ABSTRACT

SMITH, MARLEY AESOP ROBESON. Comparative Study of Sawtimber Productivity and Quality of Pine Plantations in Higher Elevation Sites of North Carolina. (Under the direction of Dr. Solomon Ghezehei).

Loblolly pine [*Pinus taeda L*] is the most commercially significant species in the region due to its growth and timber quality, but it does not grow well in areas of high elevation and cold weather. Cold-hardy loblolly pine could be an economic alternative for landowners, mills, and foresters in high altitude areas such as Western North Carolina. In this study, cold-hardy loblolly pine was compared with four other pine species that naturally grow in mountainous regions or are tolerant of cold climates. Thirty-three year-old plantations of loblolly pine, white pine [*Pinus strobus L.*], pitch pine [*Pinus rigida* Mill.], Virginia pine [*Pinus virginiana* Mill.], and Pitch × loblolly hybrid pine [*Pinus rigida* × *P. taeda*, PLH] were assessed for growth and productivity (total volume; harvestable volume stem growth and tree height; stem form, quality, and survival) at a high elevation mountain site 976 m a.s.l. in North Carolina. An analysis of variance (GLM) was run on the data. Loblolly pine had the highest average DBH (32.9 cm) and total height (20.6 m) showing that it had the best growth compared to the other species. These numbers were greater than white pine (DBH 31.9 cm; height 19.2m), pitch pine (DBH 26.2; height 12.9 m), PLH pine (DBH 28.2; height 20.5 m), and Virginia pine (DBH 27.5 cm; height 14.4 m). 79% of loblolly pines trees in the study had a stem form suitable for sawtimber. 84% of white pine trees were suitable for sawtimber, 50% percent of PLH pine can be used for sawtimber, 34% of Virginia pine was suitable for sawtimber, and 58% percent of pitch pine could be used for sawtimber. The best growth and overall stem form of loblolly pine made the species the most merchantable sawtimber on the site with 325 m^3 ha^{-1} of timber suitable for sawtimber (169 m^3 ha^{-1} of the best stem form and 156 m^3 ha^{-1} of good stem form). PLP produced a total of 164 m^3

ha^{-1} of sawtimber-suitable merchantable stem volume while white pine had the second highest sawtimber volume (best stem form 150 m^3 ha^{-1} and good stem form of 89 m^3 ha^{-1}). Pitch pine and Virginia pine the lowest volume of sawtimber-suitable stem forms (42 m^3 ha^{-1} and 45 m^3 ha^{-1}, respectively). These results suggest that cold-hardy loblolly pine can be a viable pine species for high altitude mountain regions in the southeastern U.S. for valuable sawtimber.

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Comparative Study of Sawtimber Productivity and Quality of Pine Plantations in Higher Elevation Sites of North Carolina

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Introduction

In the southern United States, over 40% of the land is covered in forests which provide products that have produced over 250 billion dollars (Henderson et al, 2015). The forest products that provide these economic benefits are wood furniture, solid wood products, and pulp and paper. In North Carolina timber products that can be taken from tree species include sawlogs, pulpwood, fuel, veneer logs, and poles. The main species that provide the best production for these products are softwoods such as pine species (USDA Forest Service, 2021). Globally, mountains cover 24% of the world's land mass, and the world's forests comprise 28% of mountain landmass (Price, 2003). Mountains provide for a source of wood throughout the world, as well as a great source for biodiversity. Monoculture plantations (single crop plantations) is the primary method for growing trees for product in the mountains (Price, 2003).

There are multiple pine species that can be found natively in high elevation or mountain regions in eastern United States. White pine [*Pinus strobus L.*], Pitch pine [*Pinus rigida* Mill.] and Virginia pine [*Pinus virginiana* Mill.] are species that grow in mountain regions in eastern United States and can be cut and sold for a profit (USDA, 2021). White pine survives well in the mountains of North Carolina (Lashley et al. 2017) and performs well on plantations with vigorous growth rates At elevations of over 600 m (Ostrander, 1970). White pine is not suitable for many structural uses such as furniture; therefore, stumpage values are low. Pitch pine a cold tolerant pine that typically occurs in natural stands in mountain regions and can be used for ship building, tough construction, fencing and pulpwood (Little and Garrett, USDA). Virginia pine typically has a poor growth form. However, when properly managed, Virginia pine could be used as a Christmas tree, and for high-value timber production as well as pulpwood (Carter et al., USDA).

Loblolly pine [*Pinus taeda L*] is the most commonly grown pine species in the Southeastern US. Loblolly pine is great for producing timber products because it is a fast-growing species that can be harvested quickly. In the Southeastern US, loblolly pine prefers to grow on coastal sites with elevations under 365 m (1,200 feet, a.s.l.). These sites allow loblolly pine to grow at a high rate but elevations higher than 365 m (1,200 feet, a.s.l.) could result in a decrease in the growth and productivity of the species. Pitch □ Loblolly hybrid (PLH) pine [*Pinus rigida*□□ *P. taeda*] is a hybrid that can occur naturally in some cases (Little et al, 1967) and has shown greater growth and stem form than loblolly pine on higher elevation sites (above 2500 feet m. a.s.l.) but lower or comparable productivity to loblolly pine at lower evaluation in the Coastal and Piedmont regions in the Southeastern US and grows faster than pitch pine [*Pinus rigida*] (Genys, 1970).

