Honors Program

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Tree Height and Diameter Relationships of White Pine and Tree Fall Patterns of Red Pine in Northern Minnesota

Biology

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Introduction

Height is a widely used measurement in both forest ecology and silviculture (Huang et al. 1992). It is useful in a variety of contexts. Tree height can be used to both assess tree volume and tree position within a stand (Wang et al. 1998). Tree height can often be difficult to measure though.

Competition in plant populations creates a hierarchy of plant sizes. Light is often the driving source of competition in forested ecosystems (Kenkel et al. 1989). Over time, taller plants gain dominance over shorter plants leading to suppression (Wiener 1986). This interplay of competition is subject to disturbance such as ground fire, damaging winds, etc. These disturbances may reset competition for light and create “patchiness” that results in successional changes within stand development (Frelich 1995; Webb 2001).

Tree height may be constrained by physiological limitations (Koch et al. 2004, Niklas 2004) or mechanical limitations (McMahon 1973, Lacointe 1999). Water transport becomes difficult for large trees due to gravity and can hinder photosynthesis. In terms of mechanical limitation, tall trees with heavy stems must allocate carbon to diameter growth in order to maintain structural support.

Nonlinear height-diameter functions can come in a variety of forms. Some of the most widely used functions in silviculture and forest ecology are the Gompertz, Weibull-type, and Chapman-Richards function. Each is useful depending on the sample size, tree species, and parameters (Huang et al. 1992).

Diameter at breast height is relatively easy to measure and can be obtained on ground level with a DBH tape measure. Height is more difficult though. There are three common methods for measuring height (1) a tape measure drop from the tree’s top, (2) the tangent method, and (3) the sine method. The first method is the most accurate because it is a direct measurement. It is difficult to climb to the top of trees and a vertical tape drop may be challenging due to foliage, crown architecture, etc. The tangent method is relatively less difficult to obtain. A predetermined distance is set from the tree with the use of a 30 meter tape measure. An angle is measured from that distance with a clinometer and a height is calculated by using similar right triangles and basic trigonometry. This method does not adequately compensate for the lean of trees (Blozan 2008). The top of a tree may be offset from its base more than 13 feet. Consequently, steep angled measurements may underestimate actual tree height. The sine method, utilizes basic trigonometry, but relies on an electronic rangefinder to determine distance. This allows for the lean of the tree to be compensated for. The top of the tree must have an open backdrop to properly assess whether or not the laser is measuring the intended object.

The Allison Plot, an old-growth red pine stand found within Itasca State Park, is the location for ongoing research concerning old-growth stand development. A University of Minnesota graduate student used a part of a data set within her research that I collected on heights and diameters of red pine trees found within the Allison Plot. Bemidji State University graduate students and faculty are studying extremely tall white pines found within the Lost 40, a Scientific and Natural Area located within the Big Fork State Forest (Itasca County, Minnesota). Their research focuses on height constraints such as temperature stress and the hydraulic limitations of water transport (Fulton 2010).Accurate height and diameter measurements shed light on the mechanical and physiological stressors that such large trees endure.

The purpose of this study is (1) to find a height-diameter relationship model for *P. strobus* within the Lost 40 and (2) explore wind damage of *P. resinosa* within the Allison Plot. Non-linear regression data analysis will be used to fit a curve for the height-diameter relationship model. Heights and diameters for 66 *P. resinosa* were measured this previous summer from the Allison plot. The area experienced a storm that produced 70 to 80 mph winds.

Methods

The white pine measurements will be from Lost 40, a 114 acre conifer stand located in the Big Fork State Forest, Itasca County, Minnesota. The stand consists of a peninsula surrounded by both a bog and swamp on either side. It contains 28 acres of red pine forest, 19 acres of spruce-fir forest, and is home to some of Minnesota's oldest white pines (MNDNR 2012). Random and non-random selection will be used to collect samples. Random sampling ensures that the model will accurately represent the stand, while selecting particularly large trees allows the model to better predict maximum heights. Random sampling consists of transects approximately 50 stride lengths. GPS navigation will be used to avoid the redundancy of sampling the same tree.

The red pine measurements were from the Allison Plot, a 2 ha stand found within the Itasca State Park (Clearwater County, Minnesota). The 13,000 ha forest is a mix of wet depressions and various upland forest communities (Webb 1989). The plot was established for research nearly 90 years ago and has been subject to numerous studies.

