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Volume, Growth, and Stand Dynamics of a 192-year Old *Pinus resinosa* (Red Pine) Forest

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Background

Pinus resinsosa (red pine, Norway pine) is an important tree species in Minnesota's forests, both economically and ecologically. Of Minnesota's 17 million acres of forested land, red pine covers 695,000 acres and is the second-most harvested tree by volume in Minnesota, and by far the largest source of sawlogs (O'Connell et al., 2015; Minnesota Department of Natural Resources, 2015). Growth equations have been developed to assess and predict individual tree and stand level volume of red pine across the Lake States—Minnesota, Michigan, and Wisconsin—and numerous studies are available on red pine growth and structure (Bradford & Palik, 2009; D'Amato et. al, 2010; Fraver & Palik, 2012). Early research was completed on a red pine stand located at the Cloquet Forestry Center (CFC) by T. Schantz Hansen (1923), the former manager of the CFC.

Old-growth red pine stands are rare in Minnesota and the greater Lake States region due to harvesting of pine forests in the late 19th and early 20th centuries. Only 9,425 acres of red pine cover type over 120-years old exist in Minnesota, and only 26,500 acres exist nationwide (O'Connell et al., 2015). One old-growth red pine stand exists at the CFC. This study seeks to understand growth and stand dynamics in an old-growth red pine stands using over 100 years of individual tree measurements.

Data

A 192-year old, 39-acre stand, named "Camp 8," was saved from logging and preserved for research purposes at the urging of Sam Green, a University Professor and Dean of the Department of Forestry. A two-acre growth and yield plot measuring the growth and volume of all pine species within the plot was established in 1912, and has been measured seven additional times in 1917, 1922, 1927, 1932, 1962, 1973, and 2015. These data were used to assess growth and stand dynamics over 103 years. Measurements prior to 2015 were available via paper records at the CFC. Measurements in all years included diameter at breast height (DBH), height, and status (alive or dead) of each tree. Additional measurements were added to the 2015 inventory as a part of this study in March of 2016: live crown ratio, crown dieback, crown density, diameter, height, and fragmentation class of dead standing trees, and DBH and height of ingrowth trees—live trees that established in the plot after 1912 and were first measured in 2015.

Individual tree measurements for each inventory year included tree basal area (BA), individual tree volume based on DBH and height using an individual tree volume equation developed by Scott (1981), and individual tree growth (volume, BA) since the previous inventory. Summarized stand level data included trees per acre (TPA), BA per acre, and volume per acre. Additionally, site index (SI) was calculated using the Carmean (1989) site index equation for red pine by taking the average height of the tallest 50% of trees in a given inventory year. The SI of several years were calculated and the average site index was found to be 53 feet.

A stand volume equation model developed by Walters and Ek (1993) predicted per acre cubic foot (CF) volume at various site indexes and stand ages. Since red pine stands are often not managed at ages longer than 100 years, their model only predicted volume through age 100. Their equations were used to calculate predicted per acre CF volume for the Camp 8 stand with a site index of 53 at age 192. Additionally, the USDA Forest Service has developed a forest management and projection tool called the Forest Vegetation Simulator (FVS). FVS Lake States Variant was used to project the 1912 stand data to 2015 to compare predicted volume and stand composition (basal area, TPA, mortality and standing dead trees) to observed values.

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Results

Stand Density and Composition Measures

FVS, which can (albeit not easily) be adjusted for various mortality rates, over-predicted living trees and under predicted dead standing trees, both in terms of BA per acre and TPA (Figure 1). Species composition by stand age and inventory year in terms of BA per acre was also tracked (Figure 2). As is expected, jack pine—being an early successional species that is typically not long-lived—died out as a component of the stand between 108 and 138 years old. Red pine increased as a proportion of the stand, and white pine also increased its presence slightly.

	Live Trees		Dead Trees	
	BA (ft^2/ac)	TPA	BA (ft^2/ac)	TPA
FVS Predicted	154.4	84	3.7	3.0
Observed	150.8	67	16.4	21.0

Figure 1: Per acre density measures of living and dead trees, with FVS predicted measures based on the 1912 measurement data compared to the observed data in 2015.

