Assessing Forest Structural Development in Old-Growth Maple-Beech and Hemlock-Hardwood Stands

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Introduction

As a forest develops in response to a disturbance, it undergoes many changes. Some of these changes are in the composition of species within the forest, while some changes are structural. The former successional development, often associated with the progression towards climax species composition within a forest community and the latter describes the development of a community from an initiation stage to old-growth. Originally described by Oliver and Larson (1996), forest structural development can be heuristically summarized into four different stages: (1) Stand initiation—where new individuals and species appear and rapidly grow for several years after a disturbance until all practical growing space is occupied, (2) Stem exclusion—when new individuals stop appearing and competition amongst established trees occurs and individuals either survive or die. Here, forest stands are still quite dense and the survivors capitalize on the canopy holes left by individuals that die, (3) Stem reinitiation—where understory development occurs due to canopy gaps created by disturbance and there is much vertical stratification, and (4) Old-growth—in which understory trees have grown and completely replaced the original pioneer cohort resulting in a large amount of course woody debris (CWD) and tree snags, a very vertically stratified forest community, and large diameter trees (Oliver and Larson 1996, Franklin et al. 2002).

Assessing where on this continuum of development a forest stand is can often be difficult, though structural characteristics like the spatial arrangement and variety of individual trees, snags and logs of various sizes and conditions have been proven to be effective elements in defining a stands' current developmental stage (Wolford n.d., Franklin et al. 2002). In addition, light availability and transmittance is a necessary component of understory plant success (Chazdon and Pearcy 1991). In this, large canopy gaps generate opportunities for understory species to grow until the light gap is occupied either by canopy reclosure or the understory species ascending to the canopy. Likewise, small gaps, or sunflecks, that are light sources which occur from intermittent openings in the canopy are crucial for shade-tolerant and understory growth (Chazdon and Pearcy 1991). In fact, some forests have less than 5.0% irradiance through the canopy, yielding an understory that is adapted to solely utilize the fleeting sunflecks for growth (Chazdon and Pearcy 1991). Overall, by assessing the light environment, as well as trees, snags, and logs, we should be able to accurately summarize a forest stand's developmental stage.

Therefore, based on these forest structural development characteristics, our objectives are two-fold: to quantify the key structural elements of old-growth hardwood stands, and to compare maple-mixed hardwood with hemlock dominated old-growth types.

Study Area

The area used for this study was the Dukes Experimental Forest, located 25-km southeast of Marquette, MI at 46°22'0.3"N 87°09'53.5"W. This forest is currently administered by the USDA's Northern Research Station and is largely comprised of old growth northern hardwoods as well as old growth eastern hemlock (Adams et al. 2013). In particular, the two areas which we studied were Maple-Beech stands and Hemlock-Hardwood stands. The soil types found in this location are well-drained Munising sandy loam, poorly drained Skanee sandy loam, poorly drained Angelica sandy loam, and Linwood muck (Adams et al. 2013). Overall, because this area is a research natural area, it is an ideal location to analyze structural development characteristics of old-growth forests.

Methods

In this study, we used standard USDA Forest Service sampling protocols for old growth forests to describe stand structure and composition. In this, we measured and quantified species composition, diameter class distributions, volume of downed wood, snag densities, decay class distributions for snags and logs, and light gaps in the canopy.

For the sampling locations in our study areas, 5 parallel 100-m transects were established perpendicular from the roadside, with sampling plots being systematically spaced at 30-m intervals along the transect. At each plot interval, circular nested plots of 9.8-m radius, 5.6-m radius and 1-m radius were used to sample large trees, small trees, and saplings respectively. Per each 9.8-m-radius plot, all living trees (≥10-cm dbh) and all dead trees (snags >2-m tall) were identified with their dbh measured and, for snags, their decay class noted. Within each 5.6-m-radius plot, trees with a dbh of 4.0-9.9 cm were counted, measured, and identified. The same sampling was done for saplings (1.0-3.9 cm dbh) within 1.0-m-radius plots.

