

Article

A Rapid Method to Assess, Map, and Develop Standards for Old Growth: Catchacoma Primary Hemlock Forest, Ontario, Canada

Peter Quinby^{1,*} and Ania Marcus^{1,2}¹ Ancient Forest Exploration & Research, Powassan, ON P0H 1Z0, Canada; ania.marcus@gmail.com² Graduate Program, School of Environmental Studies, University of Victoria, Victoria, BC V8W 2Y2, Canada

* Correspondence: pquinby@ancientforest.org

Simple Summary

Old-growth forests are exceptionally valuable ecosystems. They represent some of the largest terrestrial carbon stores on the planet and harbor the highest levels of biodiversity including rare and endemic species. They also provide abundant ecological services such as air and water purification, nutrient cycling, erosion control, and pollinator habitat, and they provide direct benefits to human health, as well as recreation, education, and research opportunities. Despite the numerous values of primary (includes old-growth) forests, their spatial extent and integrity are declining rapidly across the globe. For example, between 1990 and 2015, aside from Nigeria (98.7% loss), Canada lost the highest percentage of primary forest of all countries at 58%, mainly due to industrial logging and wildfire. A better understanding of the components of old-growth primary forests that foster resilience in the face of these threats is critical for effective management of these unique and rare ecosystems. This study contributes (1) by developing a faster way (15X) to identify whether a forest is “old growth”, (2) by using these results to develop and apply minimum standards for regional application to find old-growth forests in other landscapes, and (3) by applying GIS and GPS as a foundation for a spatial-analytical component to long-term study of a landscape.

Abstract

All eastern hemlock-dominated forests in Ontario could be gone by 2075 given current trends, which demands rapid assessment to locate these endangered ecosystems. To date, however, neither the Canadian or Ontario governments have developed field assessment protocols or minimum standards for identifying old-growth forests that provide density and biomass estimates for the primary features of these forests. This study focused on the Catchacoma Forest, Canada’s largest eastern hemlock forest, and represents a first step towards establishing minimum standards for old-growth eastern hemlock forests in the Great Lakes-St. Lawrence Forest region. Rectangular plots were systematically placed along evenly spaced east–west transects at a 2% sampling intensity for the 181 ha study area and assessed for mother trees (MTs) and cut stumps. By a factor of 15X, the method developed was more efficient for covering larger areas compared to randomly placed and intensively sampled plots typically used for long-term ecological studies. Mean integrity (stumps/ha) was 0.006/ha and mean MT density was 149/ha with a range of 0–533/ha. Four MT forest types were identified including: eastern hemlock-dominant (47%; 194 MT/ha), white pine-dominant (26%; 123 MT/ha), other MT species-dominant (9%; 169 MT/ha), and eastern hemlock–white pine co-dominant (8%; 133/ha). MTs were absent from roughly 10% of the study area.



Academic Editors: Reed F. Noss and Steve J. Carver

Received: 10 February 2026

Revised: 30 April 2026

Accepted: 26 May 2026

Published: 1 June 2026

Copyright: © 2026 by the authors.

Licensee MDPI, Basel, Switzerland.

This article is an open access article distributed under the terms and

conditions of the [Creative Commons](https://creativecommons.org/licenses/by/4.0/)[Attribution \(CC BY\)](https://creativecommons.org/licenses/by/4.0/) license.

Keywords: primary old-growth forest; eastern hemlock; mother trees; rapid assessment; old-growth forest standards; GIS isoline maps; Catchacoma Forest

1. Introduction

1.1. 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 [1–3] and harbor the highest levels of biodiversity including rare and endemic species [4–6]. They also provide abundant ecological services such as air and water purification, nutrient cycling, erosion control, and pollinator habitat [7,8] and provide direct benefits to human health as well as recreation, education, and research opportunities [7,9,10].

Despite the numerous values of primary (includes old growth) forests, their spatial extent and integrity are declining rapidly across the globe (Figure 1) [7,11]. For example, between 1990 and 2015, aside from Nigeria (98.7% loss), Canada lost the highest percentage of primary forest of all countries at 58% during this 25-year period [5], including a 16.4% decline in eastern hemlock-dominated forests in Ontario from 1987 to 2007 leading to potential extinction by 2075 [12]. Primary forest decline is mainly due to factors including industrial logging, land conversion for agriculture, fire, insects, disease, and climate change [8,13]. 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.

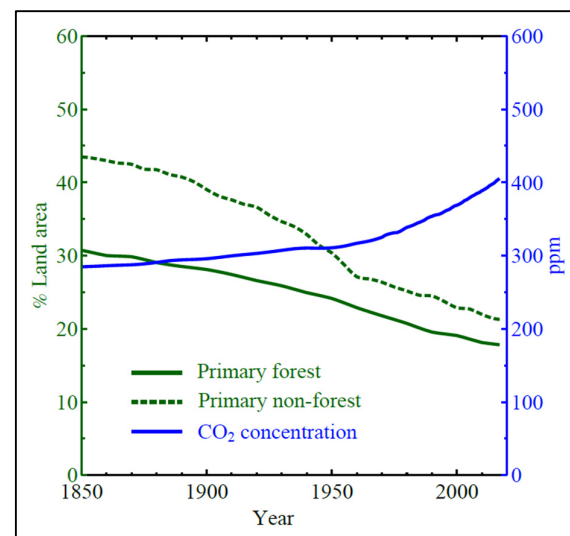


Figure 1. The global decline of primary forest and non-forest ecosystems (green) and increase in atmospheric CO₂ (blue) from 1850 to 2020 [14].

1.2. Mother Trees Are Keystone Ecological Structures

According to the [15] long-term ecological study, “the biggest and oldest trees are the most connected nodes in the forest [soil]. These highly-connected hub trees [are] also known as mother trees” (MTs; see also: [16,17]. As central biodiversity hubs they function as keystone ecological structures on the landscape [18]. As the key component of an old-growth forest, old-growth trees that meet minimum size standards are 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 [18,19].

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 [19–21]. Mother trees 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 [16,22–25]. Through soil fungi, one MT can be connected to hundreds of individual trees [15].

Zahawi et al. [26] found that the presence of an 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 [27]. Mother tree 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 [9,28,29].

1.3. Eastern Hemlock Is a Foundation Species

“Foundation species create, define, and maintain entire ecological systems” [30]. As a foundation species, eastern hemlock-dominated forests embody the four features that characterize this designation [30]: (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, and 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” [31].

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 [32]. These dense canopies can reduce temperatures at the soil surface by as much as 20 °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 [30].

Eastern hemlock 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 [33]. In summary, the unique ecological role and function of eastern hemlock cannot be replaced by any other tree [32].

1.4. Purpose

Currently, little is known about MT density patterns and dynamics within forest ecosystems including the eastern temperate forests of Canada and the USA. The objectives of this study were to characterize MT forest types, to develop a rapid field assessment protocol, and to initiate the development of old-growth forest standards. To accomplish

this, MTs were surveyed in the central portion of the Catchacoma Forest located in northern Peterborough County, Ontario. Rapid assessment is required since eastern hemlock-dominated forests in Ontario are disappearing quickly and could be gone by 2075 given current trends [12].