Defects and damages of managed timber reduce economic values of timber. For example, defects can reduce timber that can be harvested/recovered (smaller pieces or less logs) or turn a good-sized tree into solely pulpwood, which is worth less than sawtimber logs (Ostrander, 1971). Mills typically look for logs that have a diameter larger than 20 cm (8 inches) on the narrow end of the log (WNC Sawmill, 2022); this means that the tree should have a larger diameter at breast height (DBH) due to trunk tapering with height.

Tree logs are classified into different types and grades based on species, log size (length and diameter) and log quality (absence or presence of defects). As a result, mills to pay different prices depending on the type of logs. Mills (e.g., Sunrise Sawmill) may require logs to have lengths of at least 6 m and diameters of at least 45 cm with no defects (straight and no swelling, damages or knots) for them to be classified as veneer (Sunrise Sawmill, 2022) whereas with grade-3, which is the lowest sawtimber grade, logs should have diameters of at least 25 cm and a

length of 2.5 m and one side of the tree is clear of defects. For white pine, for example, logs with grade-1 are priced twice that of grade-2 and four times that of grade-3. Any logs smaller than 25-cm diameter would not be bought for sawmill use (Sunrise Sawmill). Defect such as leaning, sweep and ice damage can also reduce the economic value of stands. Loblolly pine has been shown to have a high number of leaning trees in the Allegheny Mountain range (Genys, 1970). Ice damage can cause death for trees while also causing stem bending which damages the tree (Aubrey 2007).

Problem Statement

Pine species that are native to colder regions and/or higher elevation are expected to be productive and have good timber quality in the southern Blue Ridge mountains. Loblolly pine is a high-value pine in the Southeastern US but not naturally suitable for cold regions or growing areas. Cold-hardy loblolly pines can be expected to show cold resistance and improved growth and high-value timber productivity (Mexal and Carson, 1981). Cold weather can result in defects for loblolly pine and decrease its selling. It is important to compare potential species to species that naturally grow well under particular growing conditions (for example high elevation sites).

This objective of this study was to assess sawtimber productivity and quality of plantations of cold-hardy loblolly pine and four other pine species that may have some potential to produce sawtimber at higher and colder higher elevation regions in the southeastern U.S.A (North Carolina). The following hypothesis was tested:

- Under high altitude growing conditions, cold-hardy loblolly pine has better timber growth and quality than other pine species that are known to grow (well) in high altitude regions.

The hypothesis was tested by comparing productivity and timber quality of cold-hardy loblolly (developed by the West Virginia Paper Company) against four pine species that are

native to cold regions, namely Virginia pine, Pitch pine, White pine, PLH pine. These species were chosen for various reasons. These species have potential to produce sawtimber under colder conditions and loblolly pine is known to produce high-value timber in the Southeastern US. Virginia, pitch, and white pine species were selected for the study since they are native to North Carolina's Mountain regions. Although pitch pine is native to North Carolina's mountains, there are no known plantations in the region, therefore seedlings were taken from a nursery in New Jersey. The PLH pine was chosen for the study with the expectation of high-value timber quality of loblolly pine and cold tolerance of pitch pine. After looking at the productivity and quality of each species, the type of timber that can be harvested from each species was determined.

Materials and Methods

Site description

The study site (36°24'5.16"N, 81°18'10.87"W) was located at the Upper Mountain Research Station of the North Carolina Department of Agriculture and Consumer Services in Laurel Springs (North Carolina), which is in the Southern Blue-Ridge Mountains. The study stand was 33 years old and had a density of 1344 trees per hectare (tree spacing of 2.44 m x 3.05 m). The soil series at the site is the Watauga series, which is characterized by very deep, well drained soils on gentle (2%) to very steep ridges and slopes (50%) (National Cooperative Soil Survey, U.S.A, 2011). Slope ranges from 2 to 50 percent. The soil at the site was loose loamy and at planting, it was predominantly covered with grass. The slope of the study site ranged between 28%-35%. It was noted that the slope of the site did not affect the planting spacing of the study trees.

Each of the five pine species was established as mini-stands of eight rows with 10 trees

per row (80 trees per mini-stands) and the mini-stands were replicated four times. The pine species were planted from east to west. While four pine species were planted around the same time on March 9th, 1989, the pitch pine seedlings were planted after the other pine seedlings on April 3rd, 1989. The pitch pine seedlings were bought from New Jersey, at the New Jersey State nursery. Weeks after the planting of the seedlings, a Poast herbicide was applied to the seedlings. The pitch pine seedlings were damaged due to warm weather in January and February followed by cold weather after these months.