To understand the amount of on-ground course woody debris in our study area, two methods were used. For all logs that lay within, or partially within, our 9.8-m-radius plots, the length and midpoint diameter of all logs greater than 10-cm in diameter were measured. For logs which were partially within our study area, only the part of the log that was within 9.8-m were recorded, anything outside of that radius was not included. Additionally, the second method used was a line-intercept method of measuring CWD, where any log that intercepts our 100-m transect line was recorded. Fr each log that intercepted the transect, the diameter of the log at point of interception was recorded. Likewise, for each log observed, the decay class was recorded, as described by Forest Service guidelines.

Additionally, to analyze the light gap environment, a hemispherical photo in the center of each plot was taken of the canopy. These photos were then analyzed with a GLA (Gap Light Analyzer) program where many metrics were calculated, including the percent of canopy openness, total direct sunlight, and total diffuse sunlight.

The resulting data was analyzed in Microsoft Excel, where standard statistical methods were performed. In particular for the trees that were observed, tree density and basal area were calculated and used to derive a relative importance value. Likewise, CWD density was calculated based on decay class. Overall, these methods were performed in both the Hemlock-Hardwood stand and the Maple-Beech stand, allowing for comparison between the two. Likewise, this method for characterizing a forest community was adopted from Wolford (2002).

Results

Among the 38 plots that were sampled, 14 unique tree species were observed, 5 of which were found in the Maple-Beech stand and 11 were in the Hemlock-hardwood stand. Overall, the Hemlock-hardwood stand contained much greater diversity, especially among low abundant taxa.

Both stands, however, exhibited dominance by a few species that had very high abundance and importance values. The Maple-Beech stand studied contained an unsurprisingly high amount of *Acer saccharum*, which occurred in 100% of large-tree plots and was the most dominant species in this stand-type (Table 1). Also occurring in a noteworthy number of plots was *Ostrya virginiana* and *Fagus grandifolia*, and although their overall importance is relatively low, they occur with a respective 24.9 and 18.2 trees-per-hectare (Table 1). In terms of the Hemlock-Hardwood stand, there was a much greater species diversity observed in large tree plots. The most dominant of which were *Tsuga canadensis*, followed modestly by *Acer rubrum*. In both of these stands, the large trees were clearly dominated by a single species, with several other species occurring in low levels of abundance. In Maple-beech stands, both *Fagus grandifolius* and *Ostrya virginiana* are more important among intermediate-size trees however, with IVs of 10.5 and 9.5 compared to 3.4 and 4.7 in large trees, respectively (Table 2). Likewise, *Acer saccharum* intermediate trees were found to be less important than large trees, but dominates intermediate Maple-beech stand trees overall. In intermediate Hemlock-hardwood stand trees, *Fagus grandifolia* is substantially important, with a density of 112.8 trees-per-hectare and with an IV of 28.7 (Table 2). This is surprising as there were no large F. *grandifolia* trees found in the Hemlock-hardwood stand. Conversely, *T. canadensis* continues to dominate intermediate trees in this stand, but relatively less so at 191.7 trees-per-hectare and an IV of 60.4 (Table 2). Of all plots sampled, the saplings observed were the least diverse group, with only 3 species being found. In the Maple-beech stand, *Acer saccharum* was incredibly dominant over *Fagus grandifolia*, the only other sapling species found in this stand type (Table 3). Among the saplings in the Hemlock-hardwood stand, however, the abundance pattern seen in intermediate sized trees continues, where *F. grandifolia* is of noteworthy importance (IV of 28.1) second to *T. canadensis* (Table 3).

In terms of the size of the most dominant trees observed, *A. saccharum* was much more frequent among trees with a dbh of 10-20 cm compared to *T. Canadensis* (Figure 1). Overall, *T. canadensis* trees were found to be more frequent among larger sized trees, especially of those which were 20-65 cm in dbh (Figure 1). Among all trees observed, there is a clear reverse-J trend, where the most abundant trees are of smaller size and there is a progression to least abundance among the largest trees (Figure 2).