The 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 OGFs at the highest structural (MTs and cut stumps) and functional levels (e.g., temperature regulation), particularly in temperate forests such as the Great Lakes–St. Lawrence Forest region.

2. Study Area and Methods

For this study, we defined MTs as trees that met the minimum old-growth diameters (Table 1) [34–36]. Using these minimum diameters, we surveyed for MTs in the central portion of the Catchacoma Forest (study area; Figure 2) 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 and (2) determine the size of the study area (181 ha).

Table 1. Minimum diameters for mother trees in Central Catchacoma Forest [35].

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

Dennsmore et al. [38] state that the 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. The 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 the survey area increases, the inventory intensity typically decreases [39]. When using a 314 m² randomly placed plot, Dennsmore et al. [38] state that a 2–3% sample of natural forest habitat is usually adequate, which lines up closely with our use of 300 m² plots at a 2% sampling intensity. To meet the 2% sample requirement, we assessed 141, 300 m² plots along 19 transects (Figure 2).

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.

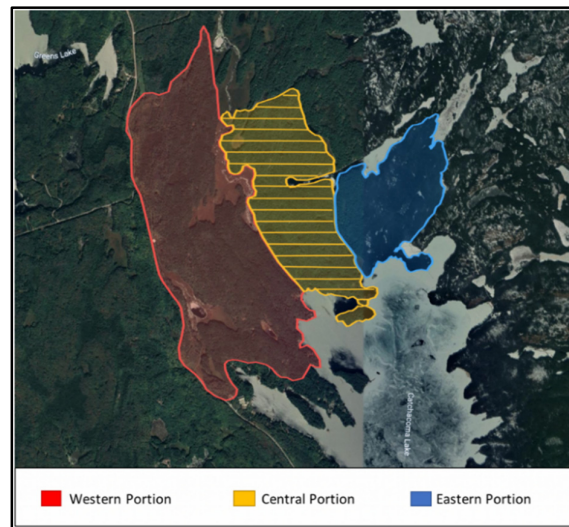


Figure 2. The western, central, and eastern portions of the Catchacoma Forest, and the 19 transects sampled in Central Catchacoma Forest, Ontario (parallel yellow lines = transects; [37]).

The Google Earth map was used as a guide to reach the starting point of each transect in the field. The Google Earth measuring tool was then used to draw a 50 m east–west line (transect) from the starting point to the ending point of the first plot along the transect. Another 50 m was then traversed unsampled 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 the 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 [40], and strip and transect line (our method) sampling are most suitable for sampling in a forest with highly variable environmental (habitat) gradients [39], which is typical of the Catchacoma Forest.

Within each 6×50 m plot, the number and species of MTs within 3 m of each side of the transect line were recorded. Tree DBH (4.5 ft.) 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 the field sampling efficiency. Forest classification cut-off values for MT species abundance for each MT forest type were provided to show composition differences among MT forest types.

MT plot density data were used in natural neighbor interpolation analyses [41] to produce spatially continuous maps of MT density for the study area. This analysis was described by ESRI [41] as an “interpolation tool [that] finds the closest subset of input samples to a query point and applies weights to them based on proportionate areas to interpolate a value. . . interpolated heights are guaranteed to be within the range of the samples used. It does not infer trends and will not produce peaks, pits, ridges, or valleys that are not already represented by the input samples.”

Thiessen polygons [41] were used to create the map of forest community type populations (plots), defined as “the area of influence around its sample point, so that any location inside the polygon is closer to that point than any of the other sample points”, resulting in connected groups of polygons of the same MT community type, including those with minimal diagonal connections at the corners.

3. Results

3.1. 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.

3.2. Mother Tree Species Abundance

Eastern hemlock MTs were by far the most common MT species in the study area at 70% relative abundance (Table 2). 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 2. Plot frequency for 11 mother tree species in Central Catchacoma Forest.

MT Species	Plot Frequency (%)
Dominant (>58% plot frequency)	
Eastern hemlock	70
Eastern white pine	59
Sub-dominant (<19% plot frequency)	
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

3.3. 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 classified, including from most to least abundant (1) eastern hemlock-dominant (47%), (2) white pine-dominant (26%), (3) other species-dominant (9%, see Table 1 for other species), and (4) eastern hemlock–white pine co-dominant (8%) (Table 3). The mean MT density for the entire study area (181 ha), including the portions with no MTs, was 149 MT/ha. However, the MT density varied substantially across the landscape in this study area (0–533/ha; see variation in Figures 3–7). MTs were absent from roughly 10% of the study area, where young forests, mature forests, and wetlands were common.

Table 3. MT densities in 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-dominant	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

Within the study area, the highest MT densities were found in the eastern hemlock-dominant type (194 MT/ha), and the 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 were 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%) had the second highest MT density of the four forest types, which indicates favorable growing conditions for 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. The data in Table 3 represent the first set of old-growth forest standards for eastern hemlock forest located in Ontario’s Great Lakes–St. Lawrence Forest, since we were unable to find this information elsewhere. More data from many other old-growth stands are required to complete this standards development process.

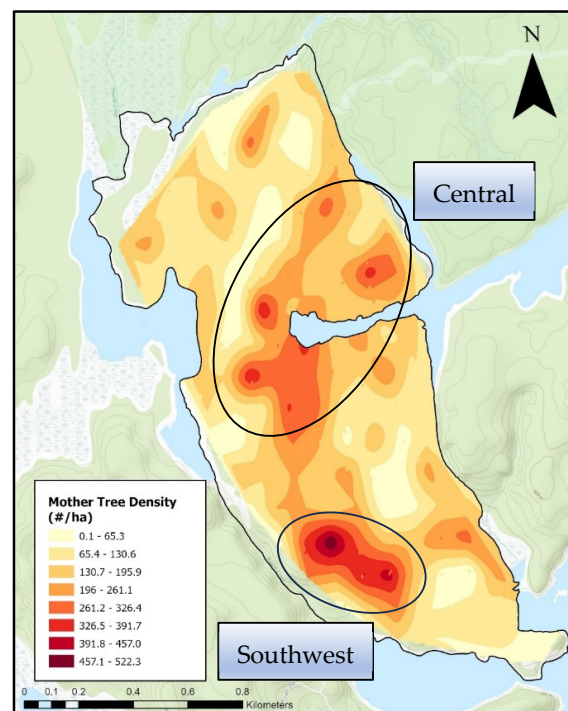


Figure 3. Density of 11 mother tree species combined (no./ha) in the Central Catchacoma Forest.

