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Patterns of Regeneration of Eastern White Pine (Pinus strobus L.) as Influenced by Large Isolated Reserve Trees and Precommercial Thinning

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PATTERNS OF REGENERATION OF EASTERN WHITE PINE (PINUS STROBUS L.) AS INFLUENCED BY LARGE ISOLATED RESERVE TREES AND PRECOMMERCIAL THINNING

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An Abstract of the Thesis Presented
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The spruce budworm epidemic of the 1970s and 1980s led to the salvage harvesting of spruce-fir stands, serving as a release for scattered immature eastern white pine (*Pinus strobus* L.) trees. These pines are now growing as large isolated reserve trees above a mixed conifer regeneration stratum. The objectives in this study were to determine any effect of varying levels of basal area (m^2 ha^{-1}) of large pine reserve trees may have on (1) the densities (stems ha^{-1}) of both eastern white pine and non-pine species in the developing regeneration stratum, and (2) the height growth of eastern white pine in the developing regeneration stratum (3) incidence of white pine weevil injury of eastern white pine in the developing regeneration stratum, and (4) determine if any differences in quality exist between the two-aged stand type and the precommercially thinned stand type, relative to white pine weevil attack, blister rust infection, and branch shedding. Our

null hypotheses were that large pine reserves have no effect on the density (stems ha^{-1}) and height growth of the regenerating understory pine, or the density (stems ha^{-1}) of the regenerating non-pine species, and also that large pine reserves have no effect on the frequency of white pine weevil injury of the regenerating understory pine, and that there were no differences in pine regeneration quality aspects between stand type. Thirteen forest stands throughout the spruce-fir region of Maine were chosen for this study. Nine of these stands were two-aged stands that were regenerated prior to 1995, have no history of precommercial thinning, and contain a significant component of heavily released eastern white pine trees growing above a developing mixed species matrix. These nine stands were harvested between the years of 1984 and 1994, and have soils ranging from somewhat poorly drained to very poorly drained. Four forest stands throughout the spruce-fir region of Maine that had been regenerated in the same time period as above, and also had a history of precommercial thinning that favored eastern white pine were also chosen for investigation in this study. One of these four stands contained a component of heavily released eastern white pine trees growing above the developing mixed species matrix. Soils ranged from poorly drained to very poorly-drained. Reserve pine basal area (m^2 ha^{-1}) was found to be positively correlated with the presence versus absence of pine in the regeneration stratum ($p = 0.0398$). The odds ratio of this model indicated that an increase of one square meter of reserve pine basal area increases the odds of pine regeneration success by 72 percent. This is true regardless of where reserve pine basal area (m^2 ha^{-1}) is held. Basal area (m^2 ha^{-1}) of reserve pine was not correlated with pine regeneration density (stems ha^{-1}) when investigating only those plots in which pine regeneration was present ($p = 0.2246$). Non-pine density (stems ha^{-1}) in the regeneration stratum was observed to be influenced more by differences in site, rather than basal area (m^2 ha^{-1}) of reserve pine trees. Reserve tree basal area (m^2 ha^{-1}) was not significant in the model. Basal area of reserve pine (m^2 ha^{-1}) had a negative ($p = 0.0886$) effect on mean annual height increment of pine regeneration. Basal area (m^2 ha^{-1}) of pine reserves was not correlated ($p = 0.3721$) with the presence versus absence of weevil injuries in the two-aged stand type. Likewise, pine reserve basal area (m^2 ha^{-1}) was not correlated with number of weevil injuries ($p = 0.6950$) when investigating only those plots in which weevil injuries were present. The two-aged stands with large isolated reserves were found to have lower incidence of weevil injury ($p = 0.0055$), with smaller weevil caused stem offsets ($p = 0.0449$). Two-aged stands also had smaller diameter branches ($p = 0.0136$). Incidence of white pine blister rust indicated caution should be used in the precommercially thinned stand type.

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CHAPTER 1

A REVIEW OF EASTERN WHITE PINE (PINUS STROBUS L.) MANAGEMENT

EASTERN WHITE PINE: PAST, PRESENT, AND FUTURE

Eastern white pine (*Pinus strobus* L.) has long been considered a high value tree species in New England. It produces wood that is lightweight and durable, with a straight grain that is resistant to decay (Abrams 2001, Lockard 1959). Commercial logging of eastern white pine had begun in Maine as early as 1650 (Lorimer 1977). These efforts were focused mainly on large, old-growth pine that existed along large river floodplains and sandy outwash sites, as well as scattered supercanopy white pine that existed within mixed-species stands (Abrams 2001). Lorimer (1977) estimated the pre-European settlement white pine resource in Maine accounted for a standing volume between 600,000 and 30 million board feet. More recent estimates indicate that the resource was much greater, with approximately 6 billion board feet in the Penobscot River watershed alone (Wilson 2005). As logging efforts continually increased throughout the 1700s and 1800s, increasing numbers of settlers witnessed the decline of virgin pine forests throughout New England (Abrams 2001, Lorimer 1977, Wilson 2005).

The shift of agriculture to the mid-western United States throughout the 19th century, led to the establishment of eastern white pine on abandoned agricultural land (Foster 1992). Old-field pine monocultures came to dominate the landscape. This second growth pine was of a poorer quality than the original pine forests, therefore short clear pieces of lumber came to drive the market for eastern white pine products in the early 1900s, with boxes becoming the most important white pine product of the time (Fedkiw and Stout 1959, Howard 1986).

As a result of the spruce budworm epidemic of the late 1970s, salvage harvesting of spruce-fir stands was common in Maine from the mid-1970s through the 1990s (McWilliams et al. 2005). Unaffected immature eastern white pines were often left to harvest at a later date. These pines had the benefit of being released, as the spruce and fir were cut, and are now growing as large isolated crop trees, within the regenerating stand. Currently, there is an estimated 142 million eastern white pine trees, five inches d.b.h. and above, growing on timberland in the state of Maine. At 2.25 million cubic feet, this accounts for almost ten percent of the total volume of all growing stock trees (McWilliams et al. 2005). It has been suggested that as global climate change continues, white pine will increase in both distribution and abundance, as it was a more dominant species in the Maine landscape under the warmer climate experienced seven to nine thousand years ago. A warming of as little as 0.5°C could favor the establishment of pine over typical Maine species, such as spruce and fir (Jacobson and Dieffenbacher-Krall 1995).

LUMBER QUALITY AND VALUE

The ability to recover high grade, defect-free lumber is the key to the financial value of eastern white pine. Eastern white pine lumber is graded based on the maximum allowable defects of the best face, including the frequency and size of knots. D select and better is the highest grade, and permits one knot up to $\frac{1}{2}$ inch in diameter, per surface foot (NeLMA 1952). Currently, lumber that is D select and better is worth approximately 2.4 times the value of the next highest grade, premium grade lumber (Random Lengths 2008). Lumber value increases with log grade (Hibbs and Bentley, 1987), thus the greatest importance is placed on the ability to grow clear, knot-free lumber.

PESTS, PATHOGEN, AND PROBLEMS

White pine weevil

The white pine weevil (*Pissodes strobi* Peck) is a native insect pest capable of damaging eastern white pine to the point of little to no value. Stem deformation and reduction in height growth are common results of weevil attack (Hamid et al. 2005, Maughan 1930). When the terminal shoot of a pine is killed by weevil attack, one or more lateral branches in the whorl below the dead portion will turn and grow upward to replace the terminal shoot. This results in a crook in the stem, as the laterals try to correct for the loss of the leader. The laterals, acting as new leaders, are the next to be attacked, continuing the cycle, and leading to numerous deformities. Repeated attacks by white pine weevil amount to trees that are "cabbaged", with several crooked and forked stems, resulting from the repeated death of the terminal shoot (Dirks 1964, Maughan 1930, Peirson 1922).

Beginning in mid-April, weevils emerge from their overwintering sites in the duff below host trees (Dixon and Houseweart 1983). The adults crawl up the bole of the host tree and feed just below the terminal bud cluster (Belyea and Sullivan 1956, Hamid et al. 2005). Preference is given by the weevil to those leaders that exhibit thick bark, and are growing in sunlight, making the tallest, most vigorous trees most susceptible to weevil attack (Dirks 1964, Droska et al. 2003, Wilkinson 1982). From May to July, female weevils lay between 100 and 200 eggs in the feeding cavities made in the terminal shoot. Upon hatching, the larvae remain inside the shoot, feeding on the cambium from the top down, thus killing the leader (Pubanz et al. 1999). Inside the shoot, larvae molt four times over five to six weeks. A pupal chamber is formed, and adult weevils chew holes through the dead leader, and emerge beginning in late-July (Dirks 1964, Hamid et al. 2005). These new adult weevils feed on buds and live bark tissues of the stem and branches of pines throughout mid-October. At this time, weevils move to their overwintering sites below the host tree. Typically, overwintering occurs beneath the crown dripline of the host tree, within 20 centimeters of the bole, between the dry needles and moist organic layer (Dirks 1964, Dixon et al. 1979, Hamid et al. 2005).

White pine blister rust

Documented in eastern North America as early as 1898, white pine blister rust (*Cronartium ribicola* J.C. Fisch) is an introduced pathogen, native to Asia (Mielke 1943, Maloy 2001). It was first documented in Maine in 1916, with a control program initiated in 1917 (Ostrofsky et al. 1988). White pine blister rust is a complex fungal organism, involving five spore stages, and requiring two hosts, eastern white pine and *Ribes* spp., to complete its life cycle (Mielke 1943, Maloy 2001). Blister rust is capable of causing high levels of damage to eastern white pine, over a wide geographic range, and has the ability to infect and eventually kill pine of all ages and developmental stages (Fowler 1959, Ostrofsky et al. 1988).

Infection of eastern white pine occurs in late-summer or fall, after a period of cool moist conditions. Specifically, a minimum of 48 hours with a relative humidity of 100 percent, combined with temperatures below 68°F are required for infection of pine to be successful (Gross 1985, Castello et al. 1995, Maloy 2001, Kinloch 2003). Basidiospores produced on *Ribes* enter the needles of the pine through the stomata. The fungus then grows into the branches of the tree, where the fungal mycelium becomes established, forms a canker, and continues to grow inward toward the bole of the pine. Upon spreading to the bole, the canker can result in girdling death (Maloy 2001), although Ostrofsky (1988) found that 45 to 70 percent of branches exhibiting cankers died before infection of the main stem occurred. After a period of one to three years, white blisters known as aecia erupt through the bark of the pine, releasing wind dispersed spores that will infect *Ribes*. The basidiospores that infect the eastern white pine are then formed on the *Ribes*, completing the life cycle (Maloy 2001, Kinloch 2003).

Control of white pine blister rust is centered on the eradication of *Ribes* species, with the use of herbicide being the primary technique (Maloy 2001, Ostrofsky 1988, Kinloch 2003). Pathological pruning is also crucial to limiting the spread of blister rust infection. This involves pruning out infected branches before the fungus reaches the bole. Moist conditions are more common near the ground level. This fact coupled with *Ribes* spp. persisting low to the ground, makes the lowest three meters of a tree the most susceptible to infection. Therefore, it is recommended that the lower branches of trees be removed. This serves to increase the air circulation and sunlight, thus reducing cool moist conditions needed by the fungus (Maloy 2001). Although many *Ribes* eradication programs throughout North America were unsuccessful, the program in Maine was employed with moderate success, accounting for a 50 percent reduction in blister rust incidence in areas treated (Ostrofsky 1988). Overall, there was greater success in eradication programs in eastern North America, compared to those of western North America, due in part to the early action taken in the east (Kinloch 2003).