Within each plot, the amount of CWD which was observed was quite substantial, with Hemlock-hardwood stands containing a total of 99.1 m^3/ha and Maple-beech stands containing 74.5 m^3/ha (Table 4). Likewise, Hemlock-hardwood stands contained a much greater area of snags at 3.71 m^2/ha compared to .34 m^2/ha in Maple-beech stands (Table 4). In general, most of the CWD that was found in our plots were of a decay class of 3 or higher, especially in the Maple-beech stand (Figure 3). Furthermore, the size of CWD logs which were found follow a similar distribution to that of tree sizes, where the most abundant logs were smaller in volume (Figure 4).

Lastly, in assessing the light gap environment, we found that the mean light transmittance between both stand types was not significantly different (P-value=0.158, df=33, α=.05). Thus, we cannot confidently say that a differences in understory tree growth is due to a disparency in the amount of light reaching the understory.

Table 1. Summary of all large tree species (≥10 cm dbh) at Dukes Experimental Forest, Skandia Township, Michigan on October 16, 2018. Sample size was 20 Maple Stand plots and 18 Hemlock Stand plots. Frequency of occurrence is the percentage of plots in which a species occurred. Density is measured in trees per hectare and Basal Area is measured in square-meters per hectare. IV is an importance value calculated as the average of relative density and relative basal area.

	Species	Freq. of Occurrence (%)	Density	Basal Area	IV
Maple Stand	*Acer saccharum*	100.0	246.9	32.84	90.5
	Ostrya virginiana	40.0	24.9	0.34	4.7
	Fagus grandifolia	45.0	18.2	0.22	3.4
	Betula alleghaniensis	5.0	1.7	0.26	0.7
	Tilia americana	5.0	3.3	0.06	0.6
Hemlock Stand	*Tsuga canadensis*	100.0	290.9	41.01	76.8
	Tilia americana	66.7	42.4	3.73	9.0
	Acer rubrum	44.4	18.4	2.33	4.6
	Acer saccharum	33.3	22.1	0.96	3.7
	Betula alleghaniensis	33.3	16.6	1.26	3.3
	Abies balsamea	5.6	1.8	1.78	2.0
	Pinus Strobus	5.6	1.8	0.04	0.3
	Thuja occidentalis	5.6	1.8	0.01	0.2

Table 2. Summary of all intermediate trees (5.0–9.9-cm dbh) observed at Dukes Experimental Forest, Skandia Township, Michigan on October 16, 2018. Sample size was 20 Maple Stand plots and 18 Hemlock Stand plots. Frequency of occurrence is the percentage of plots in which a species occurred. Density is measured in trees per hectare and Basal Area is measured in square-meters per hectare. IV is an importance value calculated as the average of relative density and relative basal area.

	Species	Freq. of Occurrence (%)	Density	Basal Area	IV
Maple	*Acer saccharum*	95.0	461.8	1.04	80.0
	Fagus grandifolia	20.0	35.5	0.20	10.5
	Ostrya virginiana	35.0	66.0	0.10	9.5
Hemlock Stand	*Tsuga canadensis*	61.1	191.7	0.77	60.4
	Fagus grandifolia	27.8	112.8	0.29	28.7
	Ostrya virginiana	16.7	16.9	0.04	4.2
	Picea glauca	5.6	5.6	0.04	2.3
	Betula alleghaniensis	5.6	5.6	0.04	2.3
	Acer saccharum	5.6	5.6	0.03	2.0

Table 3. Summary of all tree saplings (< 5-cm dbh) observed at Dukes Experimental Forest, Skandia Township, Michigan on October 16, 2018. Sample size was 20 Maple Stand plots and 18 Hemlock Stand plots. Frequency of occurrence is the percentage of plots in which a species occurred. Density is measured in trees per hectare and Basal Area is measured in square-meters per hectare. IV is an importance value calculated as the average of relative density and relative basal area.