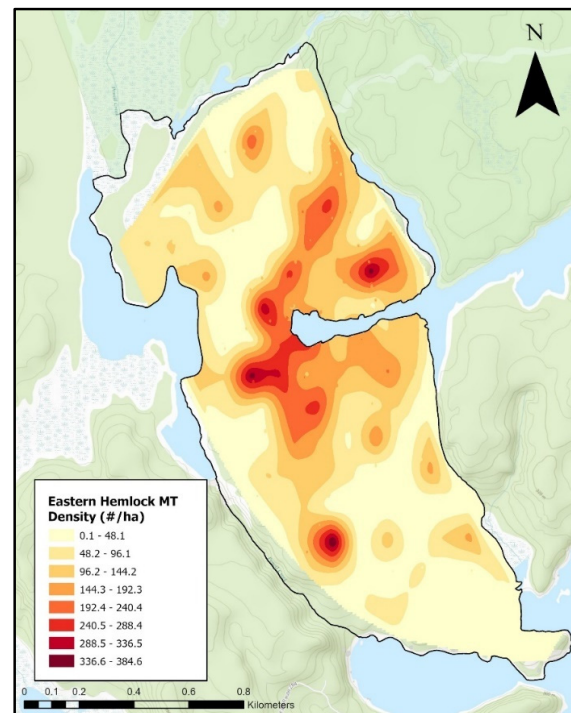


Figure 4. Density of eastern hemlock (no./ha) mother trees in Central Catchacoma Forest.

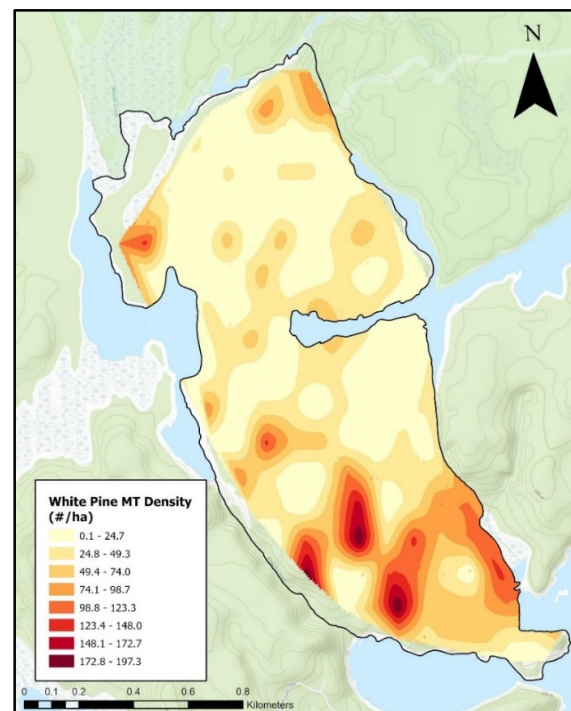


Figure 5. Density of eastern white pine (no./ha) mother trees in Central Catchacoma Forest.

3.4. Mother Tree and Community Types Mapping

Key MT maps included (1) all MT species combined, (2) eastern hemlock MTs (dominant), (3) eastern white pine MTs (co-dominant), (4) other MT species (nine), and (5) MT forest types and mature forest. Densities for all MT species combined (Figure 3) were partitioned into eight categories ranging from 0.1–65.3 MT/ha to 457.1–522.3 MT/ha, with the highest densities located in the southwest portion of the study area (up to 522/ha) and the next highest densities (up to 392/ha) occurring in the central portion of the study area (Figure 3).

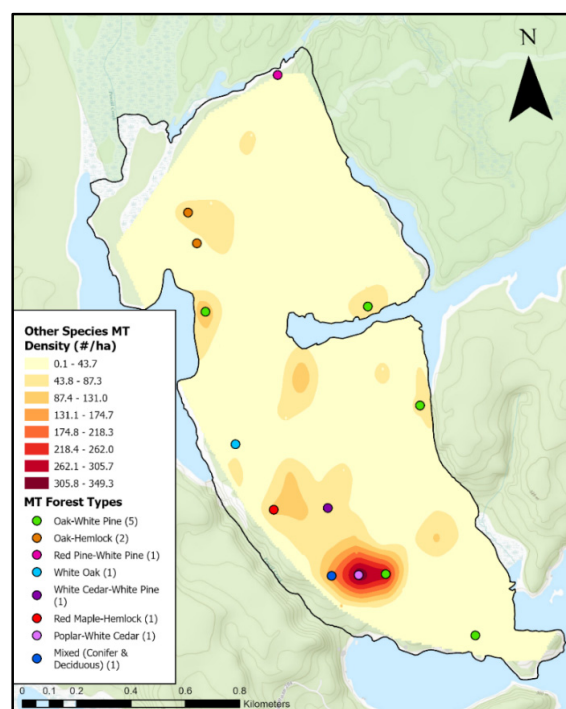


Figure 6. Density of other MT species (no./ha; nine spp.) and location of other MT forest types by plot in Central Catchacoma Forest.

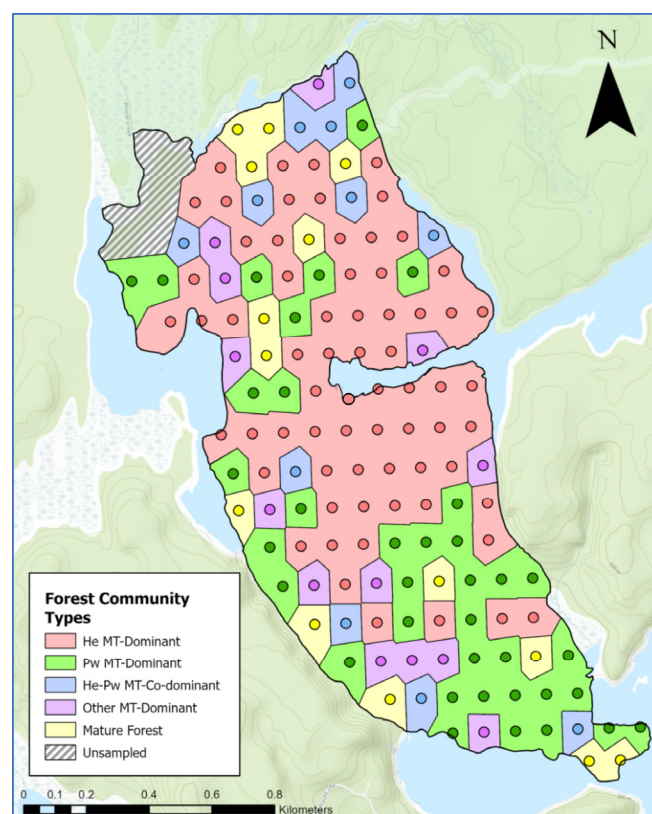


Figure 7. MT forest community types and mature forest in Central Catchacoma Forest (dots = sample locations).

Eastern hemlock was the most common MT species (70% of study area) in the central portion of the Catchacoma Forest, reaching densities as high as 385 MT/ha in both the

central and southwest portions of the study area. In contrast to eastern white pine MT density, eastern hemlock MTs were most highly concentrated in the central portion.