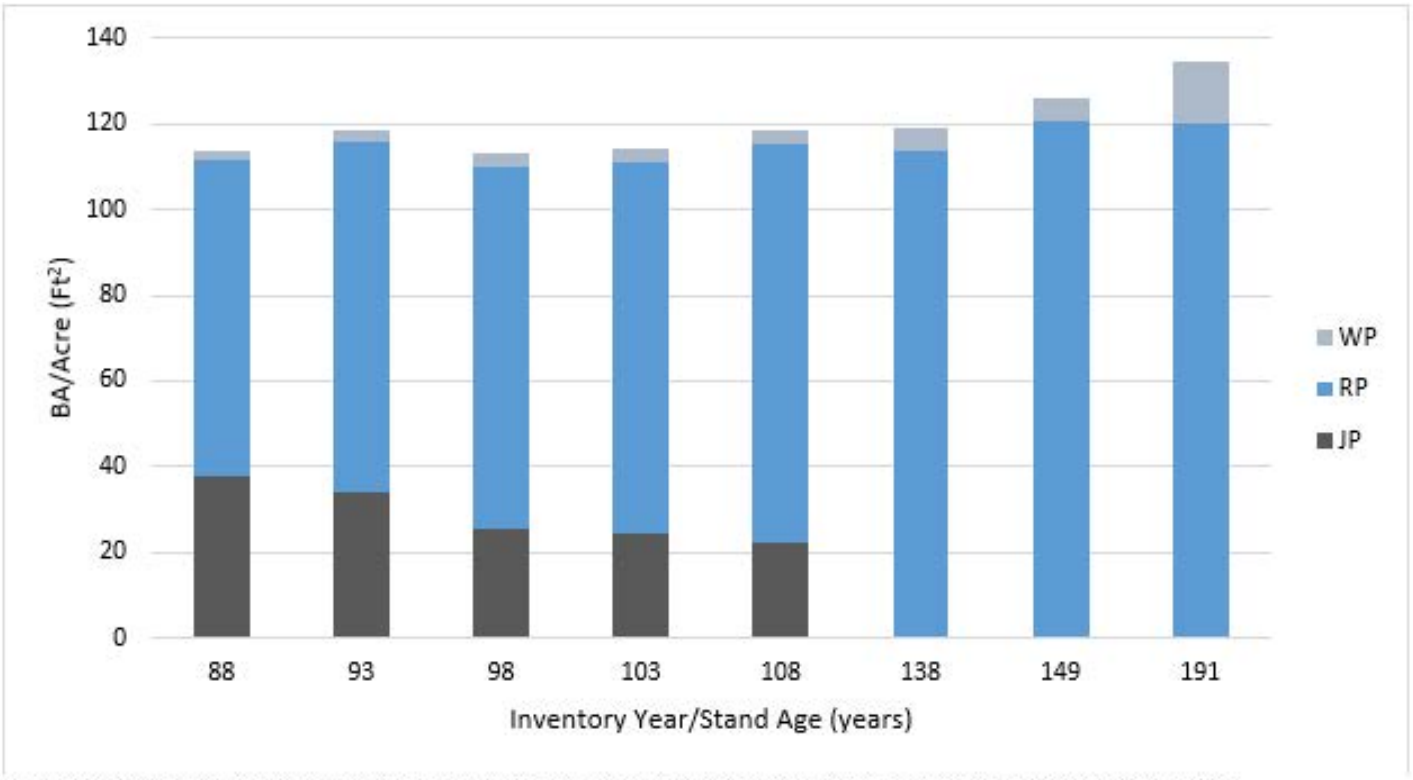

Figure 2: Species composition by BA of living trees by stand age and inventory year. 191-year old data includes in-growth trees.

Growth

The growth of the plot was measured by calculating the periodic annual increment (PAI) of the basal area and volume (Figure 3). As is expected, PAI decreased through the years as the stand aged, as growth typically slows down in older trees. An increase in PAI occurred between 103 and 108 years old, likely as jack pine mortality increased and additional resources were available for remaining live red and white pine trees.