Branch shedding

Eastern white pine has been found to be a poor natural branch shedder. Dead branches may persist on the bole from 25 to 73 years, thus natural branch shedding of the butt log is rarely achieved within the eastern white pine lifespan (Foster 1957). Loose black knots can be an obstacle to recovering valuable, high grade lumber, as there is an average of 60 limbs found in a given eastern white pine butt log, (Foster 1957, Wendel and Smith 1990).

Pruning can enhance the quality of wood, offering the opportunity to overcome the problem of loose, black knots, thus yielding defect-free lumber that will achieve a higher grade than that of unpruned trees. Pruning minimizes the size of the defect core to a diameter not much larger than that of the tree at the time of the pruning (O'Hara 2007), thus clearwood production is maximized. It is ideal to perform the first pruning of eastern white pine trees when they have reached at least one log in height, and are between four to ten inches d.b.h., with branches no larger than 1.5 inches in diameter. Following this strategy minimizes the defect core (Smith and Seymour 1986, Perkey 1999). Pruning requires a financial investment in order to substantially increase the value of pines grown to maturity (Foster 1957, Wendel and Smith 1990). Therefore, pruning should be limited to potential crop trees only. It has been shown that the return of clear lumber justifies the investment involved with intensive management practices such as pruning (Page and Smith 1994).

SILVICULTURE AND MANAGEMENT OF EASTERN WHITE PINE

Traditionally, the silviculture of eastern white pine in New England has focused on old-field monocultures, and the difficulties associated with managing them. The shelterwood method has been the most commonly recommended method for regenerating white pine

(Lancaster and Leak 1978, Wetzel and Burgess 2001). More recently, a new silvicultural system has been suggested for eastern white pine, in which residual trees are left at the time of the overstory removal cutting, and allowed to grow and maximize value for an extended period of time. This shelterwood with reserves method affords sufficient growth of established regeneration, while minimizing damage from pests and pathogens (Zenner and Krueger 2006).

To promote high quality crop trees, dense pine regeneration should be initiated by timing the establishment cut with an abundant seed year (Seymour 1995). Good seed crops of eastern white pine occur on average every 3 to 7 years (Deen 1933, Burns and Honkala 1990). Pine regeneration should be maintained for several decades under a light pine overstory at approximately 40 percent crown closure (Seymour 1995). Eastern white pine is intermediate in shade tolerance, and can survive in the understory and respond to release for 38 years or more (Kelty and Entcheva 1993). Suppressed white pine have the ability to reallocate resources to their root systems, in an effort to maximize the length of time they can survive in suppressed conditions (Bormann 1965, O'Connell and Kelty 1994). In a study comparing understory and open-grown white pine saplings, O'Connell and Kelty (1994), found that understory pine root systems had the same total biomass as that of open-grown pine root systems. This mechanism of resource reallocation is advantageous, as the size and development of the root system can limit tree vigor and the ability to respond to release (Larson 1992).

Upon release, eastern white pine has the ability to rapidly increase both diameter and height growth. Puettmann and Saunders (2000) found that partial release of pine in central Minnesota resulted in an average increase in diameter growth of 115 percent, as well as an average height growth increase of 42 percent during the first year after release. Once future crop trees have grown to a height of 17 to 25 feet, the overwood should be removed. When crop trees have achieved a dbh of approximately six inches, and a live crown base of 20 feet, up to 100 crop trees per acre should be released in a heavy crown thinning (Seymour 1995). The live crown base should be maintained at 20 feet through the use of a low-density thinning schedule. In this manner, the stand is kept well below the B-line on the stocking guide, eliminating crown recession, thus allowing for the rapid growth of the crop trees (Seymour and Smith 1987). Seymour (2007) found that heavily released pines exhibited 1.6 times the diameter growth of pines grown on stands released to the B-line. Pruning to a height of 17 to 25 feet should be done after the thinning, allowing for the recovery of clear, high value butt logs, as well as upper logs that are free of loose black knots (Smith and Seymour 1986, Seymour 2007).

Recently, there has been a trend to retain a number of large trees when removing the overwood, either in perpetuity, or simply well beyond the typical rotation. This serves to increase structural heterogeneity, by integrating structural legacies into the stand. Generally reserves are left for the purpose of maintaining wildlife habitat or aesthetics during the regeneration process (Burgess et al. 2005, Zenner and Krueger 2006). Since most of a stands volume growth occurs in the trees that are in direct sunlight (Oliver and Larson 1990), another objective of the shelterwood with reserves system could be to allow the residual trees to grow rapidly in open conditions, yielding high rates of return on their own value. These trees could then be harvested at a later point in time.

There are several benefits to regenerating eastern white pine in this manner. The dense stocking in the understory limits branch size, and thus knot size. It also promotes straight stem growth and rapid branch shedding. This has the positive effect of reducing future pruning investments (Seymour 1995). The overwood, and later the reserve trees, offer enough shade to greatly reduce white pine weevil infestations, by reducing the rate of shoot diameter growth, as well as offering suitable habitat for predators and parasites of the weevil (Krueger and Puettmann 2004, Burgess et al. 2005, Zenner and Krueger 2006). The spread of blister rust infection is also minimized through the reduction in dew formation, which reduces the moist conditions required by the blister rust to infect pine (Hodge et al. 1989).

Growing eastern white pine in mixed species stands further enhances the benefits of the shelterwood with reserves system, as multicohort, mixed species stands have the ability to exceed the production and yield of monocultures, as well as increase both wood quality and forest health (Cline and Lockard 1925). This is especially true if there is a constituent of large, long-lived trees, as competition is reduced through spatial separation (Kelty 1992). This trend is even more dramatic when species niches are exceedingly different (Oliver and Larson 1990). When grown in mixed species stands, there is an improvement in both form and quality of white pine stems (Tarbox and Reed 1924, Fajvan and Seymour 1993, Fajvan and Seymour 1999). High densities of mixed species maintain straight boles, with the added benefit of further reducing susceptibility to both white pine weevil and blister rust. When grown in the company of other more shade tolerant conifers, natural branch shedding of pine is promoted, as the tolerant conifers act as trainers, creating better quality wood (Oliver and Larson 1990).

CHAPTER 2

PATTERNS OF REGENERATION OF EASTERN WHITE PINE (*PINUS STROBUS* L.) AS INFLUENCED BY LARGE ISOLATED RESERVE TREES

ABSTRACT

Salvage harvesting of spruce-fir stands following the spruce budworm epidemic of the 1970s and 1980s commonly served as a release for scattered immature eastern white pine trees. These trees are now growing as large isolated reserve trees above a mixed conifer regeneration stratum, offering a unique opportunity to determine any effect of large pine reserve trees on the density and height growth of eastern white pine in the developing regeneration stratum, as well as the density of non-pine species in the regeneration stratum. Nine forest stands throughout the spruce-fir region of Maine that were regenerated prior to 1995 were chosen for study. These nine stands had no history of precommercial thinning, and contained a significant component of heavily released eastern white pine trees growing above a developing mixed species matrix. Harvesting of these sites took place between the years 1984 and 1994. Soils ranged from somewhat poorly drained to very poorly drained. Reserve pine basal area (m^2 ha^{-1}) was found to be positively correlated with the presence of pine in the regeneration stratum (p = 0.0398). The odds ratio of this model indicated that an increase of one square meter of reserve pine basal area increases the odds of pine regeneration success by 72 percent. This is true regardless of where reserve pine basal area (m^2 ha^{-1}) is held. Basal area (m^2 ha^{-1}) of

reserve pine was not correlated with pine regeneration density (stems ha^{-1}) when investigating only those plots in which pine regeneration was present ($p = 0.2246$). Non-pine density (stems ha^{-1}) in the regeneration stratum was influenced more by differences in site, than by basal area (m^2 ha^{-1}) of reserve pine trees. Reserve tree basal area (m^2 ha^{-1}) was not significant in the model. Basal area of reserve pine (m^2 ha^{-1}) had a negative effect ($p = 0.0886$) on mean annual height increment of pine regeneration. Large isolated reserve pines did not appear to have an effect on the density (stems ha^{-1}) of pine versus non-pine species, although there was a slightly negative effect on height growth of pine in the regeneration stratum.

INTRODUCTION

Much of the past research regarding eastern white pine has focused on the difficulties surrounding eastern white pine as a suitable crop tree. The old-field monocultures of white pine that seeded in after agricultural land abandonment risked repeated attacks by the white pine weevil (*Pissodes strobi* [Peck]), resulting in stem deformations that decreased the value and yield of the lumber (Peirson 1922). The ensuing volunteer stands of mixed hardwoods and white pine that arose after these monocultures had been cut over required costly precommercial treatments to ensure the pine saplings were not continually out-competed by the hardwood saplings (McKinnon et al. 1935).

There is, however, some research showing eastern white pine can do well as scattered crop trees growing in stratified stands of mixed conifer species (Fajvan and Seymour 1993). In a stratified system such as this, it would be possible to develop a two-aged silvicultural system, in which some scattered white pines are left after the harvesting of other shade tolerant conifers, thus releasing the pines, and allowing them to grow to large, high-value crop trees. When grown under these conditions, the more shade tolerant conifers such as spruce, fir, and hemlock act as trainers, encouraging natural branch shedding of the pine, thus reducing pruning expenses. This two-aged silvicultural system would have the additional benefit of minimizing weevil damage, as white pine grown scattered within mixed species stands is less susceptible to weevil attack (Peirson, 1922).

The spruce budworm epidemic of the 1970s and early 1980s led to the salvage harvesting of spruce-fir stands beginning during the mid-1970s. During this time, landowners commonly left unaffected immature eastern white pines to harvest at a later date. These pines had the benefit of being released, as the spruce and fir was cut, and are now growing as large isolated crop trees above the regenerating stand. Such large dominant trees contribute a disproportionately large amount of seed to a stand, but the effects of such large isolated reserve trees on the composition of the regenerating stratum have not been studied.

Our objectives in this study were to determine any effect of varying levels of basal area (m^2 ha^{-1}) of large pine reserve trees may have on (1) the densities (stems ha^{-1}) of both eastern white pine and non-pine species in the developing regeneration stratum, and (2) the height growth of eastern white pine in the developing regeneration stratum. Our null hypothesis was that large pine reserves have no effect on the density (stems ha^{-1}) and height growth of the regenerating understory pine, or the density (stems ha^{-1}) of the regenerating non-pine species.

METHODS

Study site and data collection

Nine forest stands throughout the spruce-fir region of Maine that were regenerated prior to 1995 were chosen for this study. These nine stands had no history of precommercial thinning, and contained a significant component of heavily released eastern white pine trees growing above a developing mixed species matrix. Harvesting of these sites took place between the years of 1984 and 1994. Soils ranged from somewhat poorly drained to very poorly drained (Briggs 1994) (Table 2.1). Mean stocking of pine across all sites was found to be 97.23 ± 2.72 percent stocked, with well stocked being defined as at least 50 pines ha^{-1}.

Data were collected during late spring and summer of 2008. Twelve plot centers were established on a 40m x 40m grid at each of the nine study sites, with the exception of one site (PEF C2A) in which 24 plot centers were established. A fixed radius plot of 0.1 ha was established at each plot center, and all reserve trees were measured for species and dbh, as well as distance and direction to plot center. A nested 0.001 ha plot was also established at each plot center, and all trees < 30cm dbh and > 1.3 meters tall were tallied by 2 cm diameter class, by species. Up to three pines in each diameter class were measured for total height, and base of live crown. Age was approximated with an internode count. If pine was not present in 0.001 ha plot, a 0.02 ha plot was established to determine if the area was stocked with pine. Soil drainage class was assessed using the protocol from Briggs (1994).