The eastern white pine MT density (59% of study area) was highest in the southern portion of the study area ranging up to 197 MT/ha (Figure 5). Finally, MT densities for the other nine MT species (13 plots; seven MT forest types) ranged up to 349 MT/ha (Figure 6) with distribution throughout the study areas and the highest densities in the southwest portion of the study area, where the densities of all MT species combined were also highest. Only two other MT forest types dominated in multiple plots including the oak–eastern white pine type (five plots) and the oak–hemlock type (two plots; Figure 6).

Of the five mapped MT forest community types (Figure 7), the order of abundance from most to least abundant includes eastern hemlock MT-dominant (66 plots), eastern white pine MT-dominant (37 plots), mature forest (14 plots), other MT-dominant (13 plots), and eastern hemlock–eastern white pine MT co-dominant (11 plots). The eastern hemlock MT-dominant community type was most abundant in the northern and central portions of the study, whereas the eastern white pine MT-dominant type primarily occurred in the southern portion of the study area (Figure 7). The remaining forest community types were distributed throughout the study area.

3.5. Regional Comparison of Mother Tree Densities

Evaluating the 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 are 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. This creates 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 diameters (DBH), which renders a comparison of these six related studies inappropriate (Table 4).

Table 4. 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)	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)	[this study]
Connecticut	eastern hemlock	live	>/=40	125	[42]
Maine	pine forest	live and dead	>/=40	130	[43]
Ontario (central)	red and white pine	live	>60 (super-canopy)	49	[44]
	red and white pine	live	38–60	29 [49 + 29 = 78]	
Ontario (Temagami)	white pine	live	>/=38	10–50	[45]
	red pine	live	>/=29	9–60	
	red and white pine	dead	>/=10	30	
Spain (southern)	Austrian pine (<i>Pinus nigra</i>)	live	>/=50	40	[46]

The value of providing the results of these studies is to illustrate the complications of regional comparisons in terms of live and dead wood, minimum diameters (DBH) used

by each study, and expressing MT density values. Until old-growth forest study metrics become standardized, the difficulties of comparison will remain.

4. Discussion

The most significant results from this study include (1) the 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) 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 (MT) types that can serve as the basis for developing old-growth standards, and (3) 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 a variety of integrated spatial and temporal analyses.

4.1. Eastern Hemlock Forest Types

Throughout its range, eastern hemlock is found as dominant in relatively pure stands, as co-dominant (or sub-dominant) with numerous northern coniferous species, and as an occasional member of deciduous-dominated stands [47]. In the absence of deer browsing and despite differences in climate and soils throughout the northern portion of the range of eastern hemlock, the stand structure and successional dynamics are surprisingly similar from Nova Scotia in the east through central Ontario to Wisconsin in the west [48].

In Ontario, it is found only in the Great Lakes–St. Lawrence Forest region [49], it commonly grows in association with eastern white pine, red spruce, white spruce, yellow birch, sugar maple, and beech [50], and it makes up a portion of 18 known eastern hemlock upland (14) and swamp (4) forest types (Table 5) [51–53]. Three of the four hemlock swamp forest types are rare [53].

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 [47]. By 2011, the area of hemlock-dominated forest in Ontario was so low, due primarily to logging, that [54] identified it as a rare forest type. In addition, the Forest Resources of Ontario report [49] 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 [12,30,55].

As a part of Canada's largest known and 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 2), which best fits with the eastern hemlock–conifer forest category of the NHIC [53] hemlock forest classification (Table 5). 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 5, except for the hemlock–white pine forest type that does not appear in any of these forest classifications.

Table 5. Eastern hemlock upland and swamp forest types in Ontario.

Forest Type	NHIC [53]	Ecosites of Ontario-GLSL # Region [52]	S. Ont. Silviculture Guide [51]	Quinby and Marcus (This Study)
Hemlock-Dominant Upland Forest (10)				
Hemlock Forest	X			
Hemlock–Conifer Forest	X		X	X
Hemlock–Hardwood–Mixed Forest	X		X	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; this study)				X (11 plots)
Hemlock–Yellow Birch Forest	X			
Hemlock-Subdominant Upland Forest (5)				
Hardwood–Hemlock Forest			X	X
Sugar Maple–Hemlock–Mixed Forest	X		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 (rare)	X			
Hemlock-Subdominant Swamp (3)				
Red Maple–Hemlock–Mixed Swamp (rare)	X			
White Cedar–Hemlock–Conifer Swamp (rare)	X			
White Pine–Hemlock–Conifer Swamp			X	

TABLE NOTES: # GLSL = Great Lakes–St. Lawrence.

Given the exceptional value of the Catchacoma Forest for carbon storage and biodiversity protection [56,57] and the fact that natural eastern hemlock stands in Ontario are endangered [12], poorly studied, and poorly understood, the eastern hemlock–eastern white pine forest type should be recognized as its own forest type category by current forest classification systems. We added the eastern hemlock–eastern white pine forest type to Table 5 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% (11 plots) of the study area bringing the known eastern hemlock forest types to a total of 19.

In addition, the eastern hemlock–eastern white pine forest type is a standard type recognized in New Hampshire, USA [58], and in Pennsylvania, USA [59]. Eyre and Drake [60] also identified the *Pinus strobus*–*Tsuga canadensis* (co-dominant) association (finest taxonomic level) as a type found in Michigan, Wisconsin, and Ontario stating, this “type is currently not recognized in recent Ontario publications of forest types. . . , which seems surprising” (pg. 2). The absence of this forest association 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 within the Ontario forest classification system.

4.2. Mother Tree and Community Type Spatial Patterns

Using GIS to identify, map, and analyze patterns of forest-related variables is not new (e.g., [61–64]). 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 within an old-growth forest landscape. 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. For example, MT densities of the following species were much higher in the southern portion of the study area where the eastern white pine-dominant forest is the most abundant MT forest type: large-toothed aspen, red pine, sugar maple, white cedar, white oak, and yellow birch.

Higher 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 a unique habitat that supports higher densities of some species including brown creeper (*Certhia americana*), northern parula (*Setophaga americana*) and scarlet tanager (*Piranga olivacea*) [44]. Similarly, within the Catchacoma study area, larger tree height and biomass in the Catchacoma eastern white pine-dominant forest (up to 20 m higher than eastern hemlock) provides more vertical growing space below the MT crown for colonization by other MT species (e.g., red and white oak). This facilitates higher MT species richness and density within that forest type compared to the eastern hemlock-dominant forest with a canopy (up to 30 m) that typically does not reach the extreme heights of super-canopy eastern white pine trees (up to 50 m).

Further GIS analyses should evaluate the potential influence of all measurable habitat variables on the Forest including soil composition and depth, water availability, competition, predation, and disturbance, all of which can affect the MT density, biomass, health, and regeneration success. In addition, since our data come from a very small but evenly distributed portion of the study area (2%), it is important to sample MTs in a portion of the 98% of the Forest where no data were collected to determine the accuracy of our predictive mapping, which includes the use of Thiessen polygons to characterize areas surrounding sampled data points. The potential influence of unsampled areas outside of the study area should also be investigated for potential effects on the interpolation results associated with samples located along the study area boundaries.

