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Long Term Trends in Size Distribution of Eastern Hemlocks in West Michigan Dune Forests

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Abstract:
Size distributions of trees often yield valuable clues about changing environmental conditions and the responses of populations to them. In a recent study, the size distribution of Eastern Hemlocks was measured in several forests near Lake Michigan to determine whether active recruitment into the population was taking place at a similar rate as in the past. The diameter at breast height as well as cores samples were taken for all hemlocks present in selected stands. Analysis found that the size distribution was strongly skewed toward the intermediate and larger tree size classes suggesting a failure of recent recruitment relative to that in the past. Experimental transplantation of hemlock saplings in select stands has yielded a possible link with herbivory due to the gradual increase of white tail deer populations as the primary cause of decline among hemlocks. Other studies in the Lake Michigan region, both inland and coastal, have documented a perceived decline in hemlock populations based on sample data and paleoecological trends. If the observed trend continues into the future, Eastern Hemlock will most likely continue to decline in density in these forests over the long term.

Background:

- Eastern Hemlock (*Tsuga canadensis*) is a major component of the boreal forest at high latitudes as well as along the western coast of Michigan and the shore of Lake Superior, on the dune systems formed since the end of the last glaciation.
- All of these forests are considered transitional deciduous forest, dominated by American Beech (*Fagus grandifolia*), Sugar Maple (*Acer saccharum*), White Pine (*Pinus strobus*), and others, though they are unique in that they include a significant number of Eastern Hemlocks as well.
- These forests have a unique composition owing to the microclimate created by their proximity to Lake Michigan (to approx. 900m inland) and to the topography created by the stabilized dunes.
- *T. canadensis* seems to be in decline in many of these forests however, owing to low recruitment driven by multiple environmental and anthropogenic factors.
- In forests near Lake Superior, low recruitment appears to have started in the 1970's, and appears to be attributable more to herbivory by white-tailed deer (*Odocoileus virginianus*) than to climate change.

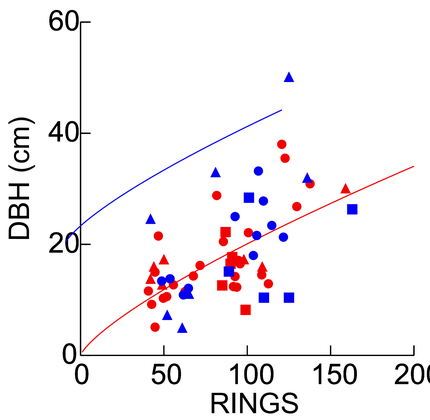

Figure 3. Annual growth rings vs. diameter at breast height (dbh) in *T. canadensis* in and near the HCNP. Lines are best nonlinear fits of the form dbh = a * rings^{b} to the data for partial cores (red) and for those with complete cores (blue). For the 23 "full" core records, the regression equation was dbh = 0.673 * rings$^{0.757}$. For the 39 "partial" core records, the regression equation was dbh = 0.601 * rings$^{0.762}$.

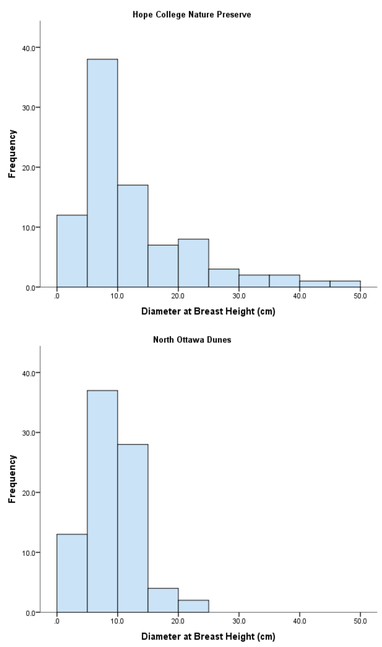

Figure 5. Size distributions of hemlocks at three study sites. The distributions differed significantly from one another (Kruskal-Wallis one-way ANOVA; H = 45.977 w/ 2 df; p<0.001).