This project design was a completely randomized design (CRD) using a statistical model as follows (Mohr et al, 2021):

$$Y_i = \mu + \tau_i + \varepsilon_i \qquad \text{Equation 1}$$

Where: Y_j is the observation of the treatment, μ is the population mean, τ is the treatment effect amd ε_i is the random error

Data Collection

During data collection, buffers (borders) were created for each mini-stand to avoid or minimize the effects of neighboring blocks on the growth and high-value timber production of the study species. The buffers were set by excluding (skipping) the first rows all-around the mini-plots from measurements. Measurements performed for the study included diameter at breast height (1.3 m above ground, DBH), total tree height and tree heights to a 20-cm top or height to a defect. Diameter at breast height was measured using loggers' tapes. Clinometers were used to measure total tree height and tree heights to a 20-cm top or to a defect. iPads were used to input the data collected from each tree species. In total, growth data were collected from 48 trees per mini-stand for four replicated mini-plots of each of the five study pine species (total

960 pine trees).

Data of survival was also collected for each species from each mini-stand. Logs were based on the growth of trees and sawtimber logs were required to have stem DBH larger than 20 cm (8 inches).For assessing sawtimber quality, it was necessary to consider the presence of defects and the stem height where the defects were. Data of the following defects were collected: forking, leaning, ice damage, insect damage, and sweeping. Any defects at the base of the tree were excluded. Based on these defects and the size of the trees, stem form data were collected for each species. Stem forms were assessed for harvestable or below-defect stems sections by rating stems using numbers 1 (best, suitable for timber) to 4 (worst, unsuitable for timber), where:

- **Stem form 1:** The best form, straight, damage-free and can be used for sawtimber
- **Stem form 2**: Straight stems with minor damages or slightly crooked stems with little damages, can be used for sawtimber
- **Stem form 3:** Stems that were moderately crooked or had significant damages, not suitable for sawtimber
- **Stem form 4:** The worst stem form, highly crooked, with lesions, not suitable for timber

Composite soil samples were collected from each mini-stand in the research site using augers (to a depth of 20 cm). One composite soil sample was collected from each mini-stand by mixing five samples collected from random sampling spots within each (a total of 20 bags of soil samples collected for the site). These samples were collected using a auger. Waters Agricultural Laboratories, Inc, was utilized for analysis of macronutrients and the micronutrients in the soil and soil pH. They used a soil extraction method of Mehlich Ⅲ, which is usually used for cation exchange capacity (CEC) and organic matter values (Waters Agricultural Laboratories, 2022).

Data Analysis

The data of DBH and heights to 20-cm top or to a defect were used to calculate total and harvestable stem volumes. The total volume was calculated by using the following formulas (Clark and Saucier, 1990):

$V = (0.00211\ (DBH^2\ TH)^{1.01241}) * 0.0283168$ If DBH < 12.7 cm Equation 2

$V = 0.00199\ (DBH^2)^{1.03101}(TH)^{1.01241}) * 0.0283168$ If DBH > 12.7 cm Equation 3

$V = (0.00211\ (DBH^2\ TH20cm)^{1.01241}) * 0.0283168$ If DBH < 12.7 cm Equation 4

$V = 0.00199\ (DBH^2)^{1.03101}(TH20cm)^{1.01241}) * 0.0283168$ If DBH > 12.7 cm Equation 5

Where V is stem volume (m^3); DBH is stem diameter (ft); and TH is total tree height (ft); TH20cm is (merchantable) tree height to a 20-cm-top, and 0.0283168 is a conversion factor of volume from ft^3 to m^3.

Statistical analysis of the data was performed using SAS software (version 9.4). Proc GLM (General linearized model) was used to compare height, stem diameter, timber volume of the species, and the soil data and Proc FREQ (Frequency) was used to compare the survival rate, timber/log forms and defects among the study species. The count (frequency data) of the stem form-classes, defects and survival were assessed using a GLM model (Proc GLM, SAS).

To assess the economic values of the study stands, information of state-wide average stumpage pine prices was obtained from the North Carolina Standing Timber Price Report published by North Carolina Extension Forestry (Bardon, 2022). The prices in the report were multiplied by the log volumes of the study species using the following assumptions:

1. Sawtimber Stumpage value: Stems with the best form (form 1) would be suitable for sawtimber. A stumpage price of $33.6 per tonne was used (from the above report) to estimate the sawtimber stumpage values of the pine species of the study.

2. Chip-and-Saw stumpage prices: All logs with stem form 2 would be suitable for chip and saw. The stumpage price of pine chip and saw was $25.9 per tonne (obtained from the report) was multiplied to the species volumes of logs with form-2 to estimate Chip-and-Saw stumpage prices of the stands.
3. Pulpwood stumpage prices: Stem forms 3 and 4 would be unsuitable for sawtimber or chip-and-saw but would be used as pulpwood. The price of $11.0 per tonne for pine pulpwood (from the above report) was multiplied with the total volume of logs with forms 3 and 4 to estimate the pulpwood stumpage prices of the study species.