	Species	Freq. of Occurrence (%)	Density	Basal Area	IV
Map.	*Acer saccharum*	55.0	954.7	0.26	95.7
	Fagus grandifolia	5.0	39.8	0.01	4.3
Hem.	*Tsuga canadensis*	27.8	442.0	0.15	71.9
	Fagus grandifolia	11.1	132.6	0.08	28.1

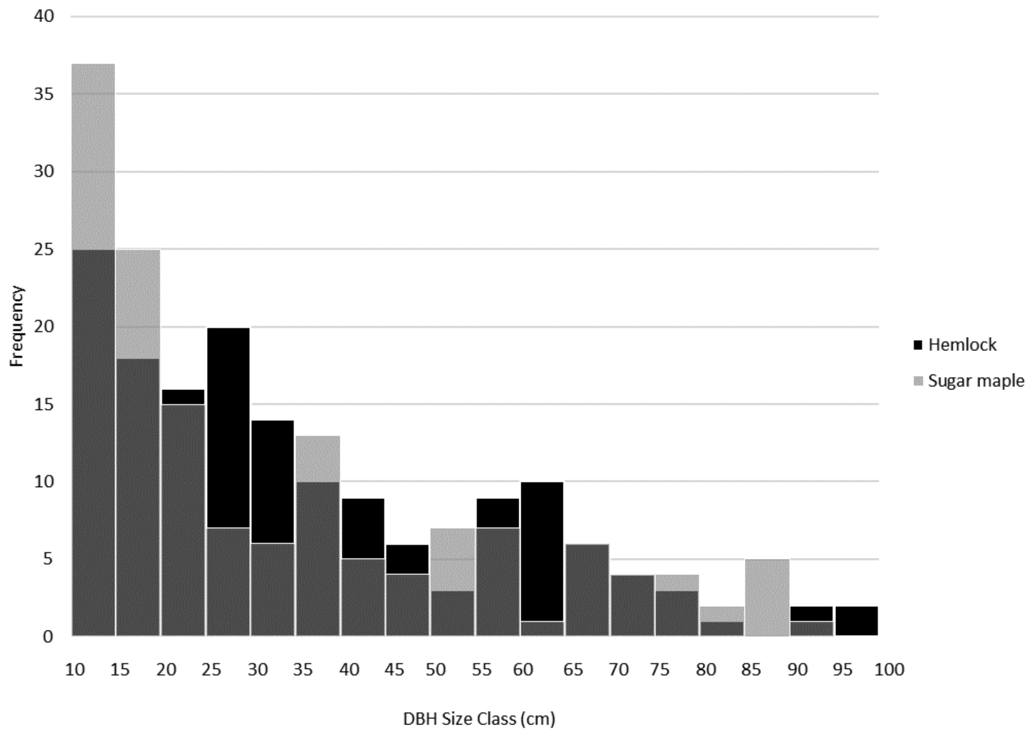

Figure 1. Histogram based on the size classes of the two most dominant large tree (≤10 cm dbh) species, Hemlock (*Tsuga canadensis*) and Sugar maple (*Acer saccharum*) at Dukes Experimental Forest, Skandia Township, Michigan on October 16, 2018.

