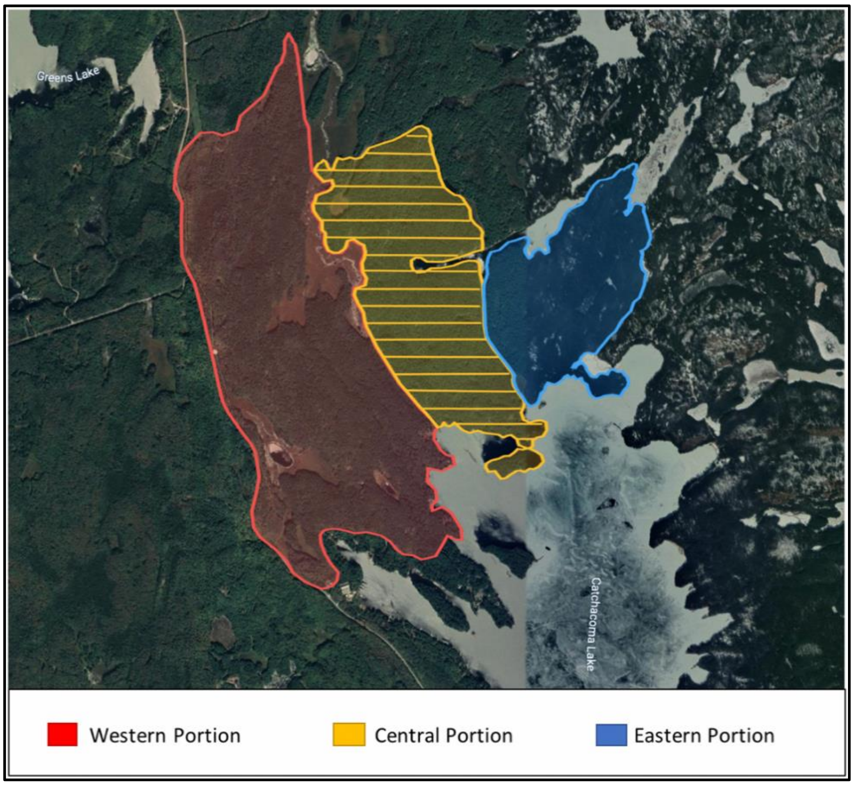


Table 2. Length, Number of Plots, and Start and End GPS Coordinates of each Transect in Central Catchacoma Forest

Transect #	Length (m)	No. of Plots	GPS Coordinate of Start	GPS Coordinate of End
1	152	2	44°46.0176′ N 78°19.9458′ W	44°46.0176′ N 78°19.8325′ W
2	654	7	44°46.0730′ N 78°20.7820′ W	44°46.0730′ N 78°19.2728′ W
3	721	7	44°46.1345′ N 78°20.4218′ W	44°46.1345′ N 78°19.9310′ W
4	818	8	44°46.2010′ N 78°19.9503′ W	44°46.2010′ N 78°20.5166′ W
5	843	8	44°46.2686′ N 78°20.5979′ W	44°46.2686′ N 78°20.0316′ W
6	850	9	44°46.3361′ N 78°20.6719′ W	44°46.3361′ N 78°20.0301′ W
7	829	8	44°46.4041′ N 78°20.1337′ W	44°46.4041′ N 78°20.7000′ W
8	837	8	44°46.4686′ N 78°20.7724′ W	44°46.4686′ N 78°20.2061′ W
9	871	9	44°46.5341′ N 78°20.1409′ W	44°46.5341′ N 78°20.7827′ W
10	865	9	44°46.6013′ N 78°20.8085′ W	44°46.6013′ N 78°20.1667′ W
11	823	8	44°46.6707′ N 78°20.1615′ W	44°46.6707′ N 78°20.7278′ W
12	709	7	44°46.7343′ N 78°20.7688′ W	44°46.7343′ N 78°20.2780′ W
13	1130	11	44°46.7989′ N 78°20.1295′ W	44°46.7989′ N 78°20.9789′ W
14	1087	11	44°46.8707′ N 78°20.0127′ W	44°46.8707′ N 78°20.2199′ W
15	1096	9	44°46.9330′ N 78°20.2413′ W	44°46.9330′ N 78°20.9401′ W
16	852	7	44°47.0031′ N 78°20.8341′ W	44°47.0031′ N 78°20.4377′ W
17	586	6	44°47.0627′ N 78°20.3927′ W	44°47.0627′ N 78°20.7891′ W
18	461	5	44°47.1272′ N 78°20.4050′ W	44°47.1272′ N 78°20.7448′ W
19	152	2	44°47.2003′ N 78°20.5457′ W	44°47.2003′ N 78°20.4324′ W
Total	**14,336**	**141**		

The *Google Earth* map was used as a guide to reach the starting point of each transect. The *Google Earth* measuring tool was then used to draw a 50 m east-west line (transect) from the start point to the end point of the first plot along the transect. Another 50 m was then traversed along the transect leading to the start of the next plot. This rapid approach was repeated until the end of the transect was reached and all plots along it were sampled every other 50 m. A compass was used to check that transect lines were oriented east-west. This kind of systematic random sampling is generally considered to be more efficient than simple random sampling under normal forest conditions (Jayaraman 1999), and strip and transect line (our method) sampling are most suitable for sampling in a forest with highly variable environmental (habitat) gradients (NRCS 2018), which is typical of the *Catchacoma Forest*. Rapid assessment is required since eastern hemlock-dominated forests in *Ontario* are disappearing quickly and could be gone by 2075 given current trends (Fig. 2).

Within each 6 x 50 m plot, the number and species of MTs within 3 m of each side of the transect line were recorded. Tree DBH was not measured unless it was unclear whether the tree met the minimum diameter requirement, in which case the DBH was checked. By not measuring the DBH of every potential and actual MT tree, samples were obtained much faster maximizing field sampling efficiency. MT plot density data were used in natural neighbor interpolation analyses (*ArcGIS ESRI Software* v.2023) to (1) produce heat maps of MTs (density, richness) used to identify *biodiversity hotspots* and (2) to examine the potential influence of slope-aspect (indicator of temperature) on MT density and richness patterns (Astrom et al. 2007). We define "biodiversity hotspots" as areas of high MT species density and richness (Reid 1998). Hotspot boundaries were not quantitatively determined and were used for visual inspection purposes only. Forest classification values (%) for the components of each forest type are provided to show how the different forest types were distinguished using MT density data for the purposes of this study.

Results

Ecological Integrity

One cut stump was found mid-way along the western boundary of the *Central Portion of the Catchacoma Forest* during this survey for a density of 0.006 cut stumps/ha across the 181 ha (456 ac.) study area. This low disturbance density is among the top few landscapes with the highest levels of ecological integrity in southern *Ontario*. If the sample plot with the cut stump was removed from the study area it would be reduced by 1 ha to 180 ha leaving the remainder as "pristine landscape". For this study we included the plot with the cut stump since we prefer to include *Pencil Creek* as the continuous natural western boundary of the study area.

Mother Tree Forest Types

Using MT species density field data, we found that the study area as a unit is composed of an eastern hemlock (70%)-eastern white pine (59%)-red maple (18%) upland forest ecosystem. Within the study area, four MT forest types were found including from most to least abundant: (1) eastern hemlock-dominant (47%), (2) white pine-dominant (26%), (3) other MT species dominants (9%, see Table 1 for other species), and (4) eastern hemlock-white pine co-dominants (8%) (Table 3). Mean MT density for the entire study area (181 ha), including the portions with no MTs, was 149 MT/ha. However, MT density varies substantially across the landscape in this study area (0 - 533/ha; see variation in Figs. 2 - 14). MTs were absent from roughly 10% of the study area where young forests, mature forests, and wetlands were common.