Results

Survival, Growth/Productivity

Each of the pine species in the study experienced significant mortality. Loblolly pine had the highest mean survival (61%) compared to the other species (Pitch pine, 25%. Virginia Pine: 41% PLH pine: 57%) while white pine had similar survival (60%) to loblolly pine (Table 1). There were significant differences in the DBH and height values among the species ($p < 0.0001$) but there was no significant difference in DBH between the top two pine species, which were loblolly pine (32.9 cm) and white pine (31.9 cm). Loblolly pine (20.6 m) had the highest total height, which was not significantly different from PLH (20.5 m). The other pine species on the site did not have a comparable mean total height with pitch pine (12.9 m) having the lowest mean total height.

Table 1. Survival of the five study (Pine species) at the high altitude (mountains) site located at the Upper Mountain Research Station in North Carolina

Pine Species	Mean Survival (%)	Block	Count (by stand)	Stand Survival (%)
Loblolly	60 a	1 2 3 4	30 32 28 26	63 67 58 54
White	59 a	1 2 3 4	32 23 25 34	67 48 52 71
PLH	57 a	1 2 3 4	29 19 32 29	60 40 67 60
Virginia	41 b	1 2 3 4	18 26 13 21	38 54 27 44
Pitch	21 c	1 2 3 4	13 9 4 15	27 19 8 31
$MSD_{\alpha = 0.05}$	13			
P-value	< 0.0001			
F-value	23.7			

MSD = Minimum significant difference; CV = coefficient variance

The merchantable height represents the size of trees that can be sold as logs for sawtimber and in this study the merchantable height was to a 20-cm top diameter. The 20-cm top diameter represents the smallest size for creating a good-sized log. Loblolly pine (14.6 m) had the greatest merchantable height in the study. The PLH pine's (10.5 m) mean merchantable height was significantly shorter when compared to its initial total height value. PLH pine initially

had a total height comparable with that of loblolly pine but significantly greater than that of white pine (10.6). However, the merchantable height that was given makes it significantly different from loblolly pine and it now has a similar merchantable height to white pine. Loblolly and white pine had similar heights to the defect although loblolly pine greater height-to-a-defect (8.3 m) than white pine (7.3 m, Table 2). PLH pine (5.4 m), pitch pine (4.9 m) Virginia pine (4.4 m) had generally comparable heights-to-defect.

Table 2. Mean Growth (diameter and height) data of the five 33-year-old pine species at the high-altitude site located at the Upper Mountain Research Station in North Carolina. (Values within columns with the same letters are not significantly different)

Pine Species	**DBH (cm)**	**Total Height (m)**	**Height to 20-cm-top (m)**	**Height to a Defect (m)**
Loblolly	32.9 a	20.6 a	14.6 a	8.3 a
White	31.9 a	19.2 b	10.6 b	7.3 ab
PLH	28.2 b	20.5 a	10.5 b	5.4 bc
Virginia	27.5 b	14. 4c	7.6 c	4.4 c
Pitch	26.2b	12.9 d	7.9 bc	4.9 bc
$MSD_{\alpha = 0.05}$	2.7	1.3	2.8	2.5
CV	20.9	15.6	34.4	58.9
P-value	< 0.0001	< 0.0001	< 0.0001	< 0.0001
F-value	18.11	107.6	21.7	9.1

MSD = Minimum significant difference; CV = coefficient variance

The pine species in this study had significantly different (*p value < 0.0001)* total volumes, merchantable volumes and volumes-to-a-defect; Loblolly pine had the highest total volume per hectare (685 m^3) since it had both the largest average total height and dbh. White pine (591 m^3) was not significantly different from loblolly pine in total stem volume per hectare (Table 3). Virginia pine (226 m^3) and pitch pine (112 m^3) both had the two lowest mean total

volumes. There were significant differences ($p < 0.0001$) among merchantable volumes of the study species (Table 3). Loblolly pine (332 m^3) has the highest volume while Virginia pine (30 m^3) and pitch pine (36 m^3) had the lowest merchantable volumes. White pine (mean 185 m^3) had significantly lower merchantable volume than loblolly pine and significantly higher merchantable volume than Virginia and Pitch pines but not pitch pine. Among the of the study species, the only significant difference ($p = 0.0248$) in volumes to defects was between white pine (98 m^3) and pitch pine (22 m^3) while the other pines had mean volumes of 54 m^3 – 85 m^3 (Table 3). This information shows that the trees with defects do not produce merchantable timber (with the required 20-cm on the narrow end) and but the majority of the stems of these trees would be used for pulpwood.