P. resinosa samples from the Allison plot were selected based on a pre-existing list of cored trees. Trees that had clear damage to their crowns were noted due to their effect on a non-linear regression analysis.

The sine method for height measurement will be used due to its accuracy and ease of use. Two to three measurement sets will be taken for each tree to ensure accuracy. The equation is as follows:

Total Tree Height=sin(A1)*D1+sin(A2)*D2

(See figure below)

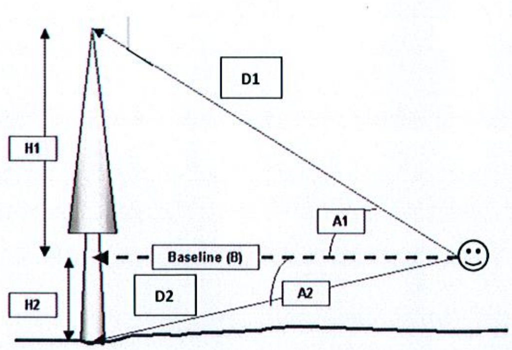

Fig. 1. A diagram of the Sine method. Angle 1 (A1) and Angle 2 (A2) are measured with a clinometer. Distance 1 (D1) and Distance 2 (D2) are measured with an electronic rangefinder.

The Alison Plot was revisited this winter to survey for damage. The list of cored trees was systematically reviewed and the following characteristics were recorded for each tree (1) broken at top, (2) broken at bottom, and (3) uprooted. Of the 66 trees, only one was found to be damaged and was broken at the bottom.

Non-linear regression analysis will be used for the for the height-diameter relationship of the *P. strobus* samples. The Chapman-Richards function will be fit to the growth model. The function was chosen due to its (1) widespread use that allows for easy comparison (2) the height-diameter relationship is expected to be sigmoidal and (3) the function has proven to be adequate fit for a variety of tree species and parameters (Huang et al. 1992; Zhang 1997; Sharma 2007). A simplified version of the equation is:

$$Y=a(1 - e^{-bX})^{y}$$

where Y is tree or stand size (e.g. height, diameter,volume), X is the independent variable (e.g. age), and a, b and g are the asymptote, rate, and shape parameters, respectively (Sharma 2004).

Results

64 total white pine trees were measured and recorded at the Lost 40 site. The height-diameter relationship exhibits a positive correlation that is commonly found in nutrient rich environments where light is the limiting growth factor (Kenkel et al. 1999). The range of height was from 5 m to 35 m. The range for diameter at breast height was 14.1 cm to 109.5 cm (Fig 2).

The Chapman-Richards function was fitted to the Lost 40 data set (Fig. 3). The line proved to be an accurate fit and an adequate description of the data. The parameters were determined by finding the most accurate fit with the use of the R statistic program (Table 1). The sum of squared error is 871.537901.

The Chapman-Richards function was also fit to the Lost 40 data using two other sets of parameters from studies to allow for comparison (Fig. 3) (Peng 1999) (Saunders and Wagner 2008). The parameters can be found in Table 1. These results will be further explained in the discussion.

The height-diameter relationship of the red pine from the Allison Plot shows more uniformity than the Lost 40 data set. 67 trees were measured and a more simplified version of the Chapman-Richards function, the Mitscherlich function, was fit to the data set. This function was chosen because it is a 2 parameter equation and the Allison Plot data set did not possess smaller stems so the function was expected to be a more accurate fit (Fig. 5). The parameters can be found in Table 2. The equation produced a sum of squared error of 157.73. A simplified version of the Mitscherlich equation:

$$Y=a(1 - e^{-bX})$$

Fig. 2. Height vs. diameter of *Pinus strobus* at Lost 40. Total trees measured: 64.