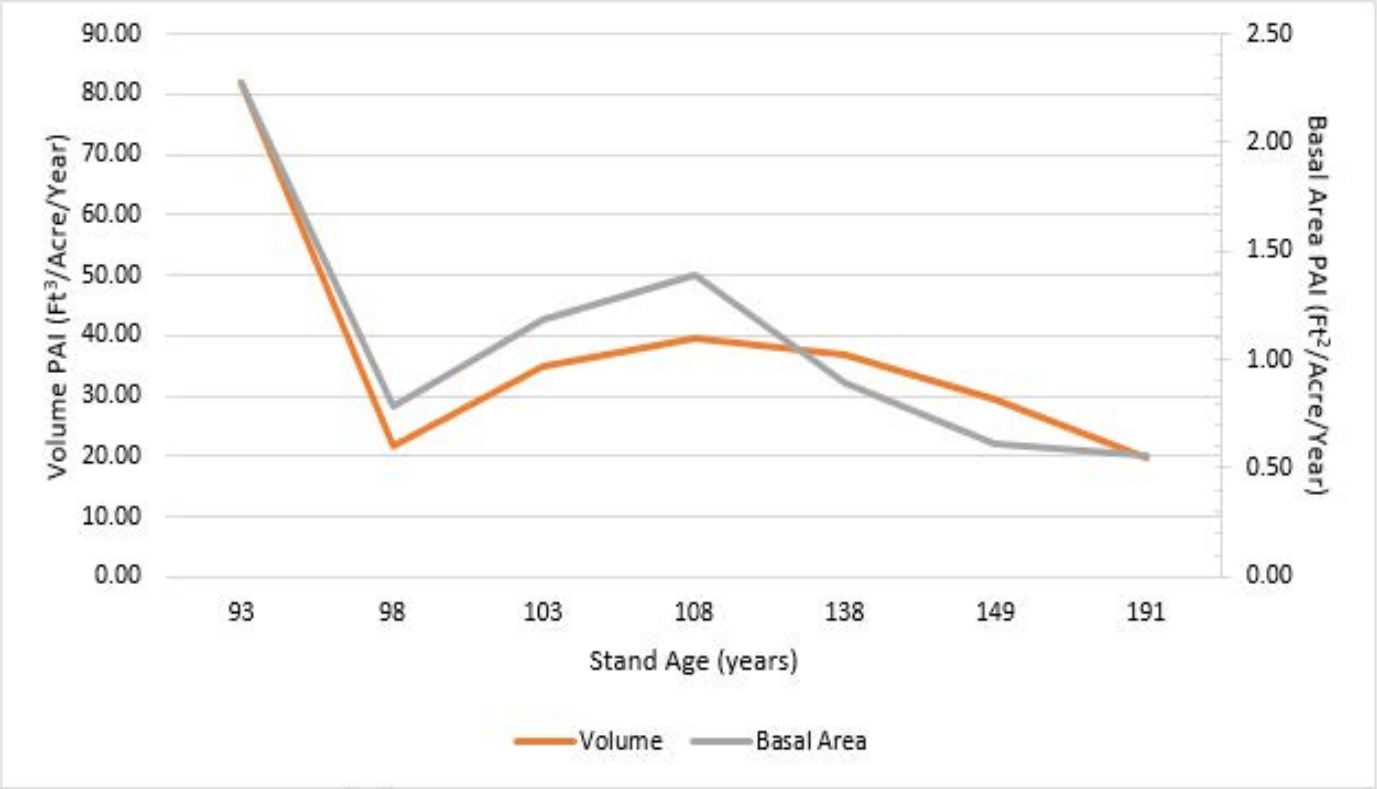

Figure 3: Periodic annual increment (PAI) of BA and cubic foot volume by each inventory year.

Individual Tree and Stand Volumes

Stand volume in CF per acre was measured multiple ways: using stand-level volume models, and by summing individual tree volume predictions. Stand-level volume methods used the Walters and Ek (993) volume model. The height of dominant and co-dominant trees and the stand BA were used to obtain cubic feet per acre, which was compared to the individual tree volume method developed by Scott (1981) in which individual tree volumes are calculated from DBH and height and summed to per acre values. The Walters and Ek (1993) volume equation yielded lower CF volumes, albeit relatively little less volume (Figure 4). However, both the Walters and Ek (1993) empirical model (without using height of dominant and co-dominant trees and BA from the Camp 8 stand, instead using a formula for both) and FVS greatly over-predicted stand volume than what was observed in the stand, especially in later years when the stand was older.