Within the study area, highest MT densities were found in the eastern hemlock-dominant type (194 MT/ha), and lowest densities were found both in the white pine-dominant type (123 MT/ha) and in the eastern hemlock-white pine co-dominant type (133 MT/ha). On average, eastern white pine MTs are larger than all other MT species. Thus, these lower densities likely do not reflect lower biomass levels due to the superior size and high growth rate of eastern white pine individuals. The other MT dominant forest type (9%) has the second highest MT density of the four forest types, which indicates favorable growing conditions for the tree species other than eastern hemlock and eastern white pine. Its cover of only 9%, however, indicates a somewhat rare habitat type at least within the study area. Table 3 can be considered the start of establishing old-growth forest standards for eastern hemlock forest located in *Ontario's Great Lakes-St. Lawrence Forest* since we were unable to find this standards information elsewhere. Much more data from many other old-growth stands are required to complete this standards development process.

Table 3. Densities of Four Mother Tree Forest Types in Central Catchacoma Forest
(He=hemlock; Pw=white pine; Mr=red maple; Ot=other MT spp.)

MT Type	Forest Classification Values (MT %)	% of Plots	No. Plots	Density (mean MT/ha)	Range (MT/ha)
All (He-Pw-Mr)	He: 70+; Pw: 40-69; Mr: 10-39	100	141	149	0 - 533
He dominant	He: 30+ > Pw; Ot	47	66	194	33 - 533
Pw dominant	Pw: 30+ > He; Ot	26	37	123	33 - 266
No MTs	na	10	14	0	0
Other MT species dominants	Ot: 30+ > He; Pw	9	13	169	33 - 433
He-Pw co-dominant	He & Pw within 5 of each other	8	11	133	67 - 333

Mother Tree Species

Eastern hemlock MTs were by far the most common MT species in the study area at 70% relative abundance (Table 4). The second-most abundant MT species was eastern white pine at 59% relative abundance, which was 41% higher than the third most abundant MT species, red maple, at 18%. The relative abundance of each of the remaining MT species was less than 12% including red oak (11%), white oak (9%), sugar maple (5%), red pine (5%), yellow birch (4%), large-tooth aspen (4%), northern white cedar (3%), and white birch (1%).

Table 4. Plot Frequency for 11 Mother Tree Species in Central Catchacoma Forest

MT Species	Plot Frequency (%)
Eastern hemlock	70
Eastern white pine	59
Red maple	18
Red oak	11
White oak	9
Sugar maple	5
Red pine	5
Yellow birch	4
Large-tooth Aspen	4
Northern white cedar	3
White birch	1

Mother Tree Mapping

MT species mapping results were grouped into the following categories: (1) all MT species combined (density and species richness), (2) MT species with >50% coverage, (3) MT species with 10+ occurrences, (4) MT species with 6 - 9 occurrences, and (5) MT species with 1 - 5 occurrences. The only habitat variable included in this study was slope-aspect, which was mapped as a broad indicator of temperature using nine categories including flat (intermediate), north (cold), northeast (cold), east (intermediate), southeast (warm), south (hot), southwest (hot), west (warm), and northwest (cool).

All Mother Tree Species Combined

MT density and species richness mapping (Fig. 4 and Fig. 5) was used to identify three biodiversity hotspots (largest and highest MT densities and richness) including, from most to least dense and species rich:

Biodiversity Hotspot A, *Biodiversity Hotspot B*, and *Biodiversity Hotspot C* (boundaries not quantitatively determined). Although there are other areas of high MT density and richness in the study area, only these three hotspots will be addressed in this report.

Figure 4. Density of Mother Trees (no./ha) of all 11 Species Combined In the Central Catchacoma Forest with Locations for the Three Largest Biodiversity Hotspots (A, B, C)

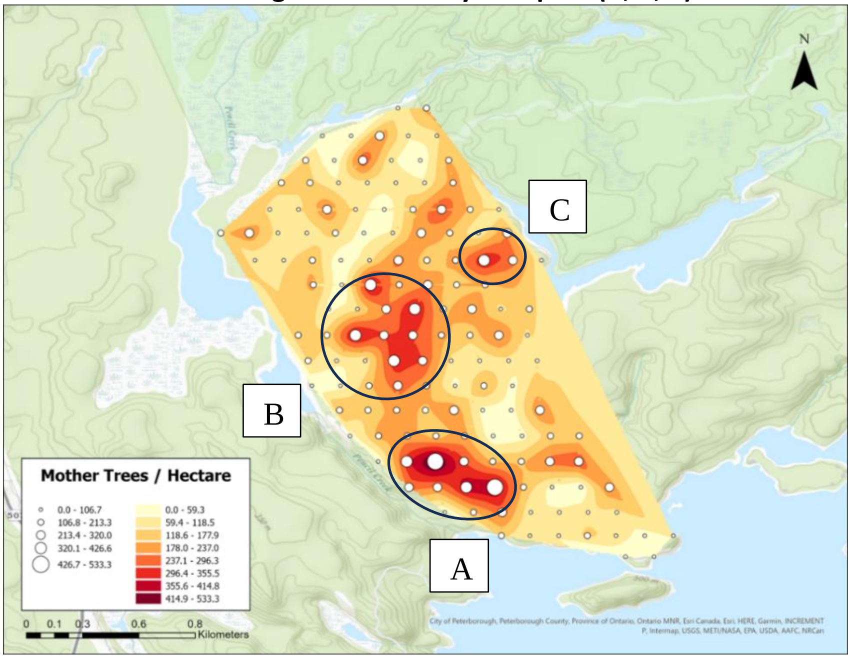
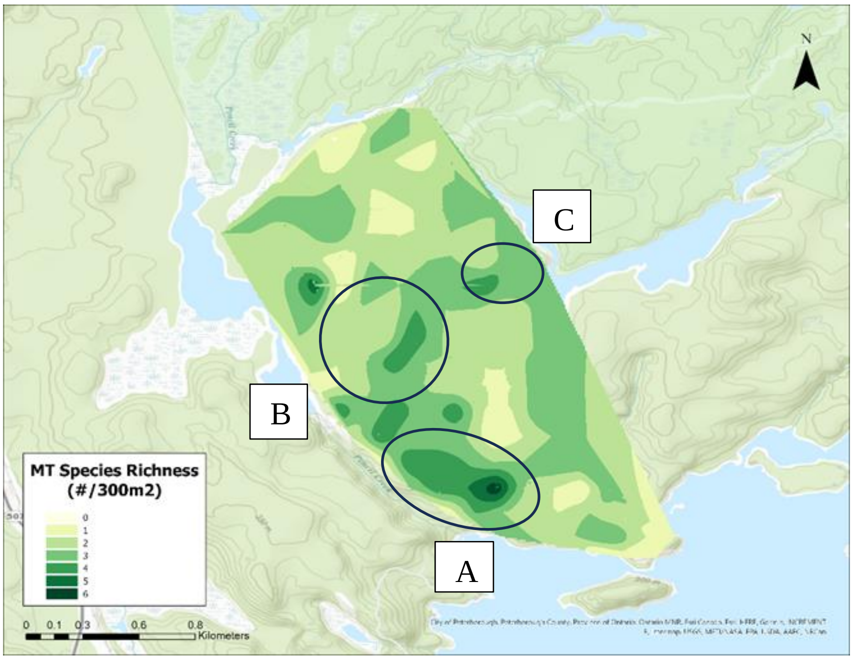


Figure 5. Mother Tree Species Richness (no./300m^2) in Central Catchacoma Forest



Hotspot A, located in the southern portion of the study area and close to *Catchacoma Lake*, is intermediate in size between *Hotspots B* and *C* (Figure 4). However, not only is *Hotspot A* the densest but it also has the highest MT species richness in the study area (Figure 5). High density *Hotspots B and C* also have relatively high MT species richness. Thus, this mapping shows that MT density and species richness are associated, likely through the influence of high-quality and/or high-diversity habitat. This association should be explored in detail in future studies.

Dominant Mother Tree Species (>50% Study Area Coverage)

Figures 6 and 7 show the spatial distribution of eastern hemlock and eastern white pine MTs, respectively, which are by far the most common MT species in the *Central Portion of the Catchacoma Forest*. In *Hotspot A* (Figure 4), eastern white pine MTs are dominant due to their high densities and the lower densities of eastern hemlock and the other MT species. Conversely, *Hotspots B and C* (Figure 4) are dominated by eastern hemlock where its MT density is highest and where eastern white pine MTs and other MT species are generally low in abundance.