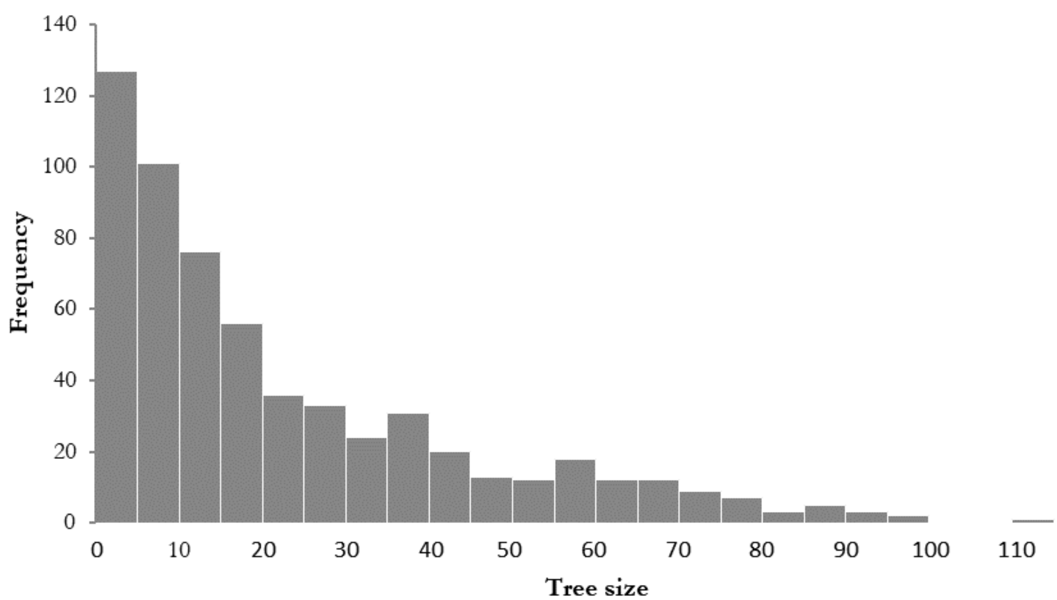

Figure 2. Diameter frequency histogram based on all species sampled and among all plot types at Dukes Experimental Forest, Skandia Township, Michigan on October 16, 2018. Tree size was measured by the diameter at breast height in centimeters.

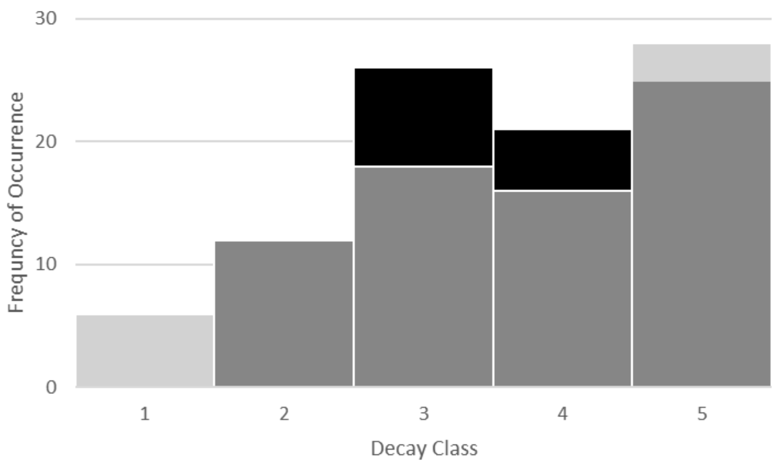

Figure 3. Distribution of CWD based on decay classes between each sampling location at Dukes Experimental Forest, Skandia Township, Michigan on October 16, 2018. In this figure, black represents Maple stands and gray represents hemlock stands. Decay class was determined based off of USDA Forest Service guidelines.

Table 4. Summary of CWD measured at Dukes Experimental Forest, Skandia Township, Michigan on October 16, 2018. CWD values expressed here are measured by cubic-meters per hectare. Likewise, BA here is the basal area of snags in study plots, expressed in square-meters per hectare.