Table 3. The total stem volume of the five pine species at the high-altitude mountain site located at the Upper Mountain Research Station in North Carolina. (Values within columns with the same letters are not significantly different)

Pine Species	**Total stem volume (m^3 ha^{-1})**	**Stem volume to 20-cm top (m^3 ha^{-1})**	**Stem volume to Defect (m^3 ha^{-1})**
Loblolly	685 a	332 a	85 ab
White	591 ab	185 b	98 a
PLH	460 b	121 bc	62 ab
Virginia	226 c	30 c	54 ab
Pitch	112 c	36 c	22 b
$MSD_{\alpha = 0.05}$	4.4	94.1	63.15
CV	16	28.2	41.9
P-value	< 0.0001	< 0.0001	0.0248
F-value	51	34.5	3.9

MSD = Minimum significant difference; CV = coefficient variance

Defects reduced the total volume of viable logs that could be harvested for sawtimber. There were different defects that affected the study species (Table 4). Forking, which was the division of the main stem into multiple stems, was the most common defect that affected the merchantable height of all of the study species. White pine (31%) had the greatest number of forking occurrences (Table 4). Leaning of trees affected the pine species studied, with only 2.4% of all trees on the site being affected by the defect (leaning). Virginia pine had the highest number of leaning trees on the site. Ice damage was common at the site and affected all the study species. Virginia pine was the most affected by ice damage with 94% of the trees on site showing signs of ice damage. White pine and PLH pine both were species that had the best resistance to ice damage with only 51% of both species having trees affected by ice damage. There was no insect damage to any of the species.

Table 4. The damage and defects that affect the study pine species in the high altitude mountains of North Carolina. (Values within columns with the same letters are not significantly different)

Pine species	**Defects (% of live trees)**		
	Forking	**Ice**	**Lean**
Loblolly	29 a	61 a	0
Pitch	12 a	67 a	10 a
PLH	28 a	51 a	3 a
Virginia	29 a	94 a	7 a
White	31 a	51 a	0
$MSD_{\alpha = 0.05}$	23	77.3	14
CV	40	55	162
P-value	0.12	0.44	0.17
F-value	2.19	1.0	1.84

MSD = Minimum significant difference; CV = coefficient variance

Timber Quality

Stem form was used for assessing the timber quality of the tree species on the site. White pine had the higher percentage (55% of standing trees) of the best quality (stem form-1) trees (other species had 8%-38%; Table 5). Loblolly pine had 79% sawtimber quality stems with similar percentages of form-1 (38%) and form-2 stems (41%). PLH pine had a majority of form-2 stem trees (35%) and form-3 stems (28%). Virginia pine had the greatest percentage of trees on site with form-4 stem trees (36%).

Table 5. The percentage breakdown of the stem form for the five pine species at the high altitude (mountains) site located at the Upper Mountain Research Station in North Carolina. (Values within columns with the same letters are not significantly different)

Pine species	**% of live trees**			
	Stem form-1	**Stem form-2**	**Stem form-3**	**Stem form-4**
Loblolly	38 ab	41 a	18 a	4 a
White	55 a	29 a	12 a	4 a
PLH	15 bc	35 a	28 a	22 a
Virginia	8 c	26 a	32 a	36 a
Pitch	33 ab	25 a	16 a	26 a
$MSD_{\alpha = 0.05}$	4.4	41	30	42
CV	45.3	59.6	64	103.8
P-value	0.0008	0.71	0.235	0.64
F-value	8.6	0.54	1.56	2.15

MSD = Minimum significant difference; CV = coefficient variance

Although white pine had the greatest number of stem form-1 trees (by count), loblolly pine had the highest total harvestable form-1 volume (169 m^3) due to its highest growth rate compared to all of the species on the site (Figure 1). Due to its great growth rate loblolly pine

also had the highest total harvestable volume for form-2 stem trees (156 m^3) and pulpwood (123.9 m^3). PLH pine had the next greatest total harvestable volume for each stem form.