Table 2.1. Stand locations, age, and soil drainage class of two-aged stands (Briggs, 1994).

Site (Harvest Year)	Location	Soil Drainage Class
Dead River Twp. (1984)	N 45° 12', W 70° 16'	3 – Somewhat Poorly Drained
Long Pond Twp. (1989)	N 45° 36', W 70° 02'	4 – Poorly Drained
Penobscot Experimental Forest, Compartment 2 (1984)	N 44° 52', W 68° 39'	3 – Somewhat Poorly Drained
Topsfield Twp. (1992)	N 45° 28', W 67° 51'	4 – Poorly Drained
T3 R12 (1987)	N 45° 56', W 69° 15'	4 – Poorly Drained
T4 R12 (1991)	N 45° 58', W 69° 11'	3 – Somewhat Poorly Drained
T5 R12 (1994)	N 46° 06', W 69° 15'	5 – Very Poorly Drained
T39 MD (1980)	N 45° 01', W 68° 18'	--------------------------

Analysis

Data were analyzed using version 2.8 of the R statistical software package (R Development Core Team 2008). All data were summarized at the plot level, using conventional mensurational variables including trees per acre, basal area, relative density, and species composition. Height and diameter distributions were also determined.

A two stage approach was employed to determine the effect of large pine reserves on the density (stems ha^{-1}) of pine in the developing regeneration stratum. This two stage approach was employed to analyze two separate processes: the effect of reserve pines on pine regeneration presence versus absence, and the effect of reserve pines on pine regeneration density. This approach enabled the analysis of a data set in which there were a substantial number of zero data points, due to pine regeneration not being present in 24 percent of the plots.

First, a mixed effects logistic regression model ($\alpha = 0.05$) was employed to determine the effect of pine reserve basal area (m^2 ha^{-1}) on the presence versus absence of pine regeneration. The model takes the form:

[1]

$$\Pr(preg_i = 1) = logit^{-1}\ (\alpha_{site[i]} \beta BAOW)$$

where *preg* is pine regeneration as a binary response in which 0 indicates absence and 1 indicates presence of pine regeneration in the *i*th plot, α is the intercept with a random effect for site, and *BAOW* is the basal area (m^2 ha^{-1}) of pine reserves, associated with the parameter estimate β. The assumptions of a discreet outcome, and no outliers in the independent variable were met.

The odds ratio of the logistic regression was calculated as follows:

[2]

$$\widehat{OR} = \exp(\beta)$$

Second, a linear mixed effects model (α = 0.05) was employed to determine the effect of the reserves on the pine regeneration, conditional on pine being present in the regeneration. For this part of the analysis, a zero truncated data set was used, in which all zero data points were eliminated. The model takes the form:

[3]

$$pd = \beta_0 + b_0 + (\beta_1 + b_1)BAOW$$

where pd is pine regeneration density (stems ha^{-1}), $BAOW$ is the basal area (m^2 ha^{-1}) of pine reserves, b_0 is a random effect for site associated with the intercept β_0, and b_1 is a random effects for site associated β_1. The assumption of normally distributed random effects was met however heteroskedasticity was present in the residuals. Weighting was attempted to correct for heteroskedasticity, however residuals remained heteroskedastic and the model was not improved.

A linear mixed effects model (α = 0.05) was utilized to determine the effect of large pine reserves on the non-pine species in the developing regeneration stratum. The non-pine species in the regeneration stratum mainly consisted of red spruce (*Picea rubens* Sarg.) and balsam fir (*Abies balsamea* (L.) Mill.). The model has the form:

[4]

$$oreg = \beta_0 + b_0 + (\beta_1 + b_1)BAOW$$

where *oreg* is non-pine regeneration density (stems ha^{-1}), $BAOW$ is the basal area (m^2 ha^{-1}) of pine reserves, b_0 is a random effect for site associated with the intercept β_0, and b_1 is a random effects for site associated β_1. As with the previous model, the assumption of normally distributed random effects was met however heteroskedasticity was present in the residuals. Weighting was attempted to correct for heteroskedasticity, however residuals remained heteroskedastic and the model was not improved.

A linear mixed effects model ($\alpha = 0.10$) was also employed in an effort to model the effect of large pine reserves on the height growth of the regenerating eastern white pine. The model takes the form:

[5]

$$MAHI = \beta_0 + b_0 + (\beta_1 + b_1)BAOW$$

where *MAHI* is the average mean annual height increment (cm) by plot, $BAOW$ is the basal area (m^2 ha^{-1}) of pine reserves, b_0 is a random effect for site associated with the intercept β_0, and b_1 is a random effects for site associated β_1. Assumptions of homoskedasticity of residuals and normally distributed random effects were met.

RESULTS

All stands had a component of large isolated eastern white pine reserve trees, with a mixed species regeneration stratum composed mainly of red spruce, fir, and eastern white pine, forming a two-aged stand structure. Mean basal area of eastern white pine reserves ranged from 1.74 ± 0.79 m^2 ha^{-1} to 7.31 ± 1.31 m^2 ha^{-1} across all sites (Table 2.2). Reserve tree density ranged from 9.2 stems ha^{-1} at the Dead River site (± 5.9) and the Topsfield site (± 4.6) to 41.7 ± 7.3 stems ha^{-1} (Table 2.3). QMD of pine reserves was found to range from 38.97 cm to 57.46 cm (Figure 2.1).

Mean basal area of the regeneration stratum ranged from 12.44 ± 2.34 m^2 ha^{-1} to 33.17 ± 4.69 m^2 ha^{-1} across all sites. Eastern white pine accounted for 10.80 ± 2.83 to 58.41 ± 11.55 % of the regeneration matrix, with basal area ranging from 1.42 ± 0.78 m^2 ha^{-1} to 15.36 ± 4.42 m^2 ha^{-1}. Non-pine species basal area ranged from 10.28 ± 2.92 m^2 ha^{-1} to 24.60 ± 4.48 m^2 ha^{-1} (Table 2.2). Mean density of the regeneration stratum ranged from 9083.33 ± 2122.96 stems ha^{-1} to 22833.33 ± 4314.94 stems ha^{-1}. Eastern white pine accounted for 666.67 ± 224.73 stems ha^{-1} to 5916.67 ± 1872.68 stems ha^{-1} (Table 2.3). Mean height of pine regeneration across all sites was found to be 4.40 ± 0.13 m, ranging from 3.07 ±0.27 m to 7.92 ± 1.09 m (Figure 2.2). Quadratic mean diameter (QMD) of eastern white pine regeneration was found to range from 2.00 cm to 3.21 cm across all sites, and QMD of non-pine species regeneration was found to range from 2.62 cm to 3.31 cm (Figure 2.3).

Table 2.2. Mean basal area ($m^2\ ha^{-1}$) of regeneration stratum and pine overwood in two-aged stands by site.

Regeneration Stratum

Site	PEF C2A	PEF C2B	T 39	Topsfield	Long Pond	T4 R12	T5 R12	T3 R12	Dead River
Pine Only									
Mean	3.21	4.85	15.36	1.42	3.46	2.99	1.72	7.29	8.57
Std. Error	0.82	1.62	4.42	0.78	1.76	1.80	0.56	2.61	3.41
Minimum	0	0	0.08	0	0	0	0	0	0
Maximum	13.29	17.46	47.03	7.71	18.32	22.26	4.72	33.11	32.32
Non-Pine									
Mean	16.49	18.70	10.28	13.98	11.69	12.33	10.72	22.72	24.60
Std. Error	2.11	6.23	2.92	4.58	2.62	3.17	1.93	3.98	4.48
Minimum	3.38	0	0	0	0.31	0.08	3.30	0.63	4.56
Maximum	47.27	65.35	28.08	48.21	31.54	37.20	25.17	52.93	50.81
All Species									
Mean	19.70	23.55	25.64	15.40	15.15	15.32	12.44	30.01	33.17
Std. Error	1.95	5.56	4.10	4.51	3.89	3.31	2.34	5.07	4.69
Minimum	6.69	4.56	7.31	0.08	0.31	0.16	3.38	7.31	9.59
Maximum	47.27	65.36	53.87	48.21	49.87	37.20	29.73	62.52	73.54

Pine Overwood

Site	PEF C2A	PEF C2B	T 39	Topsfield	Long Pond	T4 R12	T5 R12	T3 R12	Dead River
Mean	5.54	3.46	7.31	1.94	2.41	3.88	1.74	6.54	1.97
Std. Error	0.80	0.88	1.31	0.90	0.60	0.91	0.79	1.10	0.75
Minimum	0	0	0	0	0	0	0	1.19	0
Maximum	13.14	10.31	13.96	10.80	6.79	10.11	9.78	13.47	8.64

Table 2.3. Mean density (stems ha^{-1}) of two-aged stands by site.

Site	PEF C2A	PEF C2B	T 39	Topsfield	Long Pond	T4 R12	T5 R12	T3 R12	Dead River
Pine Only									
Mean	5125	5666.7	5916.7	666.7	2000	1333.3	1833.3	2083.3	916.7
Std. Error	1275.9	1639.2	1872.7	224.7	758.8	376.1	489.8	398.1	259.9
Minimum	0	0	1000	0	0	0	0	0	0
Maximum	24000	19000	23000	2000	9000	4000	5000	5000	3000
All Species									
Mean	14500	10833	12000	9083	21916	16833	22833	18250	10416
Std. Error	1645.15	1812.55	2798.8	2122.9	3826.7	4098.8	4314.9	1962.2	1151.1
Minimum	4000	4000	1000	1000	4000	0	5000	5000	3000
Maximum	36000	25000	31000	21000	50000	5000	56000	29000	16000

Pine Overwood

Site	PEF C2A	PEF C2B	T 39	Topsfield	Long Pond	T4 R12	T5 R12	T3 R12	Dead River
Mean	23.3	13.33	30.0	9.2	20.0	32.5	15.0	41.7	9.2
Std. Error	2.8	3.10	5.3	4.6	3.7	7.4	3.0	7.3	5.9
Minimum	0	0	0	0	0	0	0	10	0
Maximum	50	40	70	50	50	70	40	80	60