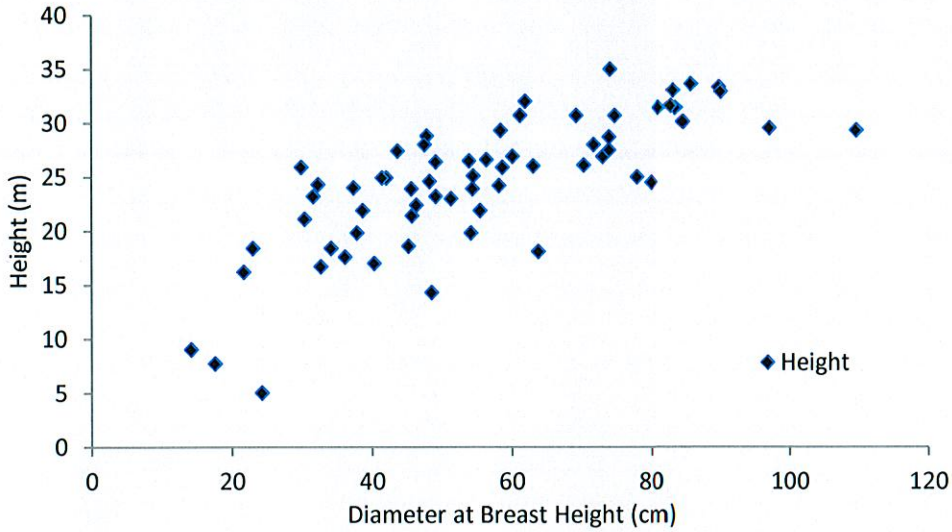

Fig. 3. Height vs. diameter of *Pinus strobus* at Lost 40. The fitted line is the Chapman-Richards function. Parameters are given in Table 1.

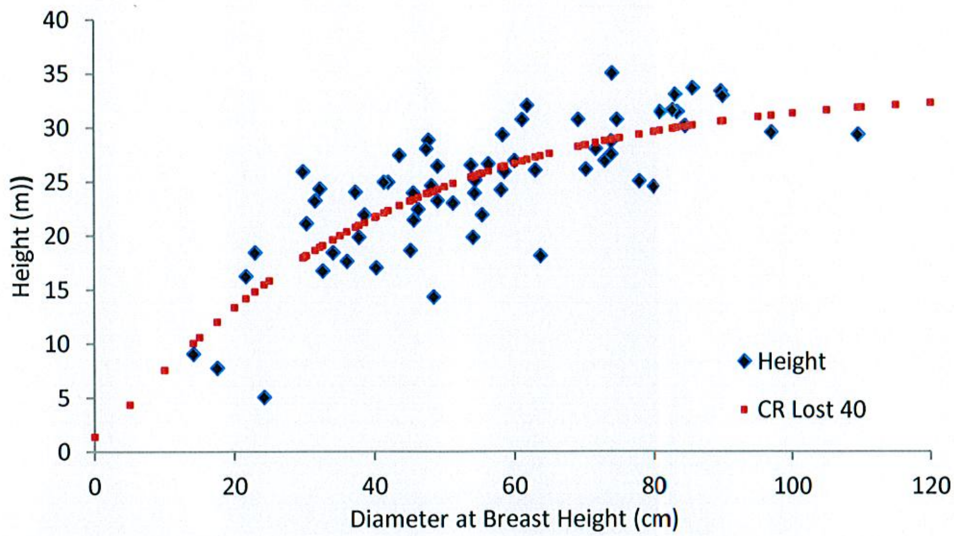

Table 1. Parameters for the Chapman-Richards function for the Lost 40 data set.

Parameters	a	b	y
Lost 40 Fit	32.13	0.028274	1.17898
Peng	31.6215	0.0367	1.1899
Saunders and Wagner	39.87	0.026	1.312

Fig. 4. Height vs. diameter of *Pinus strobus* at Lost 40. The fitted lines are the Chapman-Richards function. Parameters are given in Table 1.