Sub-dominant Mother Tree Species (10+ occurrences)

There are 10+ occurrences each of red maple and red oak MTs in the *Central Portion of the Catchacoma Forest*. The highest concentrations of red maple MTs are centrally located in the study area (Figure 8), with other occurrences distributed throughout the study area. Red oak concentrations and other occurrences (Figure 9) are distributed throughout the study area.

Figure 6. Density of Eastern Hemlock (He; no./ha) Mother Trees in Central Catchacoma Forest

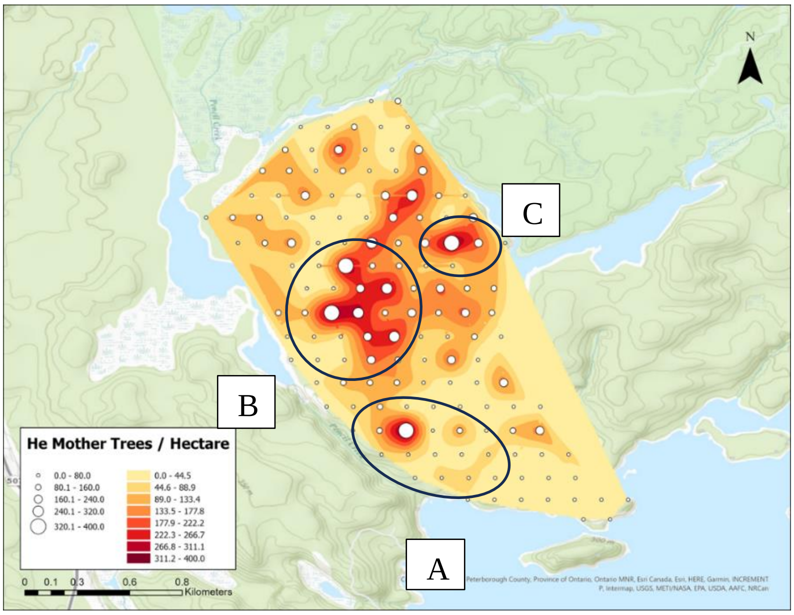


Figure 7. Density of Eastern White Pine (Pw; no./ha) Mother Trees in Central Catchacoma Forest

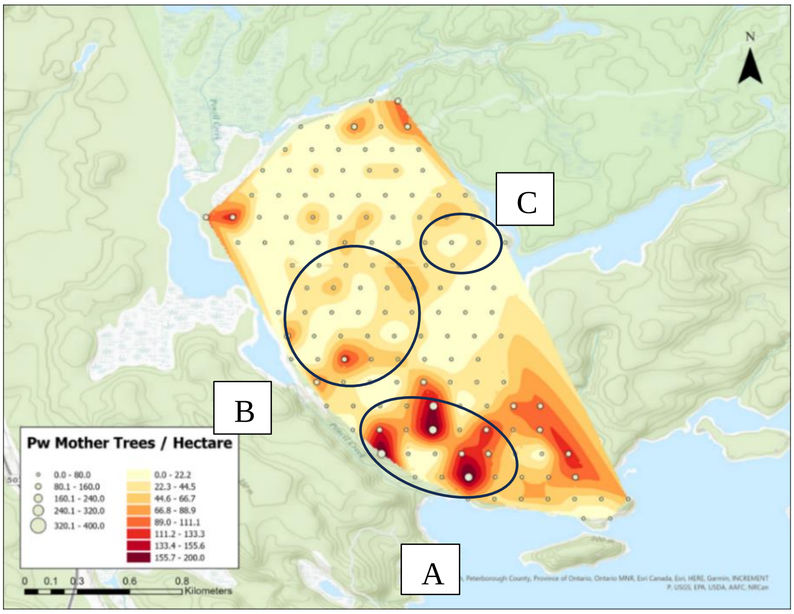


Figure 8. Density of Red Maple (Mr; no./ha) Mother Trees in Central Catchacoma Forest

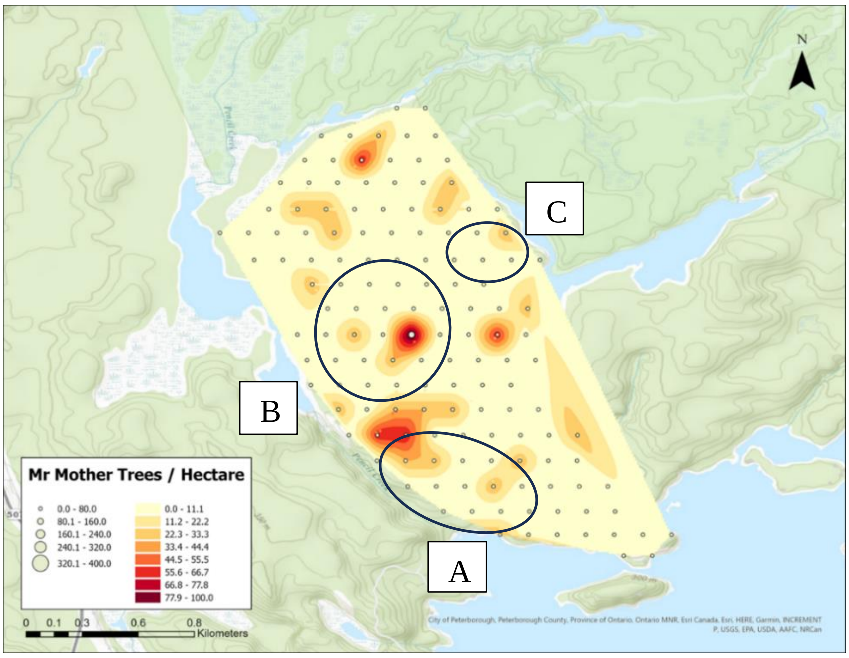
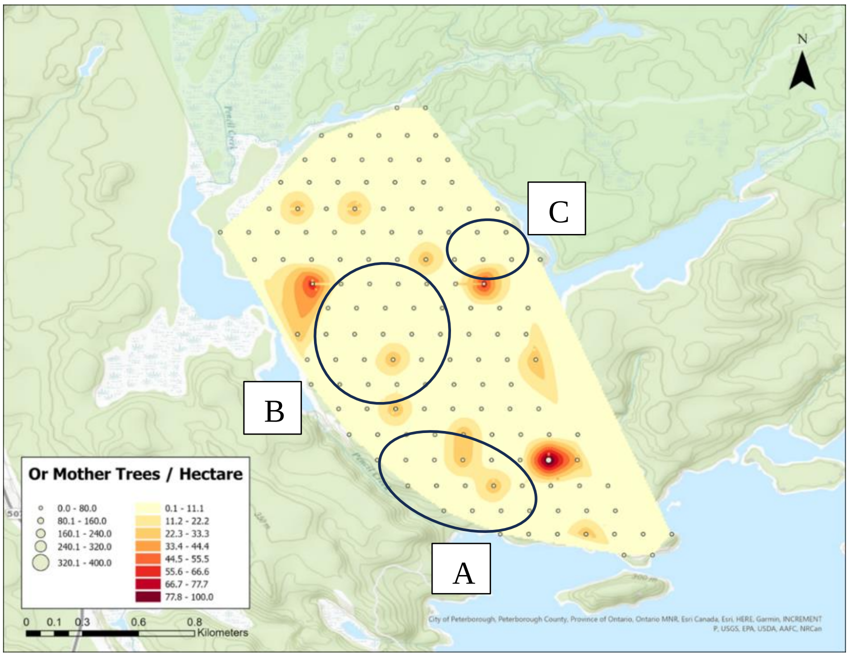


Figure 9. Density of Red Oak (Or; no./ha) Mother Trees in Central Catchacoma Forest



Minor Mother Tree Species (5 - 9 occurrences)

High MT densities for white oak (8 occurrences), red pine (5 occurrences), and sugar maple (5 occurrences) are all associated with *Hotspot A.* These MTs are also found at low densities throughout other portions of the study area (Figures 10 - 12).