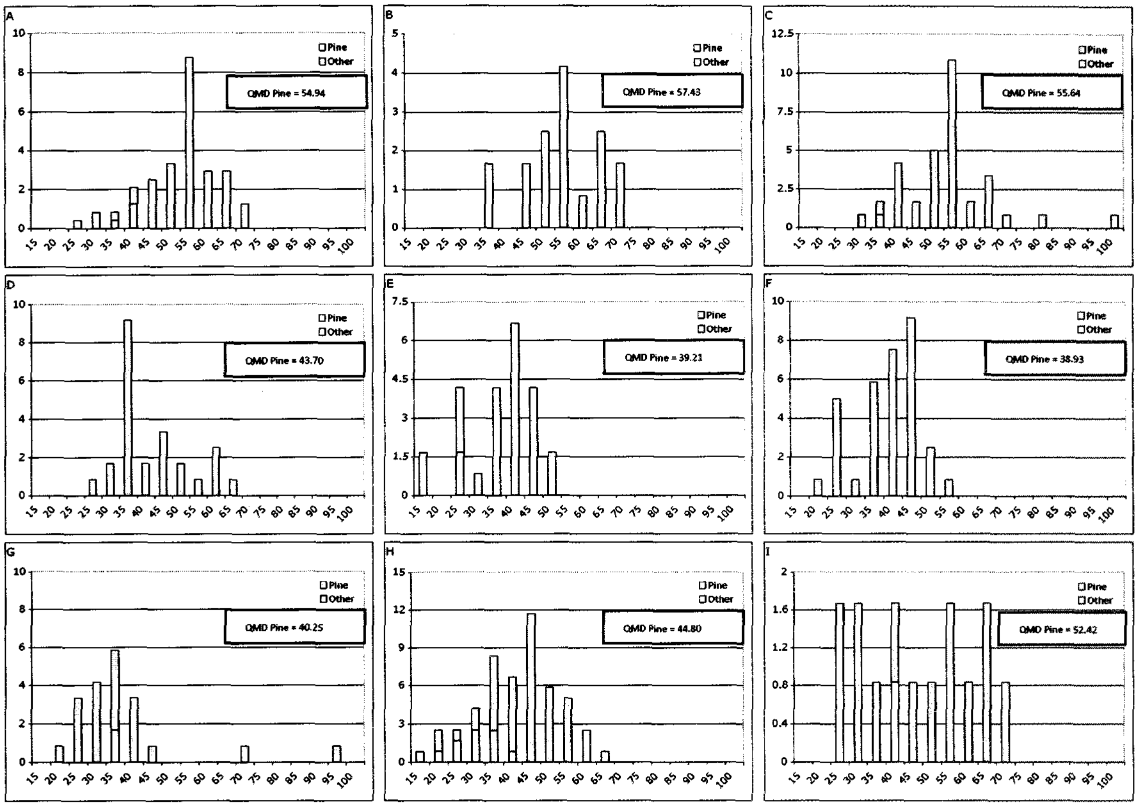

Figure 2.1. Diameter distribution of overwood by site in five cm diameter classes, and quadratic mean diameter (QMD) of pine overwood by site; A= PEF C2A, B= PEF C2B, C= T 39, D= Topsfield, E= Long Pond, F= T4 R12, G= T5 R12, H= T3 R12, I= Dead River.

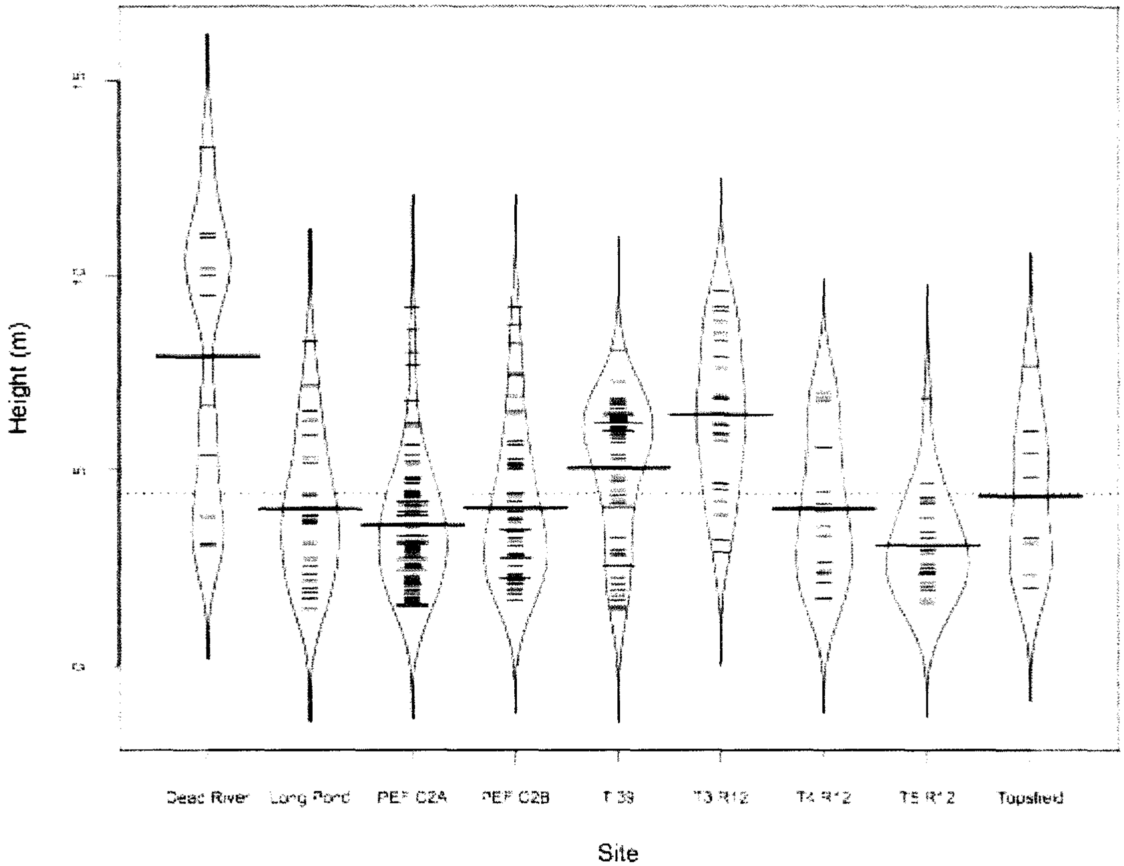

Figure 2.2. Plot of height distribution of eastern white pine regeneration of two-aged stands by site.

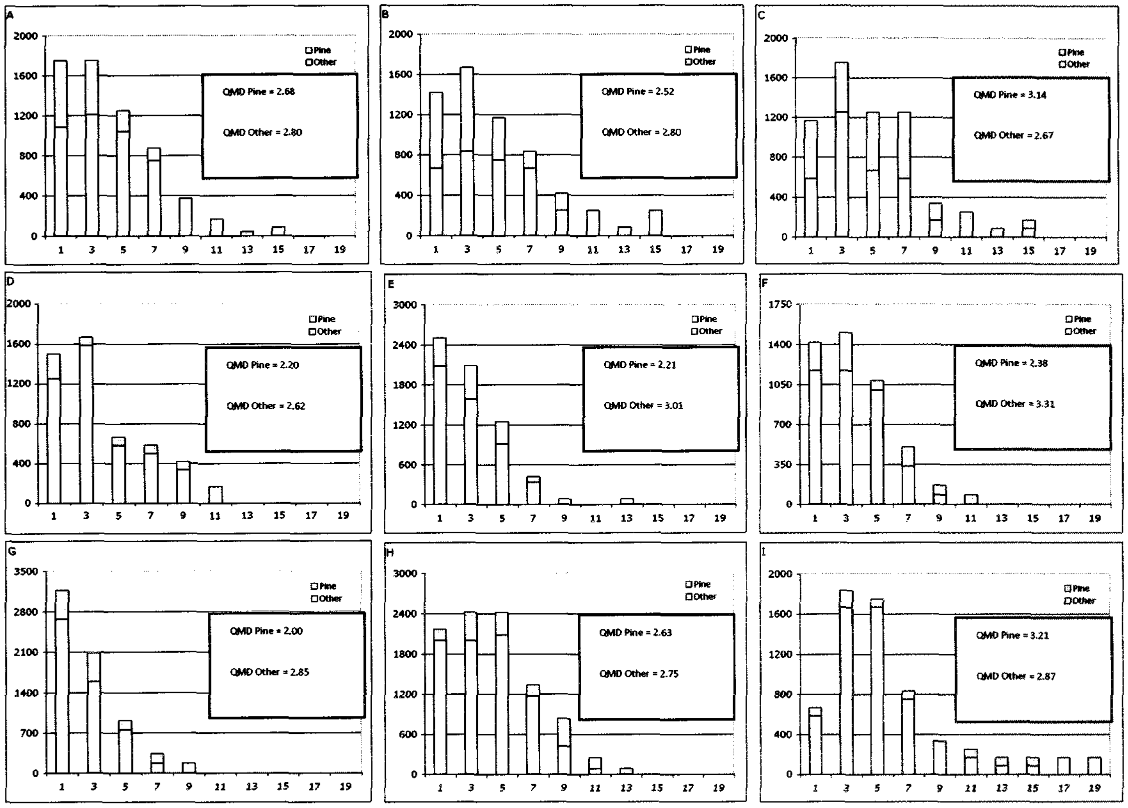

Figure 2.3. Diameter distribution in two centimeter diameter classes, and quadratic mean diameter (QMD) of regeneration stratum by site; A= PEF C2A, B= PEF C2B, C= T 39, D= Topsfield, E= Long Pond, F= T4 R12, G= T5 R12, H= T3 R12, I= Dead River.

Reserve pine basal area (m^2 ha^{-1}) was found to be positively correlated ($p = 0.0398$) with the presence of pine in the regeneration stratum (Table 2.4). This relationship exhibited little variation between sites (Table 2.5), as the random effects for site associated with the intercept were all nearly zero. The odds ratio of this model indicated that an increase of one square meter of reserve pine basal area increases the odds of pine regeneration success by 72 percent. This is true regardless of where reserve pine basal area (m^2 ha^{-1}) is held.

Basal area (m^2 ha^{-1}) of reserve pine was not significant ($p = 0.2246$) in predicting pine regeneration density (stems ha^{-1}) in plots where pine regeneration was present (Table 2.6). Further, disproportionally large random effects associated with the intercept (Table 2.7) indicated that differences in pine regeneration density (stems ha^{-1}) were influenced by differences in site more than reserve pine basal area (m^2 ha^{-1}) (Figure 2.4).

Non-pine density (stems ha^{-1}) in the regeneration stratum was also observed to be influenced more by differences in site, rather than basal area (m^2 ha^{-1}) of reserve pine trees. Reserve tree basal area (m^2 ha^{-1}) was not statistically significant in the model (Table 2.8), and random effects associated with the intercept were found to have very large values (Table 2.9) (Figure 2.5).

Basal area of reserve pine (m^2 ha^{-1}) had a negative effect ($p = 0.0886$) on mean annual height increment of pine regeneration (Table 2.10). As seen in the pine regeneration density model [Equation 3], the random effect associated with the intercept outweighed the random effect associated with basal area (m^2 ha^{-1}) of reserve pine, indicating that site differences had a greater influence on mean annual height increment than basal area (m^2 ha^{-1}) of reserve pine trees (Table 2.11) (Figure 2.6).

Table 2.4. Presence/absence of pine regeneration logistic model [Equation 1] parameter estimates and fit statistics. AIC-Akaike's Information Criteria; BIC-Bayesian Information Criteria; $\widehat{OR}$-Odds Ratio.

	Value	**Std. Error**	**P value**	**AIC**	**BIC**	**LogLik**	$\widehat{OR}$
α	1.218	0.2311	0.0000	565.43	579.37	-277.71	1.718
β	0.541	0.2601	0.0398				

Table 2.5. Random effects for presence/absence logistic regression [Equation 1].

	α_{site}
PEF C2A	-4.46×10^{-8}
PEF C2B	2.21×10^{-8}
T 39	4.53×10^{-8}
Topsfield	-5.40×10^{-8}
Long Pond	6.58×10^{-9}
T4 R12	-2.39×10^{-9}
T5 R12	1.23×10^{-8}
T3 R12	2.61×10^{-8}
Dead River	-1.13×10^{-8}

Table 2.6. Pine density (stems ha^{-1}) model [Equation 3], parameter estimates, and fit statistics. AIC-Akaike's Information Criteria; BIC-Bayesian Information Criteria; RMSE-Root mean squared error; R^2-Generalized coefficient of determination.