Stand	CWD	Line-Int. CWD	Snag BA
Hemlock	99.1	107.6	3.71
Maple	74.5	100.1	0.34

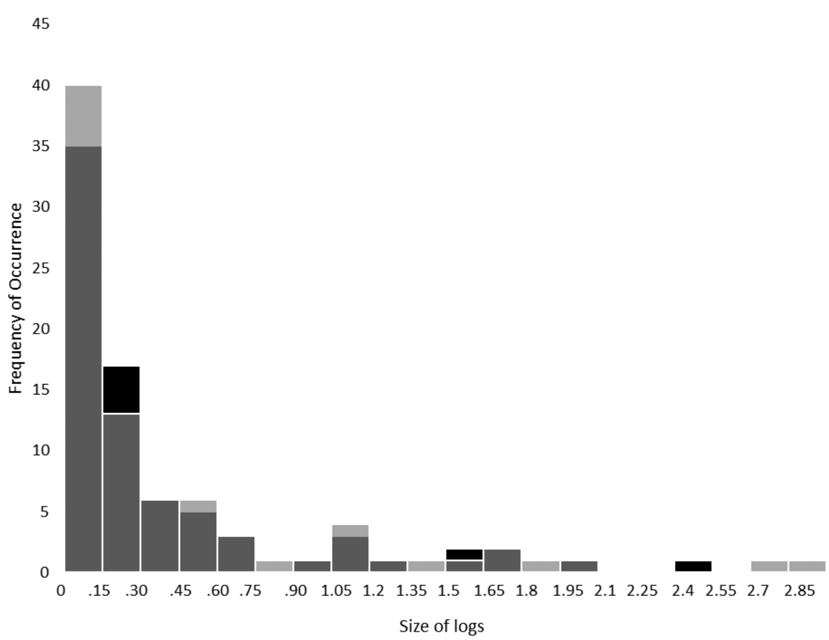

Figure 4. Size distribution of CWD between each sampling location at Dukes Experimental Forest, Skandia Township, Michigan on October 16, 2018. Here, black represents Hemlock stand CWD and gray represents Maple stand. Size classes of CWD logs are in cubic meters.

Discussion

Based on our results, we have sufficient baseline data to understand and explain the structural elements of old-growth forests in both Hemlock-hardwood and Maple-beech dominated forest communities. We can say this for several reasons. In terms of tree diameter distributions, old-growth forests have been found to have several basic patterns, that is a negative exponential pattern (reverse J), a bell-shaped unimodal, and an intermediate skewed unimodal distribution (Wolford 2002). Our data exhibits the negative exponential pattern where the largest trees are least abundant and the smallest trees are exponentially more abundant. In particular, other old-growth maple and hemlock forests in the Upper Peninsula have been described to have this type of tree diameter distribution (Wolford 2002). This means that overall, our tree size data is representative of old-growth forests. Likewise, Wolford (2002) summarized average volumes of CWD in northern hardwood stands to be 91.0-115.6 m^3/ha and hemlock-hardwood stands to be 150-200 m^3/ha, though in younger (<200 years) Hemlock-hardwood stands the average was 84.5 m^3/ha. Our Maple-beech stand values fall near this range, at 74.5 m^3/ha (100.1 m^3/ha for line-intercept measurements) and our Hemlock-hardwood values are within the young-stand CWD range. The lower than average CWD volume in our Maple-beech stand may be explained if the age of this stand is relatively young (Wolford 2002). Likewise, CWD volume has also been found to be quite variable, as decomposition is affected by many factors (Wolford 2002). Nevertheless, our CWD values quite plausibly exemplify old-growth forest communities.

Additionally, our results indicate that there is potential replacement species, *Fagus grandifolia*, that occurs particularly in Hemlock-hardwood stands. *F. granifolia* is an extremely shade tolerant species that often replaces sugar maples and it would be fascinating to see if it eventually did here, as it was the second-most important tree among saplings and intermediate-sized trees in both Hemlock-hardwood and Maple-beech stands.

Overall, this study continues an effective method surveying and analyzing forest communities. The data and results we obtained further validate the structural characteristics of old-growth forest in Michigan's Upper Peninsula that were studied in Wolford (2002). In this, we accomplished our objectives by quantifying key old-growth structural elements and comparing these elements between Maple-beech and Hemlock-hardwood forest types. Old-growth studies such as this may be a valuable aid in forest conservation and management efforts.

Literature Referenced

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