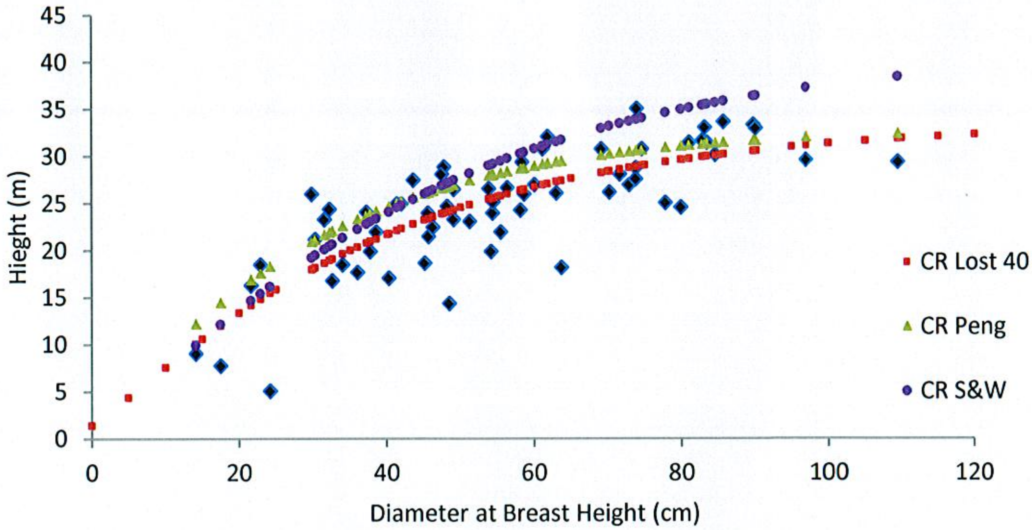

Fig. 5. Height vs. diameter of *Pinus resinosa* at Allison Plot. The fitted line is the Mitscherlich function. Parameters and the equation are given in Table 2.

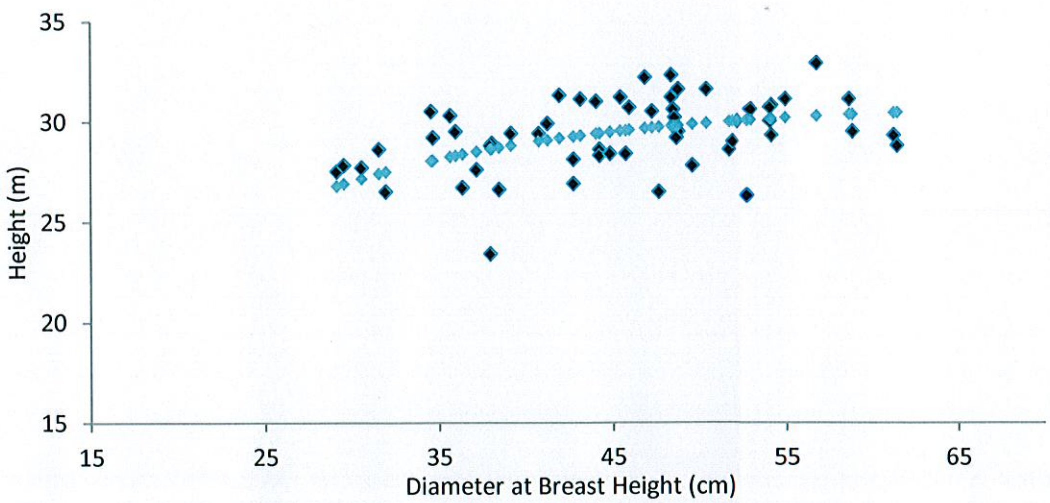

Table 2. Parameters for the Mitscherlich function for the Allison plot data set.

Parameters	a	b
Allison Plot	29.5	0.0675

Discussion

The Chapman Richards function proved to be an adequate fit for the Lost 40 data set as expected by other studies (Huang et al. 1992; Zhang 1997; Sharma 2007). Height also appears to be constrained as evidenced by the horizontality of the Chapman-Richards function as it approaches maximum height (Fig. 3).

Further comparison of other studies indicates maximum height is constrained by physiological limitations (i.e. water transport). The Peng study was conducted in Ontario, Canada, and has a similar climate to Northern Minnesota. Fig. 4 shows the parameters used in their research for the Chapman-Richards function. The Peng parameters are close to the actual Lost 40 parameters of best fit. The Saunders and Wagner study was conducted on white pine found in Maine, United States. The maritime climate there has much more precipitation and results in

less difficult water transport for trees. Fig. 4 shows the Saunders and Wagner parameters to have a higher maximum height. This indicates that white pines in Maine and other maritime climates are experiencing easier water transport than white pines in Minnesota.

The damage survey in the Allison Plot revealed one damaged tree that was broken near its base. This is evidence of the "patchiness" that high wind storms may have (Webb 2001).

The Mitscherlich function also proved to be an adequate fit for the Allison Plot data set. The uniformity of the stand produced a more linear function and the lack of smaller stems prevented the use of a 3 parameter equation like the Chapman-Richards function.

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