	Value	Std. Error	P value	AIC	BIC	LogLik	RMSE	R^2
β_0	2801.79	780.58	0.0006	1769.16	1784.09	-878.58	4069.9	0.17
β_1	193.90	158.46	0.2246					

Table 2.7. Random effects for pine density (stems ha^{-1}) linear mixed effects model [Equation 3].

	b_0	b_1
PEF C2A	1089.08	213.01
PEF C2B	1414.53	276.66
T 39	527.60	103.19
Topsfield	-561.36	-109.79
Long Pond	-117.33	-22.95
T4 R12	-647.12	-126.57
T5 R12	-329.93	-64.53
T3 R12	-694.56	-135.84
Dead River	-680.90	-133.17

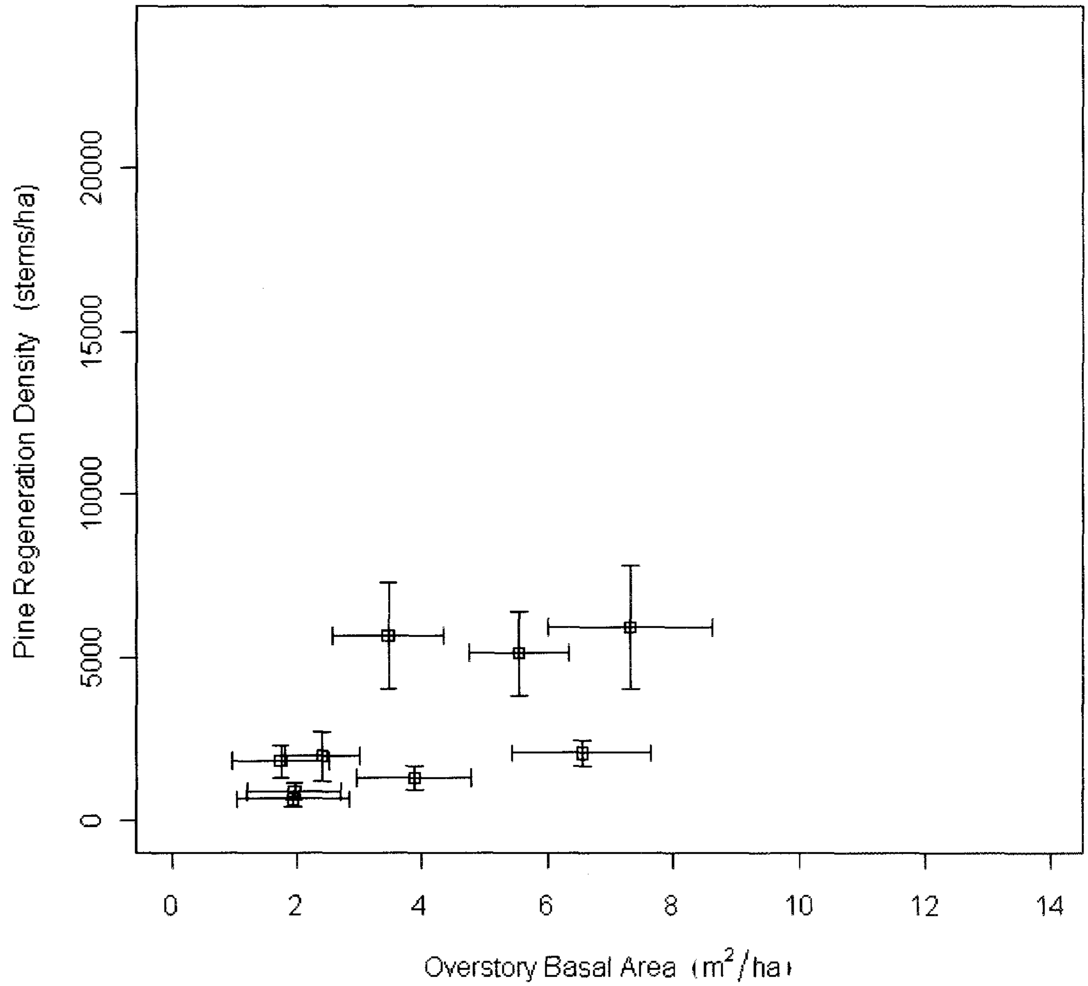

Figure 2.4. Scatterplot of pine regeneration density (stems ha^{-1}) vs basal area (m^2 ha^{-1}) of pine reserves. Grey circles represent plot observations, open squares represent site means with standard error bars.

Table 2.8. Non-pine density (stems ha^{-1}) model [Equation 4], parameter estimates, and fit statistics. AIC-Akaike's Information Criteria; BIC-Bayesian Information Criteria; RMSE-Root mean squared error; R^2-Generalized coefficient of determination.

	Value	Std. Error	P value	AIC	BIC	LogLik	RMSE	R^2
β_0	11873	2520.34	0.0000	2519.14	2535.76	-1253.57	8573.0	0.22
β_1	66.38	253.40	0.7938					

Table 2.9. Random effects for non-pine density (stems ha^{-1}) linear mixed effects model [Equation 4].

	b_0	b_1
PEF C2A	-3414.98	157.19
PEF C2B	-6680.26	307.48
T 39	-7696.89	354.28
Topsfield	-2998.04	138.00
Long Pond	7511.92	-345.77
T4 R12	3525.25	-162.26
T5 R12	7975.75	-367.11
T3 R12	4269.07	-196.50
Dead River	-2491.83	114.70

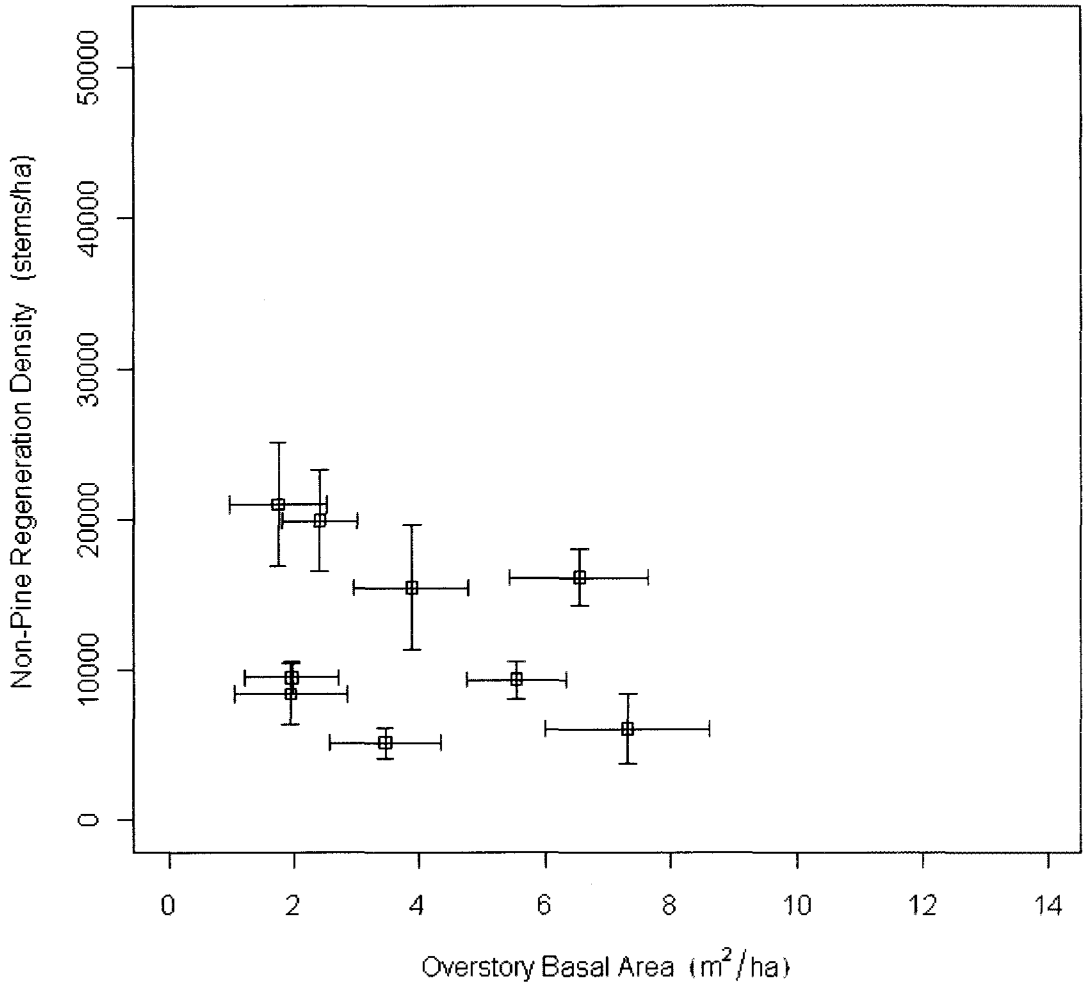

Figure 2.5. Scatterplot of non-pine regeneration density(stems ha^{-1}) vs basal area (m^2 ha^{-1}) of large isolated pine reserves. Grey circles represent plot observations, open squares represent site means with standard error bars.

Table 2.10. Mean annual height increment (cm) model [Equation 5], parameter estimates, and fit statistics. AIC-Akaike's Information Criteria; BIC-Bayesian Information Criteria; RMSE-Root mean squared error; R^2-Generalized coefficient of determination.

	Value	Std. Error	P value	AIC	BIC	LogLik	RMSE	R^2
β_0	24.46	3.032	0.0000	529.22	542.96	-258.61	6.55	0.41
β_1	-0.4811	0.2783	0.0886					

Table 2.11. Random effects for mean annual height increment (cm) linear mixed effects model [Equation 5].

	b_0	b_1
PEF C2A	-8.19	0.377
PEF C2B	-8.16	0.376
T 39	-3.40	0.156
Topsfield	4.33	-0.199
Long Pond	-2.64	0.122
T4 R12	-0.03	0.001
T5 R12	-3.09	0.142
T3 R12	13.08	-0.602
Dead River	8.10	-0.373

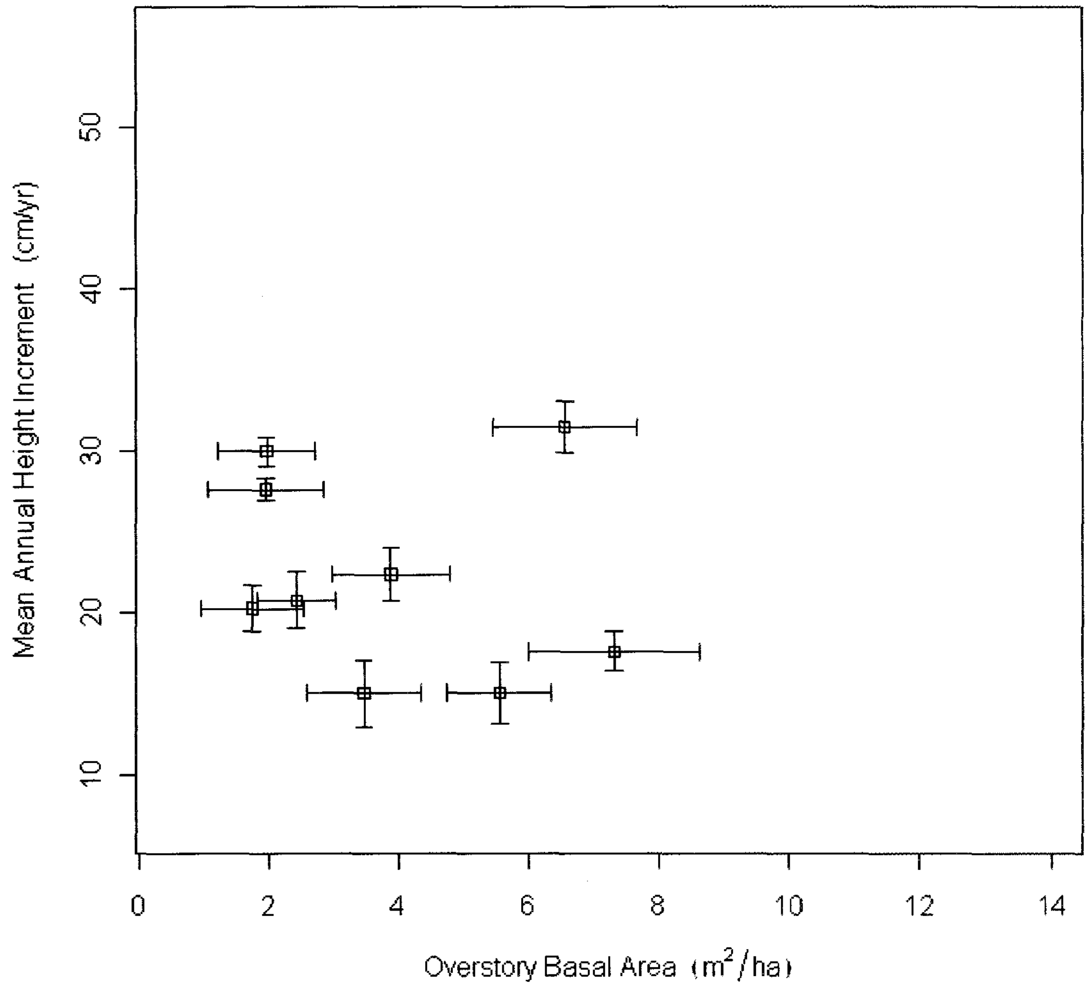

Figure 2.6. Scatterplot of mean annual height increment of eastern white pine regeneration (cm) vs basal area (stems ha^{-1}) of pine reserves. Grey circles represent plot observations, open squares represent site means with standard error bars.