Figure 10. Density of White Oak (Ow; no./ha) Mother Trees in Central Catchacoma Forest

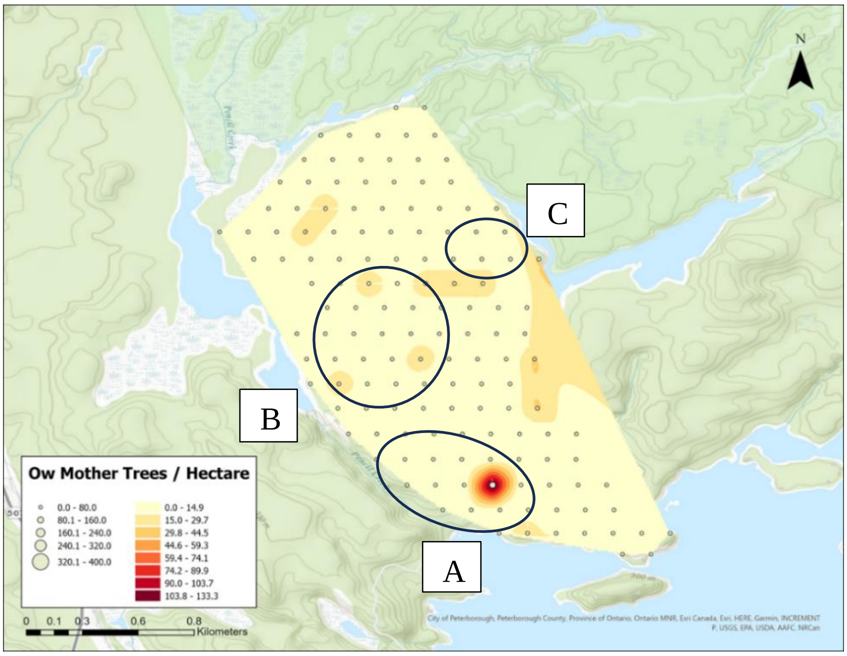


Figure 11. Density of Red Pine (Pr; no./ha) Mother Trees in Central Catchacoma Forest

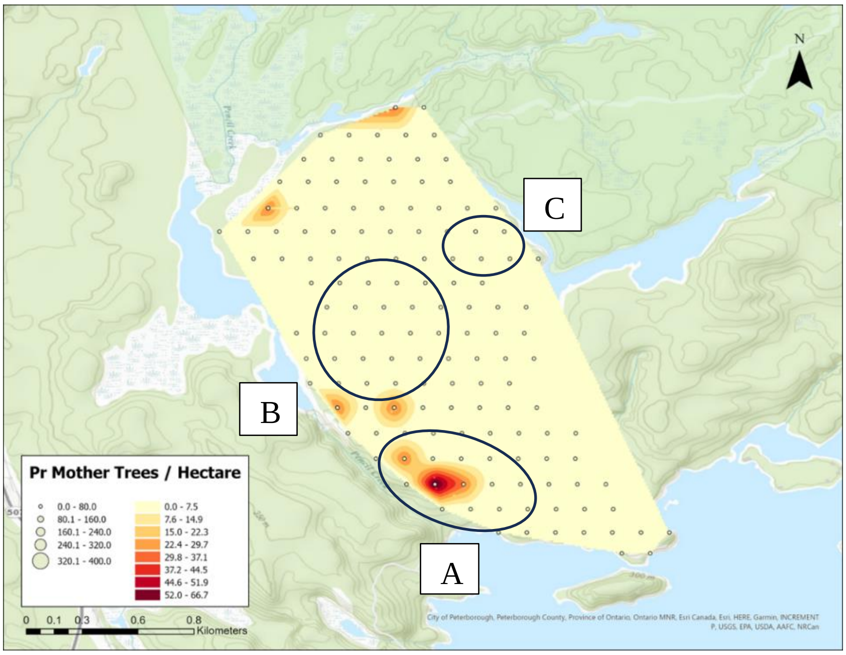
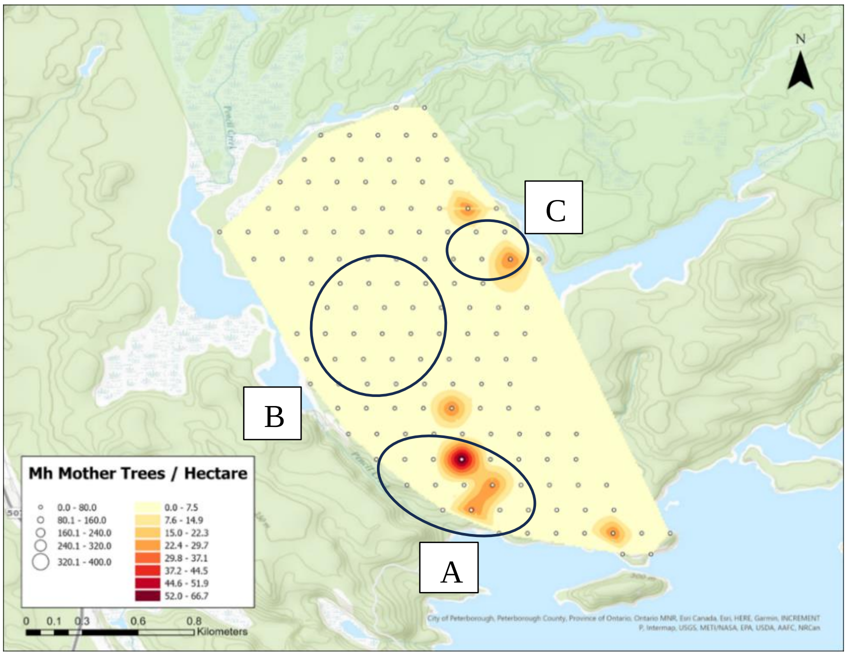


Figure 12. Density of Sugar Maple (Mh; no./ha) Mother Trees in Central Catchacoma Forest



Rare Mother Tree Species (1 - 4 occurrences)

High MT densities for white cedar (4 occurrences), yellow birch (3 occurrences), and large-tooth aspen (3 occurrences) are all associated with *Hotspot A* (Figures 13 – 15). These MTs are also found at low densities in other portions of the study area. The one occurrence of the least common MT, white birch, is located adjacent to *Hotspot A.*

Figure 13. Density of White Cedar (Cw; no./ha) Mother Trees in Central Catchacoma Forest

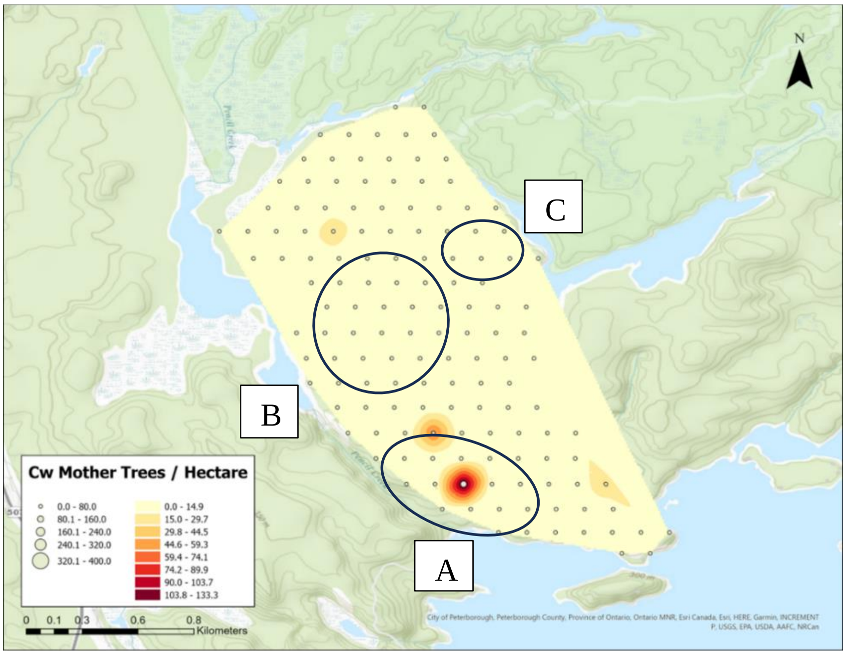


Figure 14. Density of Yellow Birch (By; no./ha) Mother Trees in Central Catchacoma Forest