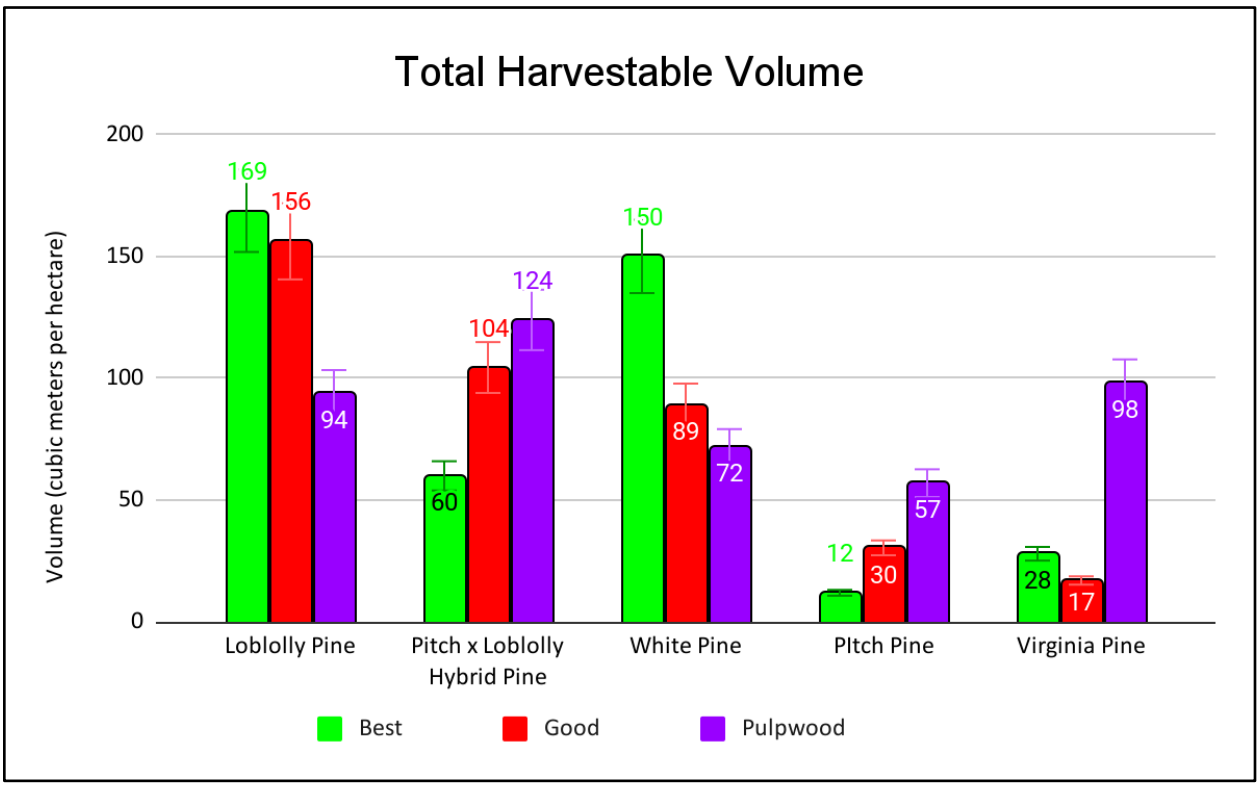

Figure 1. Comparison of total harvestable wood volume for sawtimber (best or form-1 and good or form-2) and pulpwood (forms-3 and -4) for five pine species in the study site located at a higher elevation area in western North Carolina (Laurel Springs).

Timber Value

Table 6 below represents the approximate total value that each pine species would be worth if they were harvested and sold. Loblolly pine ($28,773.16) had the greatest total value compared to the other pine species on the site. Loblolly pine had both the greatest sawtimber value ($16,369.14) and greatest chip and saw value ($11,650.36). The PLH pine had the greatest pulpwood value compared to the other species ($915.04).

Table 6. Comparison of total merchantable wood value for sawtimber (best or form-1), chip and saw (good or form-2) and pulpwood (forms-3 and -4) for five pine species (33-year old)in the study site located at a higher elevation area in western North Carolina (Laurel Springs).

Pine species	**Sawtimber**	**Chip and Saw**	**Pulpwood**	**Total Value**
Loblolly	$16,369.14	$11,650.36	$693.66	**$28,713.16**
Pitch□□ Loblolly Hybrid	$5,820.14	$7,789.28	$915.04	**$14,524.45**
White	$14,550.35	$6,634.18	$531.31	**$21,715.84**
Pitch	$1,164.03	$2,269.18	$420.62	**$3,853.83**
Virginia	$2,716.07	$1,272.53	$723.17	**$4,711.77**

Soil Nutrients

There were no significant differences in soil nutrient contents (p□ = *0.65*), soil pH (p = *0.72*) or cation exchange capacity (p = *0.34*) among the plots of the study species (Table 6). PLH pine plots had the highest average phosphorus (P), potassium (K), magnesium (Mg), and calcium (Ca) concentrations. Loblolly pine plots had the lowest phosphorus (42 kg per ha) and potassium (170 kg per ha) while the plots of white pine and pitch pine had the lowest concentration of magnesium of 248 kg per ha. Pitch pine plots had the lowest mean calcium content on the site (943 kg per ha). Mean pH and cation exchange capacity (CECs) were similar across the plots of the study species.

Table 7. The soil nutrients content of the five pine species at the high altitude mountains located at the Upper Mountain Research Station of North Carolina

Pine Species	Soil Nutrients (kg per ha)					
	Phosphorus	**Potassium**	**Magnesium**	**Calcium**	**pH**	**CEC**
Loblolly	42 a	170 a	284 a	1057 a	5.1 a	11.1 a
White	71 a	179 a	248 a	1077 a	5.1 a	10.5 a
PLH	98 a	189 a	286 a	1165 a	5.3 a	11.0 a
Virginia	47 a	189 a	256 a	1100 a	5.2 a	10.9 a
Pitch	77 a	185 a	248 a	943 a	5.1 a	10.2 a
$MSD_{\alpha = 0.05}$	134	98	119	447	0.45	1.5
CV	92	25	21	19	4.01	6
P-value	0.69	0.97	0.73	0.65	0.72	0.34
F-value	0.57	0.13	0.51	0.62	0.52	1.24

MSD = Minimum significant difference; CV = coefficient variance

Discussion

The identification of pine species with high growth rate and high stem (sawtimber) quality is beneficial to forest landowners as well as mills in mountain regions of the southeastern US. The focus of the study was to assess the growth, timber quality and survival of pine species in high elevation regions for sawtimber production; cold-hardy loblolly pine as compared with other pine species that grow in mountainous regions and tolerate cold climates.