DISCUSSION

Retention of reserve pines provides a seed source to ensure pine regeneration success. Our results indicated that the probability of pine regeneration success increased with basal area (m^2 ha^{-1}) of pine reserves. This coincides with the findings of Dovciak et al (2003), in which pine seed rain density was found to be positively correlated with overstory basal area. A possible explanation for this trend is that dominant or emergent trees provided a disproportionate amount of seed, as larger and older trees tend to allocate a greater amount of resources to reproduction (Weiner and Thomas 2001).

No significant relationship was found between basal area (m^2 ha^{-1}) of pine reserves and pine regeneration density (stems ha^{-1}), indicating that pine can persist with the more shade tolerant spruce and fir under the range of retained basal area (m^2 ha^{-1}) examined in this study. This result is supported by the findings of Zenner and Krueger (2006) in which pine regeneration was found to exhibit no reduction in growth under retention basal areas of up to 9 m^2 ha^{-1}, which is above the range examined in the current study.

Although mean annual height increment decreased with increasing reserve pine basal area (m^2 ha^{-1}), it is important to note the difference between statistical and operational significance. Although statistically significant, a reduction in height of 0.48 ± 0.28 cm for every additional square meter ha^{-1} of reserve pine basal area is hardly significant from a management standpoint. Previous research has shown that increased light above 50 percent of full sunlight resulted in no significant increase in height growth of eastern white pine (Logan 1966). Wetzel and Burgess (2001) also found that eastern white pine incurred no growth limitations down to 50 percent photosynthetically active radiation. Although light levels were not recorded in this study, casual observation suggests that light levels would not have been limiting in this two-aged silvicultural system.

It is important to recognize that this study was conducted retrospectively on nine forest stands with differing geographic locations and stand histories, with similar two-aged stand structures. Stand histories such as stand composition prior to regeneration harvests, as well as harvesting practices likely influenced current attributes of the regeneration stratum.

CONCLUSION

As forest managers become more aware of ecosystem processes, it becomes more apparent that silvicultural systems incorporating reserve trees, or "green tree retention", provide ecosystem services in the form of wildlife habitat and aesthetic benefit. This study found no discernable effect on regeneration densities (stems ha^{-1}) or height growth of increased white pine reserve basal area (m^2 ha^{-1}). These results suggest that a silvicultural system incorporating isolated reserve pines is viable from a management standpoint. When managing a stand in this way, it is also important to keep in mind the periodicity of good pine seed crops, and thus timing the cut to maximize successful pine regeneration.

CHAPTER 3

QUALITY ASSESSMENT OF POTENTIAL EASTERN WHITE PINE (*PINUS STROBUS* L.) CROP TREES AS INFLUENCED BY ISOLATED RESERVES AND PRECOMMERCIAL THINNING

ABSTRACT

Scattered immature eastern white pine trees were commonly left during the salvage harvesting of spruce-fir stands following the spruce budworm epidemic of the 1970s and 1980s. These trees are now growing as emergent reserves above a mixed conifer species regeneration stratum. This offered the opportunity to determine any effect the presence of large pine reserve trees may have on the incidence of white pine weevil attack on the eastern white pine in the regeneration stratum, as well as determine any differences in the quality of the developing eastern white pines in these two-aged stands and the quality of eastern white pine in precommercially thinned stands, relative to white pine weevil attack, blister rust infection, and natural branch shedding. Thirteen forest stands throughout the spruce-fir region of Maine were chosen for this study. Nine of these stands were two-aged stands that were regenerated prior to 1995, have no history of precommercial thinning, and contain a significant component of heavily released eastern white pine trees growing above a developing mixed species matrix. These nine stands were harvested between the years of 1984 and 1994, and had soils ranging from somewhat poorly drained to very poorly drained. Four forest stands throughout the

spruce-fir region of Maine that had been regenerated in the same time period as above, and also had a history of precommercial thinning that favored eastern white pine were also chosen for investigation in this study. One of these four stands contained a component of heavily released eastern white pine trees growing above the developing mixed species matrix. Soils ranged from poorly drained to very poorly-drained. Basal area ($m^2\ ha^{-1}$) of pine reserves was not correlated (p = 0.3721) with the presence versus absence of weevil injuries in the two-aged stand type. Likewise, pine reserve basal area ($m^2\ ha^{-1}$) was not correlated with number of weevil injuries ($p = 0.6950$) when investigating only those plots in which weevil injuries were present. The two-aged stands with large isolated reserves were found to have lower incidence of weevil injury ($p = 0.0055$), with smaller weevil caused stem offsets ($p = 0.0449$). Two-aged stands also had smaller diameter branches ($p = 0.0136$). Incidence of white pine blister rust indicated that caution should be taken in the precommercially thinned stand type. Overall, the two-aged stands tended to have better quality stems relative to the quality aspects we investigated.

INTRODUCTION

Typically, eastern white pine research has been focused on growing eastern white pine as a suitable crop tree, and the difficulties involved with this task. Following agricultural land abandonment, old-field monocultures of white pine seeded in. These eastern white pine monocultures risked repeated attacks by the white pine weevil (*Pissodes strobi* [Peck]). Weevil attack resulted in stem deformations, thus decreasing the value and yield of lumber (Peirson 1922). Volunteer stands of mixed hardwoods and white pine arose after these monocultures had been cut over, however, the difficulty of pine saplings being continually out-competed by the hardwood saplings lead to the requirement of financial outputs for precommercial treatments to ensure pine regeneration success (McKinnon et al. 1935).

Fajvan and Seymour (1993) have shown that eastern white pine can do well as scattered crop trees growing in stratified stands of mixed conifer species. In this type of stratified system a two-aged silvicultural system is developed, in which some scattered white pines are left behind during the harvesting of other tolerant conifers. These eastern white pines are released, and left to grow into large, high-value reserves. When grown under this two-aged silvicultural system, the more shade tolerant conifers such as spruce, fir, and hemlock act as trainers, encouraging natural branch shedding of the pine. The benefit is the reduction in pruning expenses. An additional benefit to growing stands in this manner is the minimizing of weevil damage, as white pine grown scattered within mixed species stands is less susceptible to weevil attack (Peirson, 1922).

Salvage harvesting of spruce-fir stands due to the spruce budworm epidemic of the 1970s and early 1980s took place from the mid-1970s. Unaffected immature eastern white pines were commonly left during this time, with the intention to harvest at a later date. Due to the release caused by the salvage harvesting, these pines are now growing as large isolated reserves, above a mixed species regeneration matrix. This offers the opportunity to study the effects of these pine reserves on the quality of pine regeneration relative to white pine weevil injury, as well as compare the quality of pine regeneration relative to white pine weevil attack, blister rust infection, and branch shedding ability in these two-aged stands to that of eastern white pine in precommercially thinned stands harvested during a similar time period. Precommercial treatments are often employed in white pine stands in an effort to increase stand value. However, it is not known if implementing precommercial treatments impacts the quality of the pines relative to white pine weevil attack, blister rust infection, and branch shedding.

Our objectives were to (1) determine any effect of varying levels of basal area (m^2 ha^{-1}) of large pine reserve trees may have on the mean number of weevil injuries in the eastern white pine regeneration of the two-aged stands, and (2) determine if any differences in quality exist between the two-aged stand type and the precommercially thinned stand type, relative to white pine weevil attack, blister rust infection, and branch shedding. Our null hypotheses were that large pine reserves have no effect on the frequency of white pine weevil injury of the regenerating understory pine, and that there were no differences in pine regeneration quality aspects between stand type.

METHODS

Study site and data collection

Nine forest stands throughout the spruce-fir region of Maine that were regenerated prior to 1995 were chosen for this study. These nine stands had no history of precommercial thinning, and contained a significant component of heavily released eastern white pine trees growing above a developing mixed species matrix. Harvesting of these sites took place between the years of 1984 and 1994. Soils ranged from somewhat poorly drained to very poorly drained (Briggs 1994) (Table 3.1). Mean stocking of pine across all sites was found to be 97.23 ± 2.72 percent stocked, with well stocked being defined as at least 50 pines ha^{-1}.

Table 3.1. Stand locations, age, and soil drainage class of two-aged stands (Briggs, 1994).

Site (Harvest Year)	Location	Soil Drainage Class
Dead River Twp. (1984)	N 45° 12', W 70° 16'	3 – Somewhat Poorly Drained
Long Pond Twp. (1989)	N 45° 36', W 70° 02'	4 – Poorly Drained
Penobscot Experimental Forest, Compartment 2 (1984)	N 44° 52', W 68° 39'	3 – Somewhat Poorly Drained
Topsfield Twp. (1992)	N 45° 28', W 67° 51'	4 – Poorly Drained
T3 R12 (1987)	N 45° 56', W 69° 15'	4 – Poorly Drained
T4 R12 (1991)	N 45° 58', W 69° 11'	3 – Somewhat Poorly Drained
T5 R12 (1994)	N 46° 06', W 69° 15'	5 – Very Poorly Drained
T39 MD (1980)	N 45° 01', W 68° 18'	--------------------------

Data was collected during late spring and summer of 2008. Twelve plot centers were established on a 40m x 40m grid at each of the nine study sites, with the exception of one site (PEF C2A) in which 24 plot centers were established. A fixed radius plot of 0.1 ha was established at each plot center, and all reserve trees were measured for species and dbh, as well as distance and direction to plot center. A nested 0.001 ha plot was also established at each plot center, and all trees < 30 cm dbh and > 1.3 meters tall were tallied by 2 cm diameter class, by species. A quality assessment was performed on each 0.001 ha plot. Up to three pine in each diameter class were measured for total height, and base of live crown. Age was approximated with an internode count. A quality assessment was performed on each 0.001 ha plot, using the same pine stems as were measured above. White pine weevil damage was assessed based on the protocol of Pubanz et al. (1999). Incidence of weevil injury was recorded by height of attack, and stem offset was measured from the pith of the original leader to the pith of the new leader. The criteria used to classify stem features as weevil damage include: stem deflection at a branch node, acute branch angles at a branch node, unusually large branches or branch clusters at a branch node, and stem offset opposite branch abnormalities. To confirm weevil damage, more than one criterion must have been met. All evidence of blister rust was recorded, and all dead white pines were inspected for blister rust caused mortality. Branch diameters were measured with calipers at the highest whorl ≤ 2 m, as an index of branch shedding and future stem quality. If pine was not present in 0.001 ha plot, a 0.02 ha plot was established to determine if the area was stocked with pine.