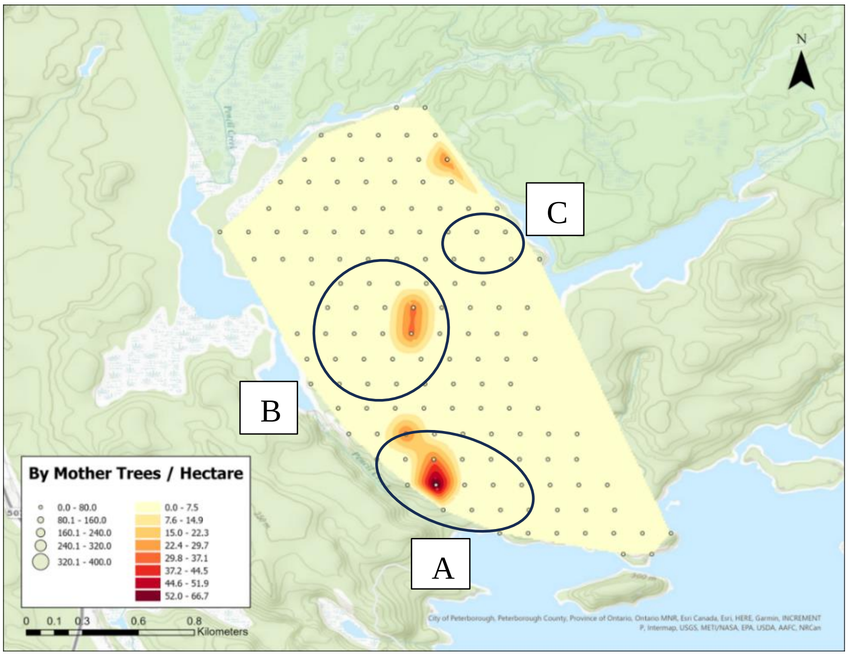


Figure 15. Density of Large-toothed Aspen (Pl; no./ha) Mother Trees in Central Catchacoma Forest

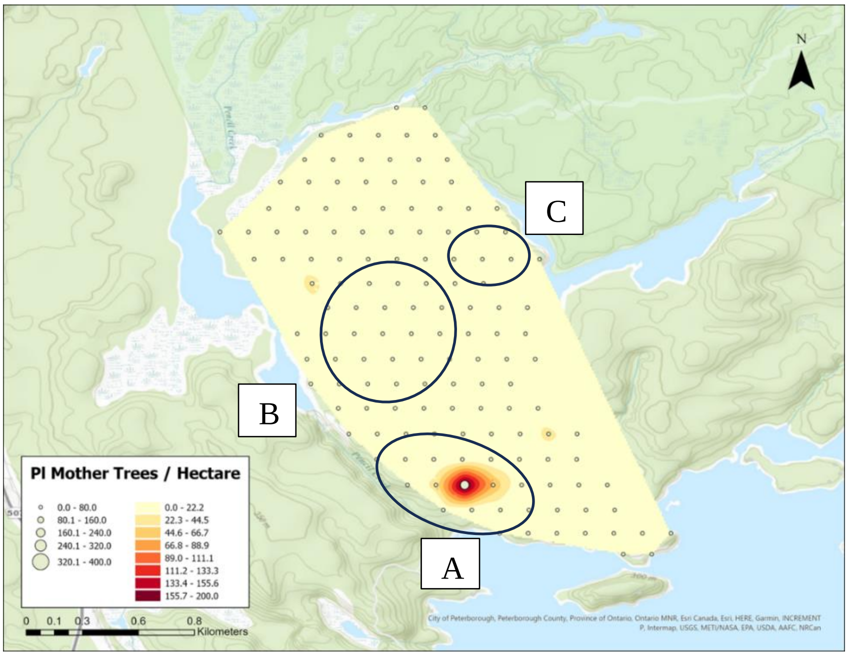
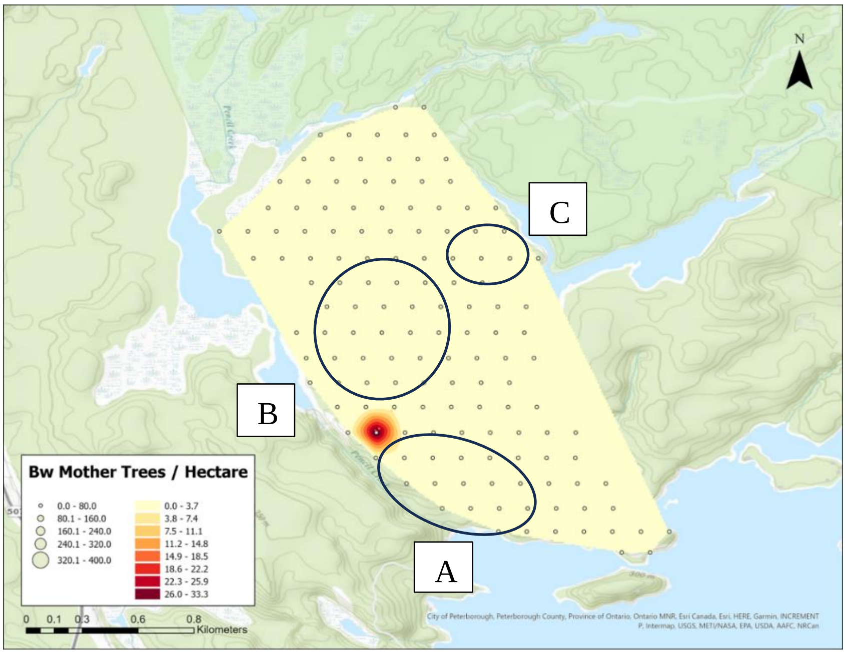


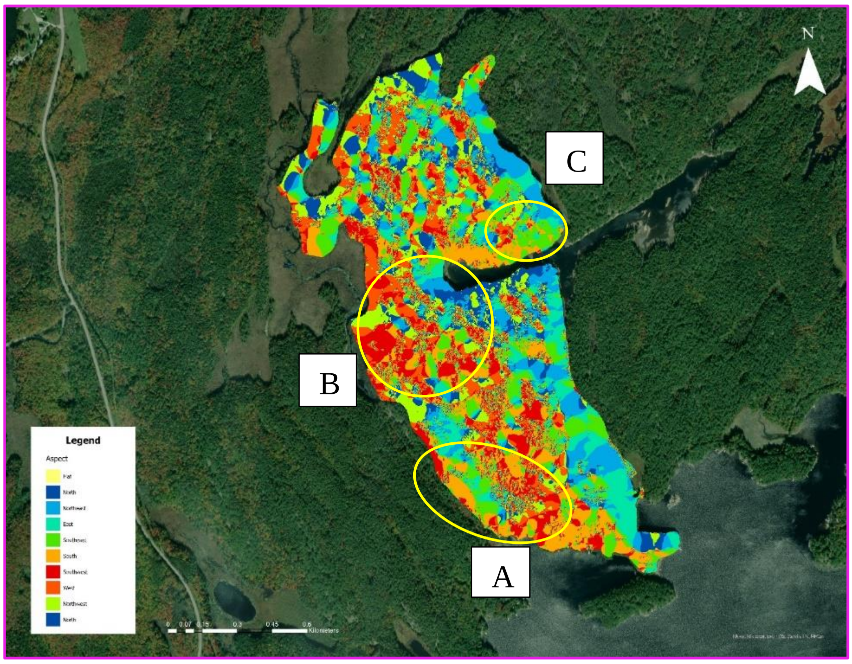
Figure 16. Density of White Birch (Bw; no./ha) Mother Trees in Central Catchacoma Forest



Slope-Aspect Distribution

Based on visual inspection of the map of slope-aspect (N, S, E, W, etc.) in the study area (Figure 17), *Hotspots A and B*, the two highest MT density areas, also appear to have the highest diversity of slope-aspects. This high habitat diversity is likely facilitating high MT densities and should be further examined quantitatively.