Study Area and Methods:

- Building upon an established grid system, in the fall of 2012 hemlocks in a 5.32 hectare area located at the Hope College Nature Preserve (HCNP) in Allegan County Michigan were measured from diameter at breast height (DBH, 1.37m above soil level).
- Hemlocks of all sizes were censused at two other sites in the fall of 2013: Rosy Mound Natural Area (43.019ºN, 86.226ºW) and North Ottawa Dunes County Park (43.086ºN, 86.252ºW).
- Between 2012 and 2015, increment cores were taken from 38 trees at the HCNP, 21 at RM, and 10 at NOD. This was done in order to establish the relationship between dbh and age. Cored trees ranged from 5 to 50 cm dbh.
- To explore the effects of herbivory and microclimate on hemlock recruitment, we transplanted 79 pairs of hemlock seedlings (30-50 cm tall) at all three sites in the spring of 2013 in four treatment combinations: deer-protected (fig. 1) vs. unprotected (fig. 2) on north- vs. south-facing slopes.
- Seedlings in the deer-protected treatment group were planted inside wood-framed exclosures covered with 2.5 cm wire mesh, approx. 22 cm diameter x 45 cm tall.
- N- and S-facing slopes were chosen to explore the effects of microclimate because S-facing slopes are warmer and more xeric than N-facing slopes.
- Following planting, censuses of these seedlings took place every 5 to 6 months.
- Criteria for overall plant condition were based on percentage of foliage dead or removed by herbivores, which led to sapling condition being classified as good, fair, poor, or dead.

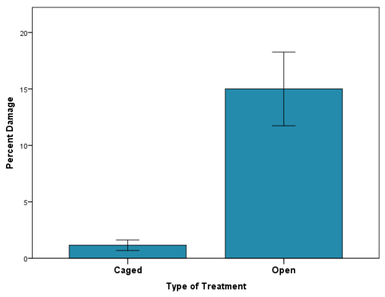

Figure 6. Percent herbivore damage on protected and exposed seedlings. Hemlock seedlings in the caged treatment had far less herbivore damage (t = 4.203 w/ 1 df; p<0.001).

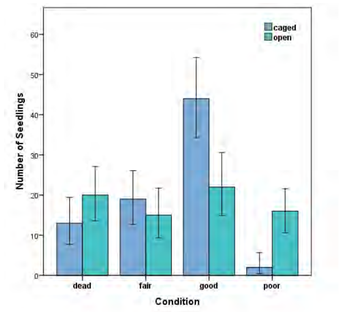

Figure 7. Seedling condition vs. treatment after 23 months. Differences in condition among treatment groups were significant (X^2= 20.034 w/ 3 df; p<0.001).

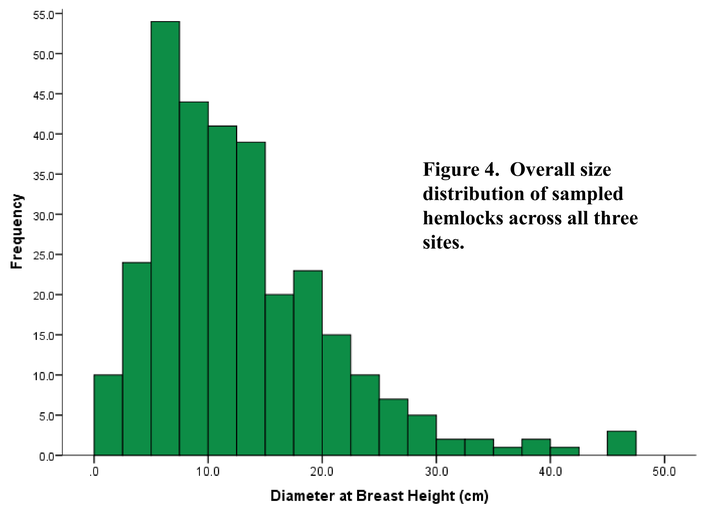

Figure 4. Overall size distribution of sampled hemlocks across all three sites.

Figure 1. Exclosure used to protect hemlock seedlings.

Figure 2. Unprotected hemlock seedling.