Four forest stands throughout the spruce-fir region of Maine that had been regenerated in the same time period as above, and also had a history of precommercial thinning that favored eastern white pine were also chosen for investigation in this study. One of these stands contained a component of heavily released eastern white pine trees growing above the developing mixed species matrix. Soils ranged from poorly drained to very poorly drained (Briggs 1994) (Table 3.2).

Table 3.2. Stand locations and soil drainage class of precommercially thinned stands (Briggs, 1994).

Site	Location	Soil Drainage Class
T5 R11 N	N 46° 06’, W 69° 12’	5 – Very Poorly Drained
T5 R11 S	N 46° 04’, W 69° 12’	4 – Poorly Drained
Penobscot Experimental Forest, Compartment 23A	N 44° 52’, W 68° 38’	4 – Poorly Drained
Summit Twp.	N 45° 06’, W 68° 29’	5 – Very Poorly Drained

Data for these precommercially thinned stands were also collected during late spring and summer of 2008. Twelve plot centers were established on a 40m x 40m grid at each of the four stands, with the exception of one site (Summit) in which only nine plot centers were established. A fixed radius plot of 0.02ha was established at each plot center and all trees < 30 cm dbh and > 1.3 meters tall were tallied by 2cm diameter class, by species. Assessment and measurement of all pine stems was carried out as outlined above in the 0.001 ha plot protocol. If heavily released reserve trees were present, protocol for 0.1 ha plots was employed, as outlined above.

Analysis

Data were analyzed using version 2.8 of the R statistical software package (R Development Core Team 2008). Data were summarized at the plot level, using conventional mensurational variables including trees per acre, basal area, relative density, and species composition. Height and diameter distributions were also determined. The eastern white pine quality data was also summarized at the plot level, including proportion of trees experiencing attack by white pine weevil, attacks per tree, maximum offset caused by white pine weevil attack per tree, and index of offset per tree (calculated as the measured offset divided by the diameter class of the stem). Largest branch diameter was also summarized, as well as the proportion of trees showing evidence of blister rust infection.

A two stage approach was employed to determine the effect of large pine reserve basal area (m^2 ha^{-1}) on the mean number of weevil injuries per tree in the regeneration stratum of the two-aged stands. This two stage approach was employed to analyze two separate processes: the effect of reserve pine basal area (m^2 ha^{-1}) on the presence versus absence of weevil injury, and the effect of reserve pine basal area (m^2 ha^{-1}) on abundance of weevil injuries on only those plots where weevil injury was present. This approach enabled the analysis of a data set in which weevil injury was not present in 64 percent of the plots, leading to a large number of zero data points.

First, a mixed effects logistic regression model ($\alpha = 0.05$) was employed to determine the effect of pine reserve basal area (m^2 ha^{-1}) on the presence versus absence of weevil injury. The model takes the form:

[1] $$\Pr(weev_i = 1) = logit^{-1}\ (\alpha_{site[i]}\beta BAOW)$$

where *weev* is number of weevil injuries as a binary response in which 0 indicates absence and 1 indicates presence of weevil injury in the *i*th plot, α is the intercept with a random effect for site, and *BAOW* is the basal area (m^2 ha^{-1}) of pine reserves, associated with the parameter estimate β. Assumptions of a discreet outcome and no outliers in the independent variable were met.

Second, a linear mixed effects model ($\alpha = 0.05$) was employed to determine the effect of the reserve basal area (m^2 ha^{-1}) on the mean number of weevil injuries in the pine regeneration of two-aged stands, conditional on weevil injury being present in the pine regeneration. For this part of the analysis, a truncated data set was used, in which all zero data points were eliminated. The model takes the form:

[2] $$mw = \beta_0 + b_0 + (\beta_1 + b_1)BAOW$$

where mw is the mean number weevil injuries, $BAOW$ is the basal area (m^2 ha^{-1}) of pine reserves, b_0 is a random effect for site associated with the intercept β_0, and b_1 is a random effects for site associated β_1. Assumptions of homoskedasticity of residuals and normally distributed random effects were met.

A chi-square test ($\alpha = 0.05$) was performed in an effort to determine if the number of weevil attacks observed on eastern white pine stems was independent of stand type. Again, the stand types were two-aged mixed species stands containing a significant component of heavily released eastern white pine trees growing above a developing mixed species matrix, and mixed species stands with a history of precommercial thinning that favored eastern white pine.

Non-parametric Kruskal Wallis tests ($\alpha = 0.05$) were performed to determine significant differences between the two stand types in regard to the following variables: mean proportion of eastern white pine trees in the regeneration stratum experiencing weevil attack, maximum weevil caused offset per tree, index of weevil caused offset per tree, largest measured branch diameter (≤ 2 meters high).

RESULTS

The nine two-aged forest stands investigated in this study all had a component of large isolated eastern white pine reserve trees, with a mixed species regeneration stratum composed mainly of spruce, fir, and eastern white pine, forming a two-aged stand structure. Mean basal area of eastern white pine reserves ranged from 1.74 ± 0.79 m^2 ha^{-1} to 7.31 ± 1.31 m^2 ha^{-1} across all sites (Table 3.3). Reserve tree density ranged from 9.2 stems ha^{-1} at the Dead River site (± 5.9) and the Topsfield site (± 4.6) to 41.7 ± 7.3 stems ha^{-1} (Table 3.4). QMD of pine reserves was found to range from 38.97 cm to 57.46 cm (Figure 3.1).

Mean basal area of the regeneration stratum ranged from 12.44 ± 2.34 m^2 ha^{-1} to 33.17 ± 4.69 m^2 ha^{-1} across all sites. Eastern white pine accounted for 10.80 ± 2.83 to 58.41 ± 11.55 % of the regeneration matrix, with basal area ranging from 1.42 ± 0.78 m^2 ha^{-1} to 15.36 ± 4.42 m^2 ha^{-1}. Non-pine species basal area ranged from 10.28 ± 2.92 m^2 ha^{-1} to 24.60 ± 4.48 m^2 ha^{-1} (Table 3.3). Mean density of the regeneration stratum ranged from 9083.33 ± 2122.96 stems ha^{-1} to 22833.33 ± 4314.94 stems ha^{-1}. Eastern white pine accounted for 666.67 ± 224.73 stems ha^{-1} to 5916.67 ± 1872.68 stems ha^{-1} (Table 3.4). Mean height of pine regeneration across all sites was found to be 4.40 ± 0.13 m, ranging from 3.07 ±0.27 m to 7.92 ± 1.09 m (Figure 3.2). Quadratic mean diameter (QMD) of eastern white pine regeneration was found to range from 2.00 cm to 3.21 cm across all sites, and QMD of non-pine species regeneration was found to range from 2.62 cm to 3.31 cm (Figure 3.3).

Table 3.3. Mean basal area ($m^2\ ha^{-1}$) of regeneration stratum and pine overwood in two-aged stands by site.

Regeneration Stratum

Site	**PEF C2A**	**PEF C2B**	**T 39**	**Topsfield**	**Long Pond**	**T4 R12**	**T5 R12**	**T3 R12**	**Dead River**
Pine Only									
Mean	3.21	4.85	15.36	1.42	3.46	2.99	1.72	7.29	8.57
Std. Error	0.82	1.62	4.42	0.78	1.76	1.80	0.56	2.61	3.41
Minimum	0	0	0.08	0	0	0	0	0	0
Maximum	13.29	17.46	47.03	7.71	18.32	22.26	4.72	33.11	32.32
Non-Pine									
Mean	16.49	18.70	10.28	13.98	11.69	12.33	10.72	22.72	24.60
Std. Error	2.11	6.23	2.92	4.58	2.62	3.17	1.93	3.98	4.48
Minimum	3.38	0	0	0	0.31	0.08	3.30	0.63	4.56
Maximum	47.27	65.35	28.08	48.21	31.54	37.20	25.17	52.93	50.81
All Species									
Mean	19.70	23.55	25.64	15.40	15.15	15.32	12.44	30.01	33.17
Std. Error	1.95	5.56	4.10	4.51	3.89	3.31	2.34	5.07	4.69
Minimum	6.69	4.56	7.31	0.08	0.31	0.16	3.38	7.31	9.59
Maximum	47.27	65.36	53.87	48.21	49.87	37.20	29.73	62.52	73.54

Pine Overwood

Site	**PEF C2A**	**PEF C2B**	**T 39**	**Topsfield**	**Long Pond**	**T4 R12**	**T5 R12**	**T3 R12**	**Dead River**
Mean	5.54	3.46	7.31	1.94	2.41	3.88	1.74	6.54	1.97
Std. Error	0.80	0.88	1.31	0.90	0.60	0.91	0.79	1.10	0.75
Minimum	0	0	0	0	0	0	0	1.19	0
Maximum	13.14	10.31	13.96	10.80	6.79	10.11	9.78	13.47	8.64

Table 3.4. Mean density (stems ha^{-1}) of two-aged stands by site.

Site	PEF C2A	PEF C2B	T 39	Topsfield	Long Pond	T4 R12	T5 R12	T3 R12	Dead River
Pine Only									
Mean	5125	5666.7	5916.7	666.7	2000	1333.3	1833.3	2083.3	916.7
Std. Error	1275.9	1639.2	1872.7	224.7	758.8	376.1	489.8	398.1	259.9
Minimum	0	0	1000	0	0	0	0	0	0
Maximum	24000	19000	23000	2000	9000	4000	5000	5000	3000
All Species									
Mean	14500	10833	12000	9083	21916	16833	22833	18250	10416
Std. Error	1645.15	1812.55	2798.8	2122.9	3826.7	4098.8	4314.9	1962.2	1151.1
Minimum	4000	4000	1000	1000	4000	0	5000	5000	3000
Maximum	36000	25000	31000	21000	50000	5000	56000	29000	16000

Pine Overwood

Site	PEF C2A	PEF C2B	T 39	Topsfield	Long Pond	T4 R12	T5 R12	T3 R12	Dead River
Mean	23.3	13.33	30.0	9.2	20.0	32.5	15.0	41.7	9.2
Std. Error	2.8	3.10	5.3	4.6	3.7	7.4	3.0	7.3	5.9
Minimum	0	0	0	0	0	0	0	10	0
Maximum	50	40	70	50	50	70	40	80	60