Other data layers generated from the same 141 plots (entire study area) will also be mapped and analyzed for spatial patterns of snag density, log density, and spring wildflower abundance as well as for joint (data layer combinations) spatial relationships. This 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 MTs.

4.3. Standards and Protocols

The Canadian federal government has not yet initiated a national effort to develop old-growth forest standards. This contrasts with the USA [36,65,66] and the European Union [67–69] 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.

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 [70]. 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 [34].

The only comprehensive old-growth forest standards for Ontario found 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 [45]. 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 [45]. These differences in number of stands sampled and sampling intensity can significantly affect the 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 and elsewhere.

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 (98.2 t C/ha) portions of the Catchacoma Forest fall within the top 15% and 36% of live carbon estimates, respectively [57]. 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. [56] 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 initiation 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 the 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 the 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 m² plot for MTs and cut stumps compared to the 10 person-hours required to assess one 400 m² permanent plot for live and dead vegetation in the overstory, mid-story, and understory; soils and microclimate; and evidence of wildlife use [71]. Standardizing for the difference in plot size, our rapid assessment (0.17 h/100 m² sampled) was much faster than the permanent plot sampling methodology (2.5 h/100 m² sampled) by a factor of 15X. Although the latter method results in more data, the additional data are not required to determine whether 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 m² plot, but it facilitates seamless integration into a GIS database that can be used for mapping and analyses, both spatial and temporal. 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 landscapes.

4.4. An Ecological Safety Net—Protect Half

To put the Catchacoma Forest landscape (662 ha) into a broader conservation context, the Global Safety Net (GSN; [72]) 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 [73]. 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 [73].

The Catchacoma Forest, with its roadless area [74] and documented high carbon content [56,57], this study, is located on the southern edge of Ontario’s Intact Wilderness [73] within a small fragment contiguous to Kawartha Highlands Provincial Park. Protection of the Catchacoma Forest landscape for both its carbon stores and its high levels of biodiversity [56] is exactly what the GSN is calling for.

Analyses indicate that the GSN would reverse further biodiversity loss, prevent CO₂ emissions from land conversion, enhance natural carbon removal, add sites of great biodiversity value, and stabilize climate [72]. A total of 50 ecoregions and 20 countries contribute disproportionately to achieving the 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 [72]—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 [73].

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 its obligation to the Global [Ecological] Safety Net.

5. Conclusions

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.

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%).

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 as follows: (a) eastern hemlock-dominant (47%), (b) white pine-dominant (26%), (c) other MT species-dominant (9%), and (d) eastern hemlock–white pine co-dominant (8%). MTs were absent from roughly 10% of the study area.

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

Unlike the USA and the European Union where federal and multi-federal actions, 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.

To conduct rapid field surveys for the detection and characterization of old-growth forests in Ontario, we recommend the 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 (6×30 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 (a) more efficient coverage (by 15X) of larger areas compared to assessing randomly placed and intensively sampled large plots ($400\text{--}500\text{ m}^2$) typically used for long-term ecological studies and (b) 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.

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 represent 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 and potentially beyond. 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 temperate forests including the Great Lakes–St. Lawrence Forest region.

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.

Author Contributions: All contributions were evenly split, except for conceptualization primarily by P.Q. and data analysis (data entry and GIS) performed by A.M. All authors have read and agreed to the published version of the manuscript.

Funding: Financial support for this work was provided by ECO Canada, Nadurra Wood Corporation, Ron Waters, and Marie Windover.

Data Availability Statement: Available upon request from P. Quinby.

Acknowledgments: We respectfully and gratefully acknowledge that our field research activities for this project took place on the traditional territory of the Mississauga Anishinaabeg. We thank Nicole King, Sammy Tangir, Jessica Zheng, Sacha Mitchell, Lia Robles-Gill, Jesse Mihevc, and Sara Nguyen (field and GIS) for assistance with surveys in the central portion of the Catchacoma Forest. Finally, thank you to the Catchacoma Forest Stewardship Committee for their continued support.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Luyssarert, S.; Shulze, E.D.; Börner, A.; Knohl, A.; Hessenmöller, D.; Law, B.E.; Ciais, P.; Grace, J. Old-growth forests as global carbon sinks. *Nature* **2008**, *455*, 213–215. [CrossRef]
2. Moomaw, W.R.; Masino, S.A.; Faison, E.K. Intact forests in the United States: Proforestation mitigates climate change and serves the greatest good. *Front. For. Glob. Change* **2019**, *2*, 27. [CrossRef]
3. DellaSala, D.A.; Mackey, B.; Norman, P.; Campbell, C.; Comer, P.J.; Kormos, C.F.; Keith, H.; Rogers, B. Mature and old-growth forests contribute to large-scale conservation targets in the conterminous United States. *Front. For. Glob. Change* **2022**, *5*, 979528. [CrossRef]
4. Keith, H.; Mackey, B.G.; Lindenmayer, D.B. Re-evaluation of forest biomass carbons stocks and lessons from the world's most carbon-dense forests. *Proc. Natl. Acad. Sci. USA* **2009**, *106*, 11635–11640. [CrossRef]
5. Morales-Hidalgo, D.; Oswalt, S.N.; Somanathan, E. Status and trends in global primary forest, protected areas, and areas designated for conservation of biodiversity from the Global Forest Resources Assessment 2015. *For. Ecol. Manag.* **2015**, *352*, 68–77. [CrossRef]
6. Messick, R.E.; Davis, S.L. Global Importance of Imperiled Old-Growth Forests with an Emphasis on the Southern Blue Ridge Mountains. In *Imperiled: The Encyclopedia of Conservation*; Elsevier: Amsterdam, The Netherlands, 2022; pp. 563–573. [CrossRef]
7. Watson, J.E.; Evans, T.; Venter, O.; Williams, B.; Tulloch, A.; Stewart, C.; Thompson, I.; Ray, J.C.; Murray, K.; Salazar, A.; et al. The exceptional value of intact forest ecosystems. *Nat. Ecol. Evol.* **2018**, *2*, 599–610. [CrossRef]
8. Lindenmayer, D.; Bowd, E. Critical Ecological Roles, Structural Attributes and Conservation of Old Growth Forest: Lessons from a Case Study of Australian Mountain Ash Forests. *Front. For. Glob. Change* **2022**, *5*, 878570. [CrossRef]
9. Cannon, C.H.; Piovesan, G.; Munné-Bosch, S. Old and ancient trees are life history lottery winners and vital evolutionary resources for long-term adaptive capacity. *Nat. Plants* **2022**, *8*, 136–145. [CrossRef]
10. Gilhen-Baker, M.; Roviello, V.; Beresford-Kroeger, D.; Roviello, G.N. Old-growth forests and large old trees as critical organisms connecting ecosystems and human health. A review. *Environ. Chem. Lett.* **2022**, *20*, 1529–1538. [CrossRef]
11. McDowell, N.G.; Allen, C.D.; Anderson-Teixeira, K.; Aukema, B.H.; Bond-Lamberty, B.; Chini, L.; Clark, J.S.; Dietze, M.; Grossiord, C.; Hanbury-Brown, A.; et al. Pervasive shifts in forest dynamics in a changing world. *Science* **2020**, *368*, eaaz9463. [CrossRef] [PubMed]
12. Quinby, P. Hemlock Decline, Reserve Selection, and Conserving Canada's Largest Remaining Old-growth Eastern Hemlock Stand at Trent Lakes, Ontario. *Nat. Areas J.* **2025**, *45*, 226–240. [CrossRef]
13. Potapov, P.; Hansen, M.C.; Laestadius, L.; Turubanova, S.; Yaroshenko, A.; Thies, C.; Smith, W.; Zhuravleva, I.; Komarova, A.; Minnemeyer, S.; et al. The last frontiers of wilderness: Tracking loss of intact forest landscapes from 2000 to 2013. *Sci. Adv.* **2017**, *3*, e1600821. [CrossRef]
14. Makarieva, A.; Nefiodov, A.V.; Rammig, A. Re-appraisal of the global climatic role of natural forests for improved climate projections and policies. *Front. For. Glob. Change* **2023**, *6*, 1150191. [CrossRef]
15. The Mother Tree Project. About Mother Trees in the Forest. 2026. Available online: <https://mothertreeproject.org/about-mother-trees-in-the-forest/> (accessed on 26 April 2026).
16. Beiler, K.J.; Durall, D.M.; Simard, S.W.; Maxwell, S.A.; Kretzer, A.M. Architecture of the wood-wide web: Rhizopogon spp. genets link multiple Douglas-fir cohorts. *New Phytol.* **2009**, *185*, 543–553. [CrossRef] [PubMed]
17. Simard, S. *Finding the Mother Tree: Discovering the Wisdom of the Forest*; Penguin Canada: Toronto, ON, Canada, 2022; 384p.
18. Liu, J.; Lindenmayer, D.B.; Yang, W.; Ren, Y.; Campbell, M.J.; Wu, C.; Luo, Y.; Zhong, L.; Yu, M. Diversity and density patterns of large old trees in China. *Sci. Total Environ.* **2019**, *655*, 255–262. [CrossRef] [PubMed]
19. Lindenmayer, D.; Laurance, W.F. The ecology, distribution, conservation and management of large old trees. *Biol. Rev.* **2017**, *92*, 1434–1458. [CrossRef] [PubMed]
20. Nilsson, S.G.; Niklasson, M.; Hedin, J.; Aronsson, G.; Gutowski, J.M.; Linder, P.; Ljungberg, H.; Mikusiński, G.; Ranius, T. Erratum to Densities of large living and dead trees in old-growth temperate and boreal forests. *For. Ecol. Manag.* **2003**, *178*, 355–370. [CrossRef]
21. Asbeck, T.; Großmann, J.; Paillet, Y.; Winiger, N.; Bauhus, J. The Use of Tree-Related Microhabitats as Forest Biodiversity Indicators and to Guide Integrated Forest Management. *Curr. For. Rep.* **2021**, *7*, 59–68. [CrossRef]