Figure 17. Slope-Aspect as a Temperature Indicator in Central Catchacoma Forest



Biodiversity Hotspots A, B and C

Hotspots B and *C* are dominated by the most common MT species in the study area, eastern hemlock, and *Hotspot A* is dominated by eastern white pine, the second-most abundant MT species. Except for one small area NW of *Hotspot B*, all three identified hotspots have higher MT species richness compared to the other portions of the study area. A visual examination of the mapping shows that, in general, more MT species and higher MT densities are associated with the eastern white pine-dominant forest compared to the eastern hemlock-dominant forest.

Regional Comparison of MT Densities

Evaluating our results from the *Central Portion of the Catchacoma Forest* is difficult since usable data describing MT densities for old-growth hemlock and pine forests in eastern *North America* is scant, particularly since the age of onset can vary substantially among tree species and some studies apply one minimum DBH for all MT species. In addition, although many studies of old-growth forests provide tree density data, often these data do not separate out MT data (oldest age class) from the other younger tree age classes. Table 5 compares MT densities from six studies located in *Ontario*, *New England* and one from *Pinus nigra* forests in *Spain*. As more work in this area is done with these species, the data can be added to the *Mother Tree Density Table*.

Table 5. Mother Tree Densities for Hemlock and Pine Forests from Six Studies

Location	Forest Type Dominant Species	Tree Condition	Inclusive DBH (cm)	MT Density (no./ha)	Mother Tree Density Rank	Source
Ontario *(Catchacoma)*	11 tree species *(see Table 1; mostly eastern hemlock)*	live	species-specific *(see Table 1)*	123 - 194 mean=149 *(4 forest types)*	1	Marcus & Quinby (2024) *(this study)*
Connecticut	eastern hemlock	live	>/= 40	125	2	Ward & Smith (1999)
Maine	pine forest	live & dead	>/= 40	130	3	Manomet (2009)
Ontario *(central)*	red & white pine	live	>60 *(super-canopy)*	49	4	Kirk et al. (2012)
	red & white pine	live	38 - 60	29 *[49+29=78]*		
Ontario *(Temagami)*	white pine	live	>/= 38	10 - 50	5	Quinby (1991)
	red pine	live	>/= 29	9 - 60		
	red & white pine	dead	>/= 10	30		
Spain *(southern)*	Austrian pine *(Pinus nigra)*	live	>/= 50	40	6	Tiscar & Lucas-Borja (2016)

Due to the problem of comparing means, minimums, and ranges of MT densities to each other as well as comparing MT data between and among different forest types and tree species with different minimum DBHs, a MT density ranking was used. A rank of 1 indicated the highest MT densities, found in the *Catchacoma Forest* (123-194/ha), whereas a ranking of 6 indicated the lowest MT densities, which was found in *Spain* (pine forest; 40/ha) (Table 5). The second highest MT density is associated with eastern hemlock-dominated old-growth forest in *Connecticut*, *USA* (125/ha). MT densities from the four studies of old-growth pine forests are all lower than those from the *Catchacoma* and *Connecticut* studies of eastern hemlock old-growth forests. Given the current disparity of comparable density criteria (e.g., minimum DBH, mean, range) it is not possible to quantify differences in MT densities among and between old-growth types from these six studies.

Discussion

The most significant results from this study include: (1) identification of four MT forest types including the hemlock-white pine forest type that is absent from government forest classifications and is likely rare, (2) identification of the top three *Catchacoma Forest Biodiversity Hotspots* (see A, B, and C on maps) showing both high MT densities and species richness as well as potential MT species connections (unsampled areas) within and outside of the hotspots, (3) determination of MT density values for the study area as a unit as well as for each of the four higher resolution old-growth forest types that can serve as the basis for developing old-growth standards, and (4) demonstration of a simple, rapid, and easily adaptable field data collection protocol that seamlessly integrates with GIS software to create a database to support mapping and analysis.

Eastern Hemlock Forest Types

Throughout its range, eastern hemlock is found as a dominant in relatively pure stands, as a co-dominant (or sub-dominant) with numerous northern coniferous species, and as an occasional member of deciduous-dominated stands (McWilliams and Schmidt 1999). In the absence of deer browsing and despite differences in climate and soils throughout the northern portion of the range of eastern hemlock, stand structure and successional dynamics are surprisingly similar from *Nova Scotia* in the east through central *Ontario* to *Wisconsin* in the west (Loucks and Nighswander 1999). In *Ontario*, it is found only in the *Great Lakes-St. Lawrence Forest Region* (Watkins 2011), it commonly grows in association with eastern white pine, red spruce, white spruce, yellow birch, sugar maple, and beech (OLRC 1995), and it makes up a portion of 18 known eastern hemlock upland (14) and swamp (4) forest types (Table 6; Strobl and Bland 2000, OMNR 2009, NHIC 2024). Three of the four hemlock swamp forest types are rare (NHIC 2024).

Stands dominated by eastern hemlock made up about 0.7% of coniferous-dominated forests and about 0.5% of all forests in *Ontario* around 1990 (McWilliams and Schmidt 1999). By 2011, the area of hemlock-dominated forest in *Ontario* was so low, due primarily to logging, that Drever et al. (2010) identified it as a rare forest type. In addition, the *Forest Resources of Ontario* report (Watkins 2011) did not list eastern hemlock-dominated forests as a separate forest type. Rather, the amount of hemlock was included only as a component of seven other forest types (hemlock percent in parentheses) including: conifer upland (5.7%), tolerant hardwoods (4.7%), red and white pine (0.7%), mixedwood (0.5%), white birch (0.5%), conifer lowland (0.3%), and poplar (0.1%). Currently, natural eastern hemlock forests continue to decline throughout their natural range (Foster 2014, Parker et al. 2023, Quinby 2023) and if trends continue, these forests could be eliminated from *Ontario* by the year 2075 (Fig. 2).

As a part of *Canada's* largest known, still unprotected eastern hemlock old-growth forest, the *Central Portion of the Catchacoma Forest* (study area; 181 ha) is composed of an eastern hemlock (70%)-eastern white pine (59%)-red maple (18%) upland forest ecosystem (Table 4), which best fits with the eastern hemlock-conifer forest category of the NHIC (2024) hemlock forest classification (Table 6). Sampling 141 plots in the study area resulted in MT forest type units that were two orders of magnitude higher in resolution (1 unit = 1.3 ha) compared to the study area as a unit (1 unit = 181 ha).

Within the study area we found four MT forest types including the hemlock-dominant type that was almost twice as abundant (47%) as the white pine-dominant type (26%). The other species-dominant type (9%) and the hemlock-white pine co-dominant type (8%) were both at least three times less abundant than the other two forest types. Each of the MT species combinations (11 species total) that make up the forest types found in the study area fit into at least one of the upland forest categories shown in Table 6, except for the hemlock-white pine forest type that does not appear in any of these forest classifications.