The current study found that cold-hardy loblolly pine had the best timber growth compared to the other species on the site that naturally grow in high altitude areas or were known to be more tolerant to cold growing conditions. Although loblolly had the second most form 1 trees between all of the species on the site, logs can still be created from trees that are stem classed 2. As long as trees with defects are cut and harvested carefully then these trees could potentially create logs without any deductions taken from them.

The results of this study showed that loblolly pine had significantly greater overall productivity, stem volume, and stem form compared with PLH pine, which contrasted with previous studies where the PLH pine had better growth rate and stem form than loblolly pine (Little et al., 1967; Genys, 1970; Genys, 1988). The two species had comparable total heights in this study. Besides the total height, there was a significant difference between it and the best growing species on the site. While also having an average growth rate the PLH had a huge amount of tree species that were stem form 3 and 4. The PLH pine of the study was initially expected to have the best timber growth and quality based on the expected adaptability of pitch pine to high altitude regions and loblolly pine's high timber quality.

The next best value species of the study was white pine. White pine showed great survival, growth rate, and timber quality, which was also found in other studies (Ostrander, 1970). White pine was expected to be the fastest growing species on the site but was outperformed by cold-hardy loblolly pine in terms of harvestable and pulpwood volumes and tree heights (total and height to 20-cm top).

There is little information on pitch pine growing in the mountain regions of North Carolina, but pitch pine had the worst timber growth and survival in this study. The seedlings for pitch pine were obtained in New Jersey where the sawtimber is typically of low quality. Only about a quarter of the logs were graded forms 1 and 2 (sawtimber quality logs). Pitch pine is used for pulpwood and fuel (Marquis, 1968) so it was not surprising that pitch pine performed poorly in terms of log quality compared to the other species in this study. Pitch pine had lower pulpwood volume than loblolly, white and the hybrid pine species. The poor survival would make pitch pine poor pulpwood producer pine compared to the other species.

Virginia pine typically grows smaller than other pine trees and does not grow straight (Carroll Co., 2006; Genys and Forbes, 1973), which was also found in this study. Virginia pine had the lowest percentages of sawtimber-quality trees and the highest percentage of stem form-3 and form-4 trees (unsuitable for sawtimber production) compared to the other species in this study. The results were similar to the limited literature available that indicated Virginia pine would be best used for pulpwood and fuel (Carter et al., USDA). There is little information on the use of Virginia pine for sawtimber production.

Forking was the most prevalent defect shown in each species on the site. Forking can cause multiple main stems to grow out from a single tree but does not necessarily mean sawtimber logs cannot be harvested from trees with forking stems. While forking reduced sawtimber volume of many trees, lower forking led to the formation of two stems with sawtimber quality logs in some cases. As long as stems have grown straight, more than one sawtimber log can still be harvested from trees with forking stems that are straight and have large-enough diameter.

Ice damage was expected to be a major concern for pines growing at high elevations (Aubrey, 2007). Over 50 percent of every tree species on the site had signs of ice damage. Although every species had shown signs of ice damage, the majority of the loblolly pine and the white pine tree species were noted to have stem forms of mostly 1 and 2. The stem forms were not significantly affected by ice damage because the damage was mostly at the top of trees and did not affect the harvestable logs. This shows that for loblolly pine, sawtimber logs can be harvested and it can be grown in the mountains for sawtimber and pulpwood.

The soil results from this project showed that the loblolly pine stands had some of the lowest nutrient content in the soil. In the fertilization of established loblolly stands, it is

mentioned that soil sites in eastern North Carolina typically are deficient in at least one macronutrient (Pickens, 2015). The nutrient that was the lowest on the site was phosphorus, which follows Bill Pickens research. Having a higher phosphorus has a direct correlation on loblolly pine having a greater height (South, D. et al, 2018). This is an opposite result of what was shown at this research site. Loblolly pine had the lowest phosphorus content out of all of the species but it still had the highest height values when compared to the other species on the site.

In the study it was shown that loblolly pine had the greatest monetary value compared to the other pine species. According to 'White Pine Old-Field Plantation Yield Study', white pine does not seem to be a species great for pulpwood (Dierauf, T and Scrivani, J, 1995). This goes with this research's data where white pine ($531.31) had one of the lowest values for pulpwood. The only species that had a lower pulpwood price was pitch pine ($420.62) which did not have as many trees on the site as white pine. Although this value was low, white pine still had great sawtimber value and a good chip and saw value as well. PLH pine having a low sawtimber value goes against 'Hybrids of Pitch Pine × Loblolly Pine'. According to this research PLH pine is supposed to have a great amount of stem-form 1 trees which would allow for a great sawtimber price. This goes against the research done in this paper as PLH pine had an estimted $5,820.14 sawtimber value, which was considerably lower compared to the estimated sawtimber values of loblolly pine ($16,369.14) and white pine ($14,550.35).