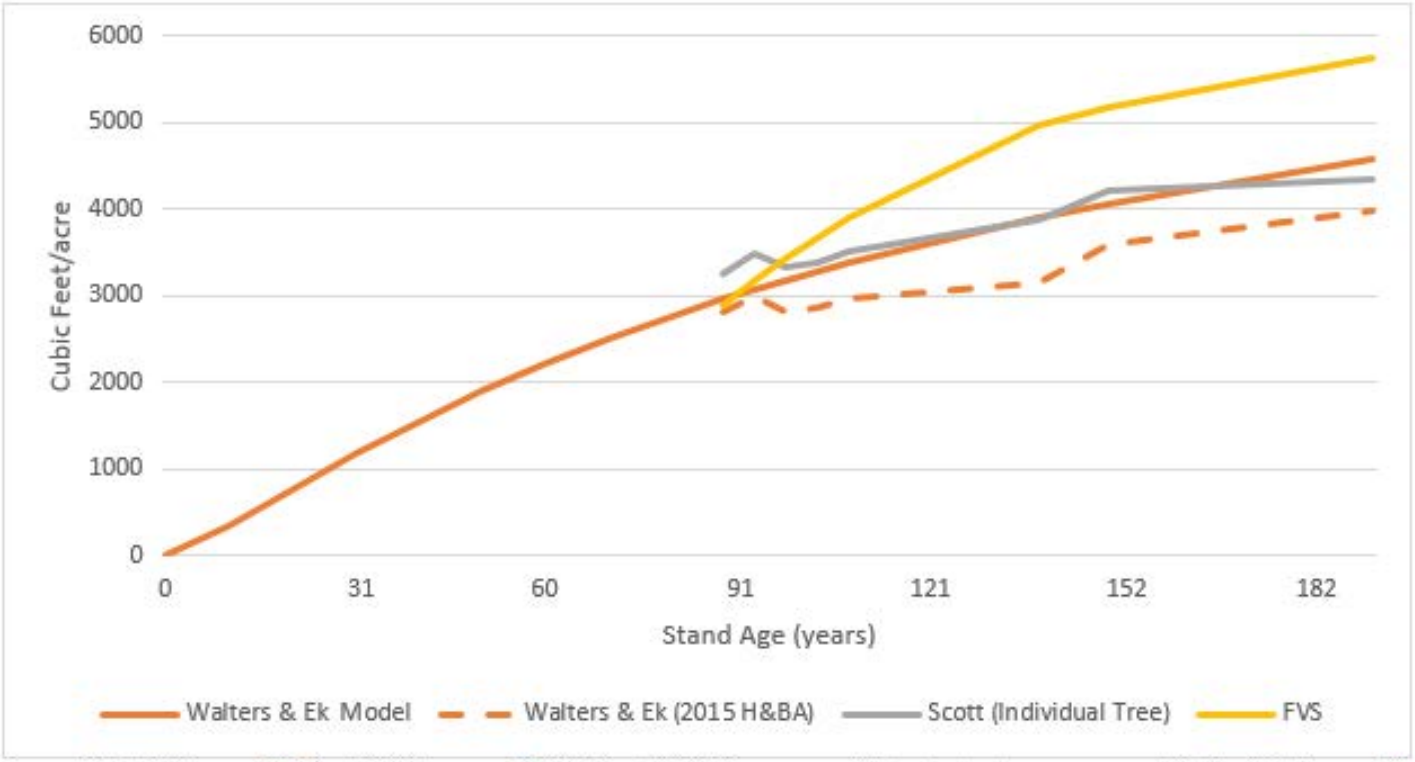

Figure 4: The "Walters and Ek Model" (Walters and Ek, 1993) and "FVS" lines are predicted stand volumes per acre, while the "Walters and Ek (2015 Data)" line is the Walters and Ek model with stand characteristics of the Camp 8 stand, and the "Scott" line is the sum of individual tree volumes based on an individual tree volume equation developed by Scott (1981).

Discussion

Tools like FVS help forest managers project stands to see likely future conditions, and are a very useful tool. However, these results show that stand volume can often be over-predicted in older stands. The PAI growth at age 93 was similar to what Buckman et al. (2006) found in their study of red pine plots, but was substantially lower than their published results in subsequent years. This is likely because mortality plays a larger role in older stands than it does in younger stands, and the admitted lack of abundance of older red pine stands in the Buckman et al. (2006) study—and in general on the landscape--suggests that less is known about mortality rates in older stands. The Camp 8 stand, monitored closely by CFC forest managers and technicians, has experienced increased mortality in the last five years due to Armillaria root disease. This disease has killed a number of mature red pine trees in a part of the two-acre growth and yield plot and has affected the health of living trees as indicated by crown measurements collected in 2015. Armillaria is one example of a factor that can lead to the mortality of older red pine trees. Furthermore, stand volume was over-predicted by both FVS and the Walters and Ek volume equation model, suggesting that less is known about how growth and mortality affect older red pine stands. These factors can play a meaningful role in the ecological and economic decisions that forest managers face when managing older red pine stands.

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