Table 6. Eastern Hemlock Upland and Swamp Forest Types in Ontario

Forest Type*	**NHIC (2024)**	**Ecosites of Ontario (OMNR 2009)**	**S. Ont. Silviculture Guide (Strobl & Bland 2000)**	**Quinby & Marcus (2024; this study)**
Hemlock-Dominant Upland Forest (10)				
Hemlock Forest	X			
Hemlock-Conifer Forest	X			
Hemlock-Hardwood-Mixed Forest	X			
Hemlock-Oak-Mixed Forest	X			
Hemlock-Sugar Maple Forest	X			
Hemlock-Sugar Maple-Mixed Forest	X			
Hemlock-White Birch-Mixed Forest	X			
Hemlock-White Cedar-Conifer Forest		X		
Hemlock-White Pine Forest (*likely rare*)				X (11 plots)
Hemlock-Yellow Birch Forest	X			
Hemlock-Subdominant Upland Forest (5)				
Hardwood-Hemlock Forest			X	
Sugar Maple-Hemlock-Mixed Forest	X			
Sugar Maple-Hemlock-Yellow Birch Forest	X			
Sugar Maple-Hemlock-Yellow Birch-Red Maple Forest	X			
White Cedar-Hemlock-Conifer Forest		X		
Hemlock-Dominant Swamp (1)				
Hemlock-Conifer Swamp	X			
Hemlock-Subdominant Swamp (3)				
Red Maple-Hemlock-Mixed Swamp	X			
White Cedar-Hemlock-Conifer Swamp	X			
White Pine-Hemlock-Conifer Swamp			X	

***NOTE:** * forest/swamp types in italics are rare in Ontario per NHIC; forest types in bold are newly identified*

Given the exceptional value of the *Catchacoma Forest* for carbon storage and biodiversity protection (Obrian et al. 2023, Marcus 2023, Quinby 2023) and the fact that natural eastern hemlock stands in *Ontario* are endangered, poorly studied, and poorly understood, the eastern hemlock-eastern white pine forest type should be recognized as its own forest type category by *Ontario* government classification systems. We added the eastern hemlock-eastern white pine forest type to Table 6 since it describes the forest type that occupies the study area as a single unit (181 ha), as well as one of four MT forest types at the higher resolution plot level, which occupied 8% of the study area bringing the known eastern hemlock forest types to a total of 19. The current absence of this forest type from the *Ontario* forest classification system is an indication that it is likely a rare forest type, which is even more reason to include it. The eastern hemlock-eastern white pine forest is a standard type recognized by other *North American* jurisdictions (e.g., Sperduto and Nichols 2011, Zimmerman et al. 2012).

Mother Tree Spatial Patterns

Using GIS to identify, map, and analyze patterns of forest-related variables is not new (e.g., Hessburg et al. 1991, Mladenoff et al. 1993, Frey et al. 2016, Hoffman et al. 2023). However, we were unable to find studies that used GIS interpolation to estimate MT species abundance in unsampled areas to create heat maps of MT densities and richness within an old-growth forest landscape. Comparing *Hotspot A* (old-growth white pine-dominant) with *Hotspots B* and *C* (old-growth hemlock-dominant), we found that in general, more MT species and higher MT densities are associated with the eastern white pine-dominant forest (*Hotspot A*) compared to the eastern hemlock-dominant forest (*Hotspots B and C*). For example, MT densities of the following species were much higher in *Hotspot A*: large-toothed aspen, red pine, sugar maple, white cedar, white oak, and yellow birch.

Greater structural diversity of old-growth forests and the superior height and biomass of super-canopy eastern white pine trees relative to mature eastern white pine forests provided unique habitat that supports higher densities of some species including brown creeper (*Certhia americana*), northern parula (*Setophaga americana*) and scarlet tanager (*Piranga olivacea*) (Kirk et al. 2012). Similarly, within the *Catchacoma* study area, greater tree height and biomass in the *Catchacoma* eastern white pine-dominant forest is likely facilitating higher MT species richness and density there compared to the eastern hemlock-dominant forest with a canopy that typically does not reach the extreme heights of super-canopy eastern white pine trees. In addition to structural diversity, habitat conditions in *Hotspot A* may be more suitable (more diversity and productivity) for a greater number of MT species and to facilitate the accumulation of more total biomass compared to *Hotspots B* and *C*.

As shown in Figure 17, slope-aspect (temperature) is more spatially diverse in each of the three biodiversity hotspots relative to non-hotspot areas. However, further GIS analyses should be used to quantitatively evaluate the potential influence of all measurable habitat variables in addition to temperature. These other habitat influences include soil composition and depth, water availability, competition, predation, and disturbance, all of which can affect MT density, biomass, health, and regeneration success.

Since our data come from a very small but evenly distributed portion of the study area (2%), it is important to sample a portion of the 98% of the *Forest* where no data were collected to determine the accuracy of our predictive mapping. Other data layers generated from the same 141 plots (entire study area) sampled for this study will also be mapped to show the spatial patterns of snag density, log density, and spring wildflower abundance. Once all data are loaded into GIS, all four data layers (MTs, snags, logs, wildflowers) can be analyzed for individual as well as joint (data layer combinations) spatial relationships. Inclusion and analysis of these additional data describing old-growth features will facilitate a better understanding of the ecology of the *Forest* and will add more key metrics (e.g., snags, logs) for use in developing old-growth forest standards for landscapes containing significant amounts of eastern hemlock trees.

Standards and Protocols

Unlike the *USA* (Barnett et al. 2023, The White House 2023, USFS 2023) and the *European Union* (O'Brien et al. 2021, European Commission 2023, Mikolas et al. 2023) where federal and multi-federal action, respectively, are leading the effort to develop comprehensive standards for the assessment, identification, mapping, and protection of old-growth and primary forests, the *Canadian* federal government has not yet initiated a national effort to develop such standards. To date, only six provinces – *Newfoundland and Labrador*, *Nova Scotia*, *New Brunswick*, *Ontario*, *Saskatchewan*, and *British Columbia* – have developed official operational definitions of old-growth forest, however, none of them have prepared minimum standards for the variety of old-growth forest types that occur in their province (Issekutz 2020). The most significant achievement by the *Ontario* government has been the classification of old-growth forest types and the determination of the age-of-onset for each of these forest types (OMNR 2003).

The only comprehensive old-growth forest standards for *Ontario* that we know of were produced using data from 41 plots within 30 of the oldest and largest old-growth red and eastern white pine forest stands in *Temagami*, *Ontario* ranging in size from 11 to 913 ha (Quinby 1991). Although only one stand was sampled for this *Catchacoma* study compared with the 30 stands sampled in *Temagami*, the sampling intensity of 141 plots/stand was much higher than the mean of 1.4 plots/stand in *Temagami* (Quinby 1991). These differences in number of stands sampled and sampling intensity can significantly affect results making comparisons dubious, which emphasizes the need for an accurate, robust, efficient, and consistent field protocol to assess for and describe old-growth forests in *Ontario*.

Compared to five other old-growth forests dominated by eastern hemlock and pine (Table 5), MT density in the *Central Portion of the Catchacoma Forest* ranked highest at a mean of 149/ha, which is 19% higher than the stand with the next highest MT stand density at 125/ha (*Connecticut* eastern hemlock stand). Compared to the stand with the lowest MT density (*Spain Austrian* pine), density in the *Catchacoma Forest* was almost four times greater. A comparison of above-ground live carbon (excluding snags and logs) for 55 studied temperate old-growth and mature forest stands across *NE North America* showed that the *Western* (136 t C/ha) and *Central Portions* (98.2 t C/ha) of the *Catchacoma Forest* fall within the top 15% and 36% of live carbon estimates, respectively (Marcus 2023). These results based on field data demonstrate the high carbon storage capacity of the *Catchacoma Forest* and its significance compared to other studied *North American* mature and old-growth forests. Using remote sensing data, Obrien et al. (2023) also identified the high carbon content of the *Catchacoma Forest* as significant at the provincial level.

The MT data in Table 3 can be considered the start of establishing old-growth forest standards for the eastern hemlock forest type located in *Ontario's Great Lakes-St. Lawrence Forest*, however, many more old-growth eastern hemlock forests need to be sampled for primary old-growth features to ensure representation of all eastern hemlock forest habitat types. Old-growth forest standards should also be developed for the other forest types in the *Ontario Great Lakes-St. Lawrence Forest*. To do this, we recommend rapid assessment of old-growth metrics with systematic plot placement along evenly spaced transects at a 2% minimum sampling intensity within old-growth stands.