Conclusion

The results of this study showed that the cold-hardy loblolly pine had the best growth rate and timber growth while white pine had the best form between all of the species. The cold-hardy loblolly pine had the highest harvestable volume and pulpwood volume among all of the species.

The growth and quality parameters studied showed that loblolly pine would be sold at mills at a higher total value than the other pine species in this study. This result shows that the cold-hardy loblolly pine would be recommended for sawtimber and pulpwood production in the high elevation regions and the mountain regions of North Carolina.

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APPENDIX

Figure 1. The location of the study site (36°24'5.16"N, 81°18'10.87"W) in Laurel Springs, North Carolina.

Table 1. The 5 pine species survival on high altitude mountains at the Upper Mountain Research Station in North Carolina

Pine Species	Survival range (in blocks)
Loblolly Pine	54- 63%
White Pine	48-71%
PLH (Pitch x Loblolly hybrid) Pine	40-67%
Virginia	27-54%
Pitch	10-22%

Timber Quality

Table 2. Loblolly pine stem form ratings on high altitude mountains at the Upper Mountain Research Station in North Carolina

Loblolly Pine	Form 1	Form 2	Form 3	Form 4	Total (live trees out of 48)
Block 1	16	10	2	2	30
Block 2	6	12	11	3	32
Block 3	10	12	6	0	28
Block 4	11	13	2	0	26

Table 3. White pine stem form ratings on high altitude mountains at the Upper Mountain Research Station in North Carolina

White Pine	Form 1	Form 2	Form 3	Form 4	Total (live trees out of 48)
Block 1	15	8	5	4	32
Block 2	13	5	4	1	23
Block 3	11	10	4	0	25
Block 4	23	10	0	0	33

Table 4. PLH pine stem form ratings on high altitude mountains at the Upper Mountain Research Station in North Carolina

PLH (Pitch x Loblolly Hybrid) Pine	Form 1	Form 2	Form 3	Form 4	Total (live trees out of 48)
Block 1	3	11	9	6	29
Block 2	0	0	8	11	19
Block 3	12	14	5	1	32
Block 4	3	17	7	2	29

Table 5. Virginia pine stem form ratings on high altitude mountains at the Upper Mountain Research Station in North Carolina

Virginia Pine	Form 1	Form 2	Form 3	Form 4	Total (live trees out of 48)
Block 1	0	2	7	9	18
Block 2	4	7	10	5	26
Block 3	1	8	3	1	13
Block 4	0	1	6	14	21

Table 6. Pitch pine stem form ratings on high altitude mountains at the Upper Mountain Research Station in North Carolina

Pitch Pine	Form 1	Form 2	Form 3	Form 4	Total (live trees out of 48)
Block 1	2	5	1	5	13
Block 2	3	2	0	4	9
Block 3	2	0	2	0	4
Block 4	5	6	1	3	15

Table 7. Slope for all pine species at the high altitude (mountains) site located at the Upper Mountain Research Station in North Carolina

Pine Species	Slope (in blocks)
Loblolly Pine	28-35%
White Pine	28-35%
Pitch x Loblolly hybrid	28-35%
Virginia	28-32%
Pitch	30-35%

Soil

Table 8. The soil data breakdown for each pine species at the high altitude (mountains) site located at the Upper Mountain Research Station in North Carolina

Pine Species	block	Phosphorus (kg per ha)	Potassium (kg per ha)	Magnesium (kg per ha)	Calcium (kg per ha)	pH	CEC
Loblolly	1	62	156	259	1096	5.1	11.2
	2	33	169	285	1012	5.2	10.8
	3	37	219	296	1035	4.8	11.7
	4	36	136	297	1084	5.4	10.5
White	1	160	216	164	723	4.7	9.7
	2	62	167	259	1237	5.1	10.8
	3	26	176	285	1202	5.4	10.8
	4	37	155	282	1144	5.2	10.6
PLH (Pitch □□ Loblolly hybrid)	1	101	141	230	1013	5.3	10.1
	2	28	159	288	1098	5.4	10.6
	3	63	203	354	1291	5.1	12.5
	4	201	251	272	1258	5.2	10.6
Virginia	1	50	139	250	1222	5.0	11.1
	2	39	281	244	987	5.2	11.1
	3	69	186	267	1167	5.2	11.1
	4	28	148	261	1022	5.2	10.3
Pitch	1	220	163	185	845	5.2	10.0
	2	24	202	171	525	5.0	9.7
	3	25	145	261	1049	4.8	9.9
	4	39	229	373	1353	5.2	11.1