22. Teste, F.P.; Simard, S.W.; Durall, D.M.; Guy, R.D.; Jones, M.D.; Schoonmaker, A.L. Access to mycorrhizal networks and roots of trees: Importance for seedling survival and resource transfer. *Ecol. Soc. Am.* **2009**, *90*, 2808–2822. [CrossRef]
23. Beresford-Kroeger, D. *The Global Forest: Forty Ways Trees Can Save Us*; Penguin Books: London, UK, 2010.
24. Schiffman, R. ‘Mother Trees’ Are Intelligent: They Learn and Remember. *Scientific American*, 4 May 2021. Available online: <https://www.scientificamerican.com/article/mother-trees-are-intelligent-they-learn-and-remember/> (accessed on 16 July 2024).
25. Pardos, M.; Vázquez-Piqué, J.; Benito, L.; Madrigal, G.; Alejano, R.; Fernández, M.; Calama, R. Does the Age of *Pinus sylvestris* Mother Trees Influence Reproductive Capacity and Offspring Seedling Survival? *Forests* **2022**, *13*, 937. [CrossRef]
26. Zahawi, R.A.; Werden, L.K.; San-José, M.; Rosales, J.A.; Flores, J.; Holl, K.D. Proximity and abundance of mother trees affects recruitment patterns in a long-term tropical forest restoration study. *Ecography* **2021**, *44*, 1–12. [CrossRef]
27. Mao, P.; Han, G.; Wang, G.; Yu, J.; Shao, H. Effects of Age and Stand Density of Mother Trees on Early *Pinus thunbergii* Seedling Establishment in the Coastal Zone, China. *Sci. World J.* **2014**, 468036. [CrossRef]
28. Struve, D.K.; McKeand, S.E. Importance of Red Oak Mother Tree to Nursery Productivity. *J. Environ. Hortic.* **1994**, *12*, 23–26. [CrossRef]
29. Frelich, L.E.; Reich, P.B. Perspectives on development of definitions and values related to old-growth forests. *Environ. Rev.* **2003**, *11*, 9–22. [CrossRef]
30. Foster, D. *Hemlock: A Forest Giant on the Edge*; Yale University Press: New Haven, CT, USA, 2014. Available online: https://harvardforest1.fas.harvard.edu/publications/pdfs/Foster_Arnoldia_2014.pdf (accessed on 14 April 2024).
31. Ellison, A.M.; Plotkin, A.A.B.; Khalid, S. Foundation Species Loss and Biodiversity of the Herbaceous Layer in New England Forests. *Forests* **2015**, *7*, 9. [CrossRef]
32. HCNS (Hemlock Conservation Nova Scotia). Medway Community Forest Cooperative. 2024. Available online: <https://www.medwaycommunityforest.com/hemlocks> (accessed on 17 December 2024).
33. Yamasaki, M.; DeGraaf, R.M.; Lanier, J.W. Wildlife Habitat Associations in Eastern Hemlock—Birds, Smaller Mammals, and Forest Carnivores. In *Proceedings of the Symposium on Sustainable Management of Hemlock Ecosystems in Eastern North America, Durham, NH, USA, 24 June 1999*; GTR NE-267; USDA Forest Service: Salt Lake City, UT, USA, 1999. Available online: <https://research.fs.usda.gov/treesearch/14691> (accessed on 14 November 2024).
34. OMNR (Ontario Ministry of Natural Resources). *Old-Growth Forest Definitions for Ontario*; Ontario Ministry of Natural Resources, Queen’s Printer for Ontario: Toronto, ON, Canada, 2003. Available online: <https://www.publications.gov.on.ca/old-growth-forest-definitions-for-ontario-009288> (accessed on 15 March 2024).
35. Quinby, P. *Minimum Diameters for Old-Growth Trees in Ontario’s Northern Temperate Forests*; Forest Landscape Baselines Report No. 36; Ancient Forest Exploration & Research: Powassan, ON, Canada, 2020. Available online: https://www.ancientforest.org/_files/ugd/1eacbf_f857ca1b80e94a1ca78408f57c144b09.pdf (accessed on 17 May 2024).
36. USFS (United States Forest Service). *Mature and Old-Growth Forests: Definition, Identification, and Initial Inventory on Lands Managed by the Forest Service and Bureau of Land Management, Fulfillment of Executive Order 14072, Section 2(b)*; Report FS-1215a; United States Forest Service: Washington, DC, USA, 2023. Available online: https://www.fs.usda.gov/sites/default/files/fs_media/fs_document/Mature-and-Old-Growth-Forests.pdf (accessed on 25 May 2026).
37. Google Maps. Map of Northern Catchacoma Lake, Ontario. 2024. Available online: <https://maps.google.com/> (accessed on 16 February 2024).
38. Densmore, N.; Thompson, R.; McGeough, D.; Kilpatrick, K. Protocol for Stand-Level Biodiversity Monitoring: Steps for Field Data Collection and Administration. Forest and Range Evaluation Program, B.C. Ministry of Forests and B.C. Ministry of the Environment. 2009. Available online: https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/forestry/frep/protocol-documents/frep-slr-protocol-2024_v6.pdf (accessed on 22 March 2024).
39. NRCS (Natural Resources Conservation Service). Forestry Inventory Methods. In *Forestry Inventory Methods Technical Note No. 190, USDA*; USDA: Washington, DC, USA, 2018. Available online: https://www.nrcs.usda.gov/wps/cmیس_proxy/https://ecm.nrcs.usda.gov:443/fncmis/resources/WEBP/ContentStream/idd_304C3F76-0000-C614-BE74-8397C78FD743/0/MT-FOR-1.pdf (accessed on 14 October 2024).
40. Jayaraman, K. *A Statistical Manual for Forestry Research, Chapter 5—Sampling Techniques*; Kerala Forest Research Institute: Thrissur, India; FAO United Nations: Bangkok, Thailand, 1999. Available online: <https://www.fao.org/3/X6831E/X6831E00.htm> (accessed on 16 July 2024).
41. ESRI Inc. *ArcGIS Desktop*, Version 10.8.2; Computer Software; ESRI: Redlands, CA, USA, 2024. Available online: <https://www.arcgis.com/index.html> (accessed on 26 February 2024).
42. Ward, J.S.; Smith, D.M. Dynamics of Connecticut’s Hemlock Stands. In *Proceedings of the Symposium on Sustainable Management of Hemlock Ecosystems in Eastern North America, Durham, NH, USA, 22–24 June 1999*; GTR NE-267; USDA Forest Service: Salt Lake City, UT, USA, 1999; pp. 50–54. Available online: <https://research.fs.usda.gov/treesearch/14638> (accessed on 25 May 2026).