Results:

- Age-size relationship - We used nonlinear regression to fit curves of the form dbh = a * rings^{b} to the data from trees from which increment cores were collected (fig. 3). In general, hemlocks at the HCNP grew about 12 cm in diameter in 50 years.
- Size distributions - In all, 303 Eastern Hemlocks were censused at the three sites: 91 at the HCNP, 84 at NOD, and 128 at Rosy Mound. The modal size class was 5-10 cm at the HCNP and North Ottawa Dunes, while at Rosy Mound it was 10-15 cm. Although the distributions were all unimodal (figs. 4), they differed significantly from one another, with mean dbh being slightly higher at Rosy Mound (15.5 cm), intermediate at the HCNP (12.4 cm), and smallest (8.8 cm) at North Ottawa Dunes (Kruskal-Wallis one-way analysis of variance; H = 45.977 w/ 2 df; p<0.001). Modal dbh at RM, the HCNP, and NOD corresponded to 62.9, 36.7, and 34.2 years of growth respectively (fig. 5).
- Survival of transplanted seedlings - Due to herbivory, unprotected seedlings were significantly shorter (an average of 13.85cm) than protected seedlings (fig. 6). Thus it was noted that there was a tendency for protected seedlings to be more healthy than those that were exposed to herbivores (fig. 7). On north- and south-facing slopes, there was no significant difference in overall seedling dryness (fig. 8). Seedlings planted in locations with less canopy cover were found to be significantly healthier than those with a more enclosed canopy (fig. 9). It was found that there was no significant difference in canopy cover between the three sites used (fig. 10).

Discussion:

- The size (and, hence, age) distributions in figures 4 and 5 suggest that *T. canadensis* recruitment at all three sites has been much lower in the last 35-65 years than it was historically.
- Tree populations with healthy annual recruitment have J-shaped size distributions; i.e., the smallest individuals comprise the most frequent size class, and larger trees are less frequent due to self-thinning and other mortality factors.
- However, across our three sites, only 11.2% of the trees are younger than 19 years (5 cm dbh), while 32.4% are between the ages of 19 and 45 years (5-10 cm dbh; fig. 4). Low recruitment in these populations is of particular concern because *T. canadensis* is a diagnostic component of the dune forests that fringe the eastern shore of Lake Michigan.
- The condition of transplanted seedlings after 23 months suggests that damage by herbivores (probably White-tailed Deer), rather than lack of water or higher insolation on south-facing slopes, is the primary factor behind the low recruitment rate. Similar conclusions have been reached by other investigators in forests near Lake Superior. (**Rooney T.P., McCormick R.J., Solheim S.L., Waller D.M. 2000.** Regional variation in recruitment of hemlock seedlings and saplings in the upper Great Lakes, USA. *Ecological Applications* **10(4):** 1119-1132)

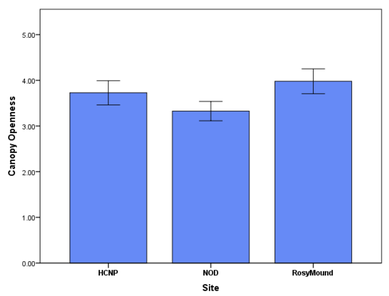

Figure 10. Canopy openness over seedlings at the three study sites. Mean sunlight exposure did not differ across the three sites (Kruskal-Wallis one-way ANOVA; H = 1.607 w/ 2 df; p=0.448).

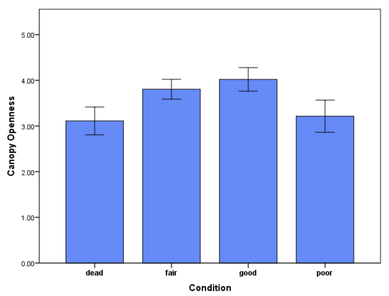

Figure 9. Canopy openness vs. seedling condition. Mean sunlight exposure was higher for seedlings in both good and fair condition than in those that were dead or in poor condition (Kruskal-Wallis one-way ANOVA; H = 9.634 w/ 3 df; p= 0.022).

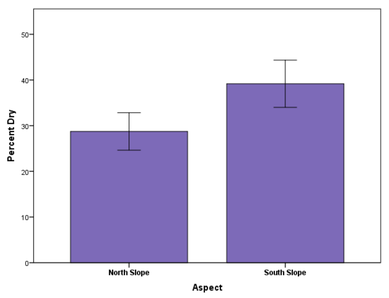

Figure 8. Needle condition on seedlings from north- and south-facing slopes. Mean percent dryness did not differ between slopes. (t = -1.581 w/ 1 df; p=0.116)

Acknowledgements
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