For our rapid assessment on average, 0.5 person-hours were required to assess one 300 m^2 plot for MTs and cut stumps compared to the 10 person-hours required to assess one 400 m^2 permanent plot for live and dead vegetation in the overstory, mid-story, and understory; soils and microclimate; and evidence of wildlife use (Folland et al. 2022). Standardizing for the difference in plot size, our rapid assessment (0.17 hrs./100 m^2 sampled) was much faster than the permanent plot sampling methodology (2.5 hrs./100 m^2 sampled) by a factor of 15X. Although the latter method results in much more data, the additional data is not required to determine if a forest meets the minimum MT (old-growth tree) density and maximum human disturbance level for a given old-growth forest type.

Not only does our rapid assessment method cover much more area per unit of time relative to an intensively sampled 400 m^2 plot, but it facilitates seamless integration into a GIS database that can be used for mapping and analyses. The database will also serve as the foundation for long-term studies, which are required to ultimately understand the structure, function, and dynamics of forested ecosystems. Only with this understanding of long-term dynamics can we hope to maintain and restore these unique and critical ecosystems.

An Ecological Safety Net

To put the *Catchacoma Forest* landscape (662 ha) into a broader conservation context, the *Global Safety Net* (GSN; Dinerstein et al. 2020) envisions the motto, "think globally, act locally", applied to nature conservation and stewardship at a planetary scale by expanding terrestrial protected areas globally from 15% (currently) to 50% through action at the grassroots level (Finkelstein 2023). Recent findings show that *Ontario's* most unique and valuable contribution to the GSN is the large extent of roadless areas and the high carbon storage in terrestrial ecosystems (Finkelstein 2023). The *Catchacoma Forest*, with its roadless area (Quinby et al. 2022) and documented high carbon content (Marcus 2023, Obrien et al. 2023, this study), is located on the southern edge of *Ontario's* Intact Wilderness (Finkelstein 2023) within a small fragment contiguous to *Kawartha Highlands Provincial Park* (Fig. 18). Protection of the *Catchacoma Forest* landscape for both its carbon stores and its high levels of biodiversity (Obrien et al. 2023) is exactly what the GSN is calling for.

Figure 18. Conservation Zoning Including "Intact Wilderness" in Ontario (Finklestein et al. 2023)

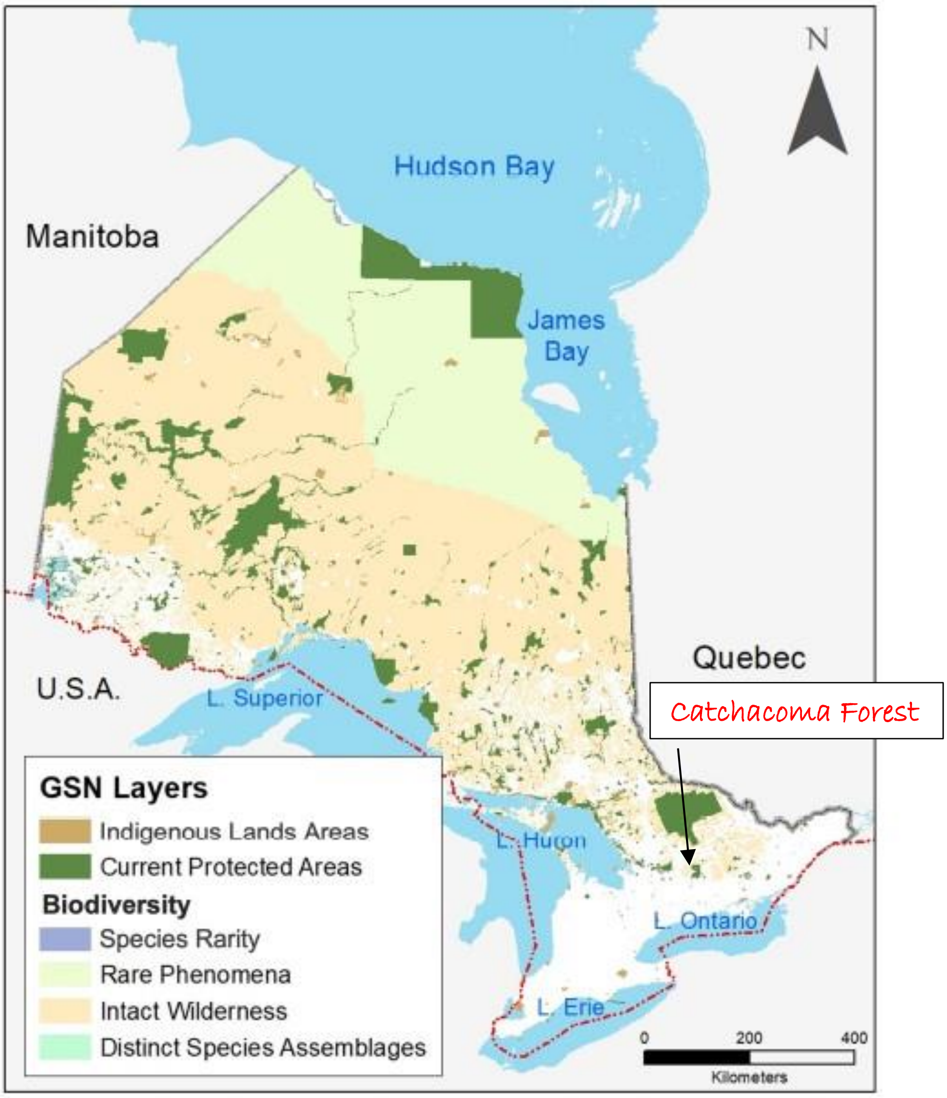


Fig. 1. Existing protected areas, officially recognized Indigenous lands, and additional areas in the Province of Ontario selected in the Global Safety Net (GSN) (Dinerstein et al. 2020) for biodiversity conservation priorities. Following the GSN methodology, each layer is added sequentially with no overlap in the same order as shown in Table 1. As a result, an area may conform to multiple biodiversity criteria but will only be shown associated with the layer that was mapped first. Small areas selected in the GSN for species rarity on the Hudson and James Bay coasts are not shown. Source for Indigenous Lands shapefile: Natural Resources Canada (2017). The map is drawn using the GCS North American 1983 Geographic Coordinate System, the NAD83 datum, and the Great Lakes and St Lawrence Albers Projection.

Analyses indicate that the GSN would reverse further biodiversity loss, prevent CO_2 emissions from land conversion, enhance natural carbon removal, add sites of great biodiversity value, and stabilize climate (Dinerstein et al. 2020). A total of 50 ecoregions and 20 countries contribute disproportionately to achieving proposed GSN protection targets, which include *Ontario's* northern *Great Lakes-St. Lawrence Forest Region* and *Boreal Forest*. The GSN estimates that protection of 671 million ha of intact, roadless area is required for *Canada* to meet its global conservation obligations (Dinerstein et al. 2020) – some of which will come from *Ontario*. Using the percentage of *Canada* that is occupied by *Ontario* (11%), the province's contribution of currently unprotected intact, roadless areas would be 74 million ha or 68.8% of the provincial land area. This high amount of targeted protected area is likely due to the disproportionate contribution of *Ontario's* roadless areas to global terrestrial carbon storage (Finkelstein 2023).

Following the motto, "one step at a time", given the numerous, rare, and vital values of the *Catchacoma Forest*, its protection would add more stability and resiliency to the southern edge of *Ontario's* intact wilderness and contribute significantly to a strong *Ontario* ecological safety net that meets it obligation to the *Global [Ecological] Safety Net*.

Acknowledgements

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AFER Principles

AFER is a non-profit scientific organization with a mission to carry out research and education that lead to the identification, description, and protection of ancient (pristine) forested landscapes, including old-growth forests. The earth-stewardship principles that guide our work include the following.

- Many forest ecosystem types are now endangered. We consider these ecosystems and other ancient forests to be non-renewable resources, which is not consistent with the practice of mining or logging them.
- We consider biodiversity conservation needs at local, provincial, federal and international scales.
- We support the *Government of Canada's* official commitment to increase protected areas to 30% of the *Canadian* land base by 2030.
- We support the *New York Declaration on Forests* to end natural forest loss by 2030.

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