43. Manomet Center for Conservation Sciences. LS (Late successional) Index (Revised): Northern Pine Forest. In *Forest Mosaic Science Notes*; Manomet Conservation Sciences: Plymouth, MA, USA, 2009. Available online: <https://www.manomet.org/page/2/?s=pine+forest> (accessed on 12 March 2024).
44. Kirk, D.A.; Welsh, D.A.; Baker, J.A.; Thompson, I.D.; Csizy, M. Avian assemblages differ between old-growth and mature white pine forests of Ontario, Canada: A role for super-canopy trees? *Avian Conserv. Ecol.* **2012**, *7*, 4. [CrossRef]
45. Quinby, P. *Preliminary Definitions of Old-Growth Red and White Pine Forest in Central Ontario*; Tall Pines Project; Temagami Wilderness Society & Earthroots: Toronto, ON, Canada, 1991. Available online: https://www.ancientforest.org/_files/ugd/1eacbf_bbd4b2be63154eb682c5927d800959c8.pdf (accessed on 2 December 2024).
46. Tiscar, P.A.; Lucas-Borja, M.E. Structure of old-growth and managed stands and growth of old trees in a Mediterranean *Pinus nigra* forest in southern Spain. *Forestry* **2016**, *89*, 201–207. [CrossRef]
47. McWilliams, W.H.; Schmidt, T.L. Composition, Structure, and Sustainability of Hemlock Ecosystems in Eastern North America. USDA, Forest Service. In *Proceedings of the Symposium on Sustainable Management of Hemlock Ecosystems in Eastern North America*, Durham, NH, USA, 22–24 June 1999. Available online: <https://research.fs.usda.gov/treesearch/14631> (accessed on 6 June 2024).
48. Loucks, O.; Nighswander, J. Recognizing All-aged Hemlock Forests. In *Proceedings of the Symposium on Sustainable Management of Hemlock Ecosystems in Eastern North America*, Durham, NH, USA, 22–24 June 1999; GTR 267; USDA, Forest Service: Salt Lake City, UT, USA, 1999. Available online: <https://research.fs.usda.gov/download/treesearch/4141.pdf> (accessed on 3 April 2024).
49. Watkins, L. *The Forest Resources of Ontario 2011*; Ontario Ministry of Natural Resources, Forest Evaluation and Standards Section, Forests Branch: Sault Ste. Marie, ON, Canada, 2011. Available online: <https://www.ontario.ca/page/forest-resources-ontario-2011> (accessed on 14 November 2024).
50. OLRC (Ontario LandOwner Resource Centre). *Eastern Hemlock*; Ontario Extension Notes; Sir Sanford Fleming College, Queen's Printer for Ontario: Toronto, ON, Canada, 1995.
51. Strobl, S.; Bland, D. *A Silviculture Guide to Managing Southern Ontario Forests*; Southcentral Sciences Section, Ontario Ministry of Natural Resources: North Bay, ON, Canada, 2000. Available online: <https://www.publications.gov.on.ca/a-silvicultural-guide-to-managing-southern-ontario-forests> (accessed on 29 March 2024).
52. OMNR (Ontario Ministry of Natural Resources). *Ecosites of Ontario, Operational Draft*; Ecological Land Classification Working Group: Peterborough, ON, Canada, 2009. Available online: https://www.ontario.ca/page/ecological-land-classification#:~:text=Ecosites%20are%20used%20by%20sustainable%20forest%20license,sustainable%20forest%20management.%20*%20wildlife%20habitat%20management (accessed on 19 November 2024).
53. NHIC (Natural Heritage Information Centre). *Plant Community List (Excel File)*; Natural Heritage Information Centre: Peterborough, ON, Canada, 2024. Available online: <https://www.ontario.ca/page/natural-heritage-information-centre> (accessed on 12 August 2024).
54. Drever, C.R.; Snider, J.; Drever, M.C. Rare forest types in northeastern Ontario: A classification and analysis of representation in protected areas. *Can. J. For. Res.* **2010**, *40*, 423–435. [CrossRef]
55. Parker, W.C.; Derry, V.; Elliott, K.A.; MacQuarrie, C.J.K.; Reed, S. Applying three decades of research to mitigate the impacts of hemlock woolly adelgid on Ontario's forests. *For. Chron.* **2023**, *99*, 205–225. [CrossRef]
56. O'Brien, P.; Gunn, J.S.; Clark, A.; Gleeson, J.; Pither, R.; Bowman, J. Integrating carbon stocks and landscape connectivity for nature-based climate solutions. *Ecol. Evol.* **2023**, *13*, e9725. [CrossRef]
57. Marcus, A. *Carbon Storage Reduction and CO₂ Produced by Logging in the Catchacoma Old-Growth Forest*; Research Report No. 43; Ancient Forest Exploration & Research: Powassan, ON, Canada, 2023. Available online: https://www.ancientforest.org/_files/ugd/1eacbf_1e7af83ee10c4b2cbd1e7daa68aa3fcc.pdf (accessed on 22 March 2024).
58. Sperduto, D.D.; Nichols, W.F. *Natural Communities of New Hampshire*, 2nd ed.; New Hampshire Natural Heritage Bureau, Concord, New Hampshire and UNH Cooperative Extension: Durham, NH, USA, 2011. Available online: https://extension.unh.edu/sites/default/files/migrated_unmanaged_files/Resource000425_Rep447.pdf (accessed on 9 June 2024).
59. Zimmerman, E.; Davis, T.; Podniesinski, G.; Furedi, M.; McPherson, J.; Seymour, S.; Eichelberger, B.; Dewar, N.; Wagner, J.; Fike, J. (Eds.) *Terrestrial and Palustrine Plant Communities of Pennsylvania*, 2nd ed.; Pennsylvania Natural Heritage Program, Pennsylvania Department of Conservation and Natural Resources: Harrisburg, PA, USA, 2012. Available online: https://www.naturalheritage.state.pa.us/docs/community/communities_intro_s1.pdf (accessed on 20 March 2024).
60. Eyre, F.H.; Drake, J. CEGL002590 *Pinus strobus-Tsuga canadensis* Great Lakes Forest. National Vegetation Classification, Ecological Society of America and United States Geological Survey. 1996. Available online: https://explorer.natureserve.org/Taxon/ELEMENT_GLOBAL.2.687681/Pinus_strobus_-_Tsuga_canadensis_Great_Lakes_Forest (accessed on 23 July 2024).
61. Hessburg, P.F.; Smith, B.G.; Salter, R.B. Detecting change in forest spatial patterns from reference conditions. *Ecol. Appl.* **1991**, *9*, 1232–1252. [CrossRef]

62. Mladenoff, D.J.; White, M.A.; Pastor, J.; Crow, T.R. Comparing Spatial Pattern in Unaltered Old-Growth and Disturbed Forest Landscapes. *Ecol. Appl.* **1993**, *3*, 294–306. [\[CrossRef\]](#)
63. Frey, S.J.K.; Hadley, A.S.; Johnson, S.L.; Schulze, M.; Jones, J.A.; Betts, M.G. Spatial models reveal the microclimatic buffering capacity of old-growth forests. *Sci. Adv.* **2016**, *2*, e1501392. [\[CrossRef\]](#)
64. Hoffman, C.M.; Ziegler, J.P.; Tinkham, W.T.; Hiers, J.K.; Hudak, A.T. A Comparison of Four Spatial Interpolation Methods for Modeling Fine-Scale Surface Fuel Load in a Mixed Conifer Forest with Complex Terrain. *Fire* **2023**, *6*, 216. [\[CrossRef\]](#)
65. Barnett, K.; Aplet, G.H.; Belote, R.T. Classifying, inventorying, and mapping mature and old-growth forests in the United States. *Front. For. Glob. Change* **2023**, *5*, 1070372. [\[CrossRef\]](#)
66. The White House. FACT SHEET: Biden-Harris Administration Advances Commitment to Protect Old Growth Forests on National Forest System Lands. Briefing Room, Statements and Releases. 19 December 2023. Available online: <https://www.presidency.ucsb.edu/documents/fact-sheet-biden-harris-administration-advances-commitment-protect-old-growth-forests> (accessed on 25 May 2026).
67. O'Brien, L.; Schuck, A.; Fraccaroli, C.; Pötzelsberger, E.; Winkel, G.; Lindner, M. *Protecting Old-Growth Forests in Europe: A Review of Scientific Evidence to Inform Policy Implementation*; Final Report; European Forest Institute: Joensuu, Finland, 2021. [\[CrossRef\]](#)
68. European Commission. *Commission Guidelines for Defining, Mapping, Monitoring and Strictly Protecting EU Primary and Old-Growth Forests*; European Commission: Brussels, Belgium, 2023. Available online: https://environment.ec.europa.eu/publications/guidelines-defining-mapping-monitoring-and-strictly-protecting-eu-primary-and-old-growth-forests_en (accessed on 13 June 2024).
69. Mikolas, M.; Piovesan, G.; Ahlström, A.; Donato, D.C.; Gloor, R.; Hofmeister, J.; Keeton, W.S.; Muys, B.; Sabatini, F.M.; Svoboda, M.; et al. Protect old-growth forests in Europe now. *Science* **2023**, *380*, 466. [\[CrossRef\]](#) [\[PubMed\]](#)
70. Issekutz, P.B. *A Critical Evaluation of Old-Growth Forest Definitions in Canada*; Department of Earth and Environmental Sciences; Dalhousie University: Halifax, NS, Canada, 2020; Available online: https://dalspace.library.dal.ca/bitstream/handle/10222/79232/PeterIssekutz_Apr2020.pdf?sequence=1 (accessed on 24 May 2024).
71. Folland, A.; Woolley, N.; Angel, B.; Quinby, P. *Establishing a Long-Term, Permanent-Plot Research Program in the Catchacoma Forest, Trent Lakes, Ontario*; Research Report No. 42; Ancient Forest Exploration & Research: Powassan, ON, USA, 2022; Available online: https://www.ancientforest.org/_files/ugd/1eacbf_a05d012b3478464ea05e46841073f5e0.pdf (accessed on 25 August 2024).
72. Dinerstein, E.; Joshi, A.R.; Vynne, C.; Lee, A.T.L.; Pharand-Deschênes, F.; França, M.; Fernando, S.; Birch, T.; Burkart, K.; Asner, G.P.; et al. A “Global Safety Net” to reverse biodiversity loss and stabilize Earth’s climate. *Sci. Adv.* **2020**, *6*, eabb2824. [\[CrossRef\]](#) [\[PubMed\]](#)
73. Finkelstein, S.A.; Doherty, C.; Loder, A.L. Safety Net Ontario: Ontario’s outsized role in the “Global Safety Net” for climate and biodiversity. *FACETS* **2023**, *8*, 1–17. [\[CrossRef\]](#)
74. Quinby, P.A.; Elliott, R.E.; Quinby, F.A. Decline of regional ecological integrity: Loss, distribution and natural heritage value of roadless areas in Ontario, Canada. *Environ. Chall.* **2022**, *8*, 100584. [\[CrossRef\]](#)

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.