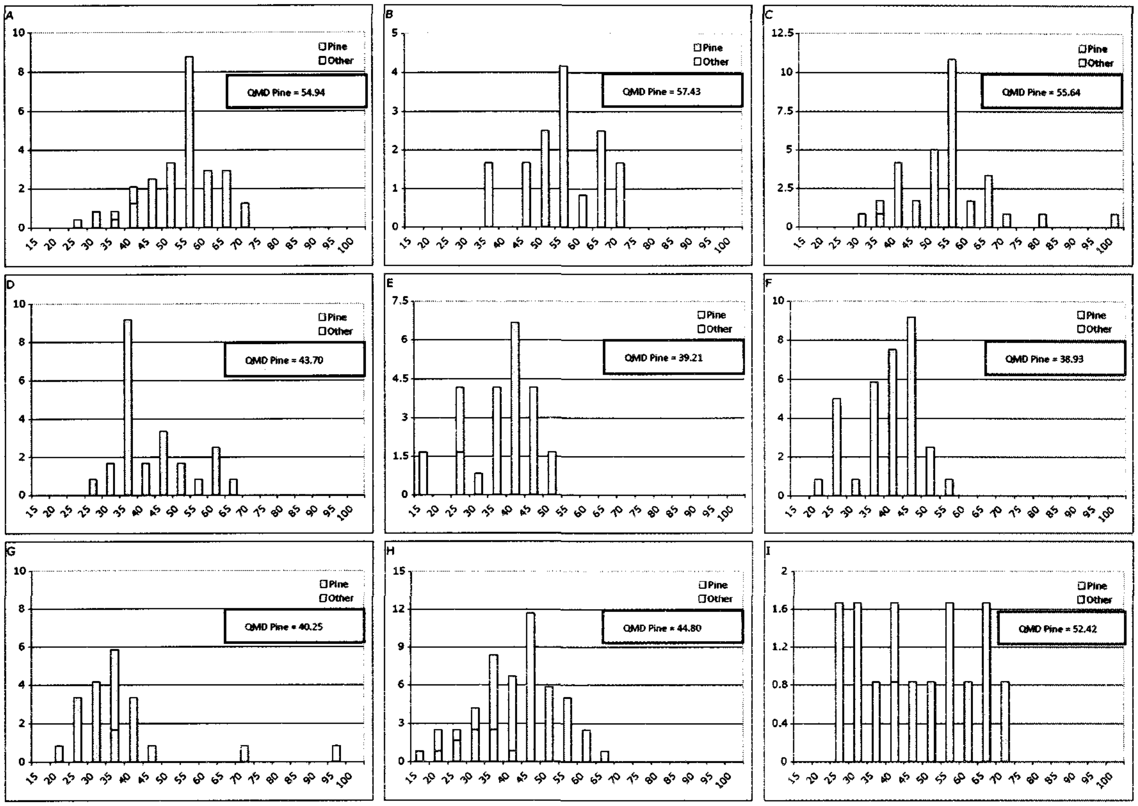

Figure 3.1. Diameter distribution of overwood by site in five cm diameter classes, and quadratic mean diameter (QMD) of pine overwood by site; A= PEF C2A, B= PEF C2B, C= T 39, D= Topsfield, E= Long Pond, F= T4 R12, G= T5 R12, H= T3 R12, I= Dead River.

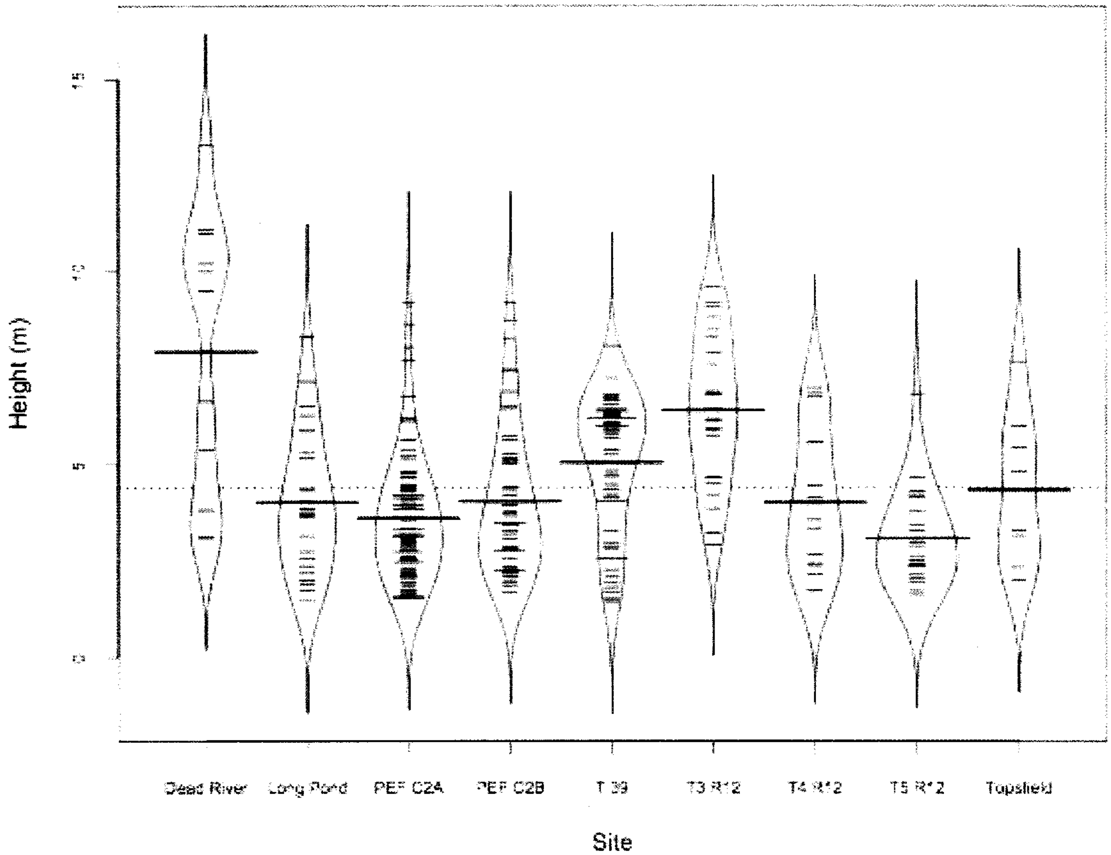

Figure 3.2. Plot of height distribution of eastern white pine regeneration of two-aged stands by site.

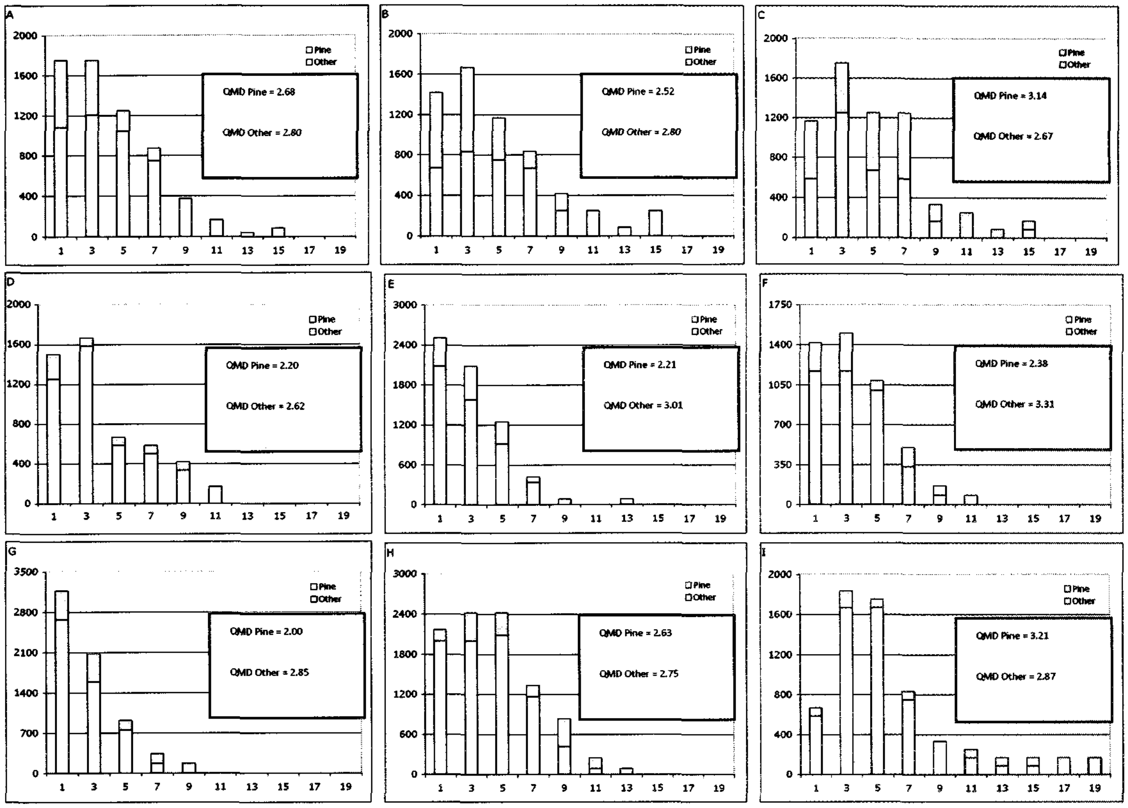

Figure 3.3. Diameter distribution in two centimeter diameter classes, and quadratic mean diameter (QMD) of regeneration stratum by site; A= PEF C2A, B= PEF C2B, C= T 39, D= Topsfield, E= Long Pond, F= T4 R12, G= T5 R12, H= T3 R12, I= Dead River.

Mean basal area of the precommercially thinned stands ranged from 17.44 ± 0.63 m^2 ha^{-1} to 33.82 ± 0.87 m^2 ha^{-1} across all sites. Mean basal area of eastern white pine only ranged from 1.24 ± 0.59 m^2 ha^{-1} to 13.86 ± 1.75 m^2 ha^{-1}. Non-pine species ranged from 12.89 ± 0.96 m^2 ha^{-1} to 32.58 ± 0.98 m^2 ha^{-1}. Mean basal area of eastern white pine overwood on the Summit site was 0.17 ± 0.01 m^2 ha^{-1} (Table 3.5). Mean density ranged from 2916.67 ± 243.50 stems per ha to 6250 ± 567.89 stems per ha across all sites. Mean density of eastern white pine only ranged from 41.67 ± 13.53 to 525 ± 72.95 (Table 3.6). Mean height across all precommercially thinned sites was found to be 9.49 ± 0.55 m, ranging from 8.10 ± 0.20 m to 10.45 ± 0.15 m (Figure 3.4). Quadratic mean diameter (QMD) of eastern white pine stems was found to range from 15.78 cm to 20.46 cm across all sites, while QMD of non-pine stems was found to be 7.81 cm to 12.39 cm across all sites. QMD of pine overwood on the Summit site was found to be 56.44 cm (Figure 3.5).

Table 3.5. Mean basal area ($m^2\ ha^{-1}$) of precommercially thinned stands by site.

Site	T5 R11 N	T5 R11 S	PEF C23A	Summit
Pine Only				
Mean	3.80	13.86	1.24	1.51
Std. Error	0.54	1.75	0.59	0.71
Minimum	0.66	3.50	0.00	0.00
Maximum	7.57	24.92	5.03	5.95
Non-Pine				
Mean	13.64	12.89	32.58	24.49
Std. Error	0.44	0.96	0.98	1.01
Minimum	11.95	7.28	29.08	21.33
Maximum	16.44	19.65	38.37	29.22
All Species				
Mean	17.44	26.75	33.82	26.00
Std. Error	0.63	1.51	0.87	0.85
Minimum	14.89	17.99	29.24	21.98
Maximum	21.71	34.08	38.37	29.27
Pine Overwood				
Mean	---	---	---	0.17
Std. Error	---	---	---	0.01
Minimum	---	---	---	
Maximum	---	---	---	

Table 3.6. Mean density (stems ha^{-1}) of precommercially thinned stands by site.

Site	T5 R11 N	T5 R11 S	PEF C23A	Summit
Pine Only				
Mean	200	525	41.67	66.67
Std. Error	27.52	72.95	13.53	20.41
Minimum	50	150	0	0
Maximum	350	950	100	150
All Species				
Mean	3933.33	3629.17	6250	2911.11
Std. Error	219.70	472.28	567.89	243.50
Minimum	2900	2000	3800	1700
Maximum	5550	7600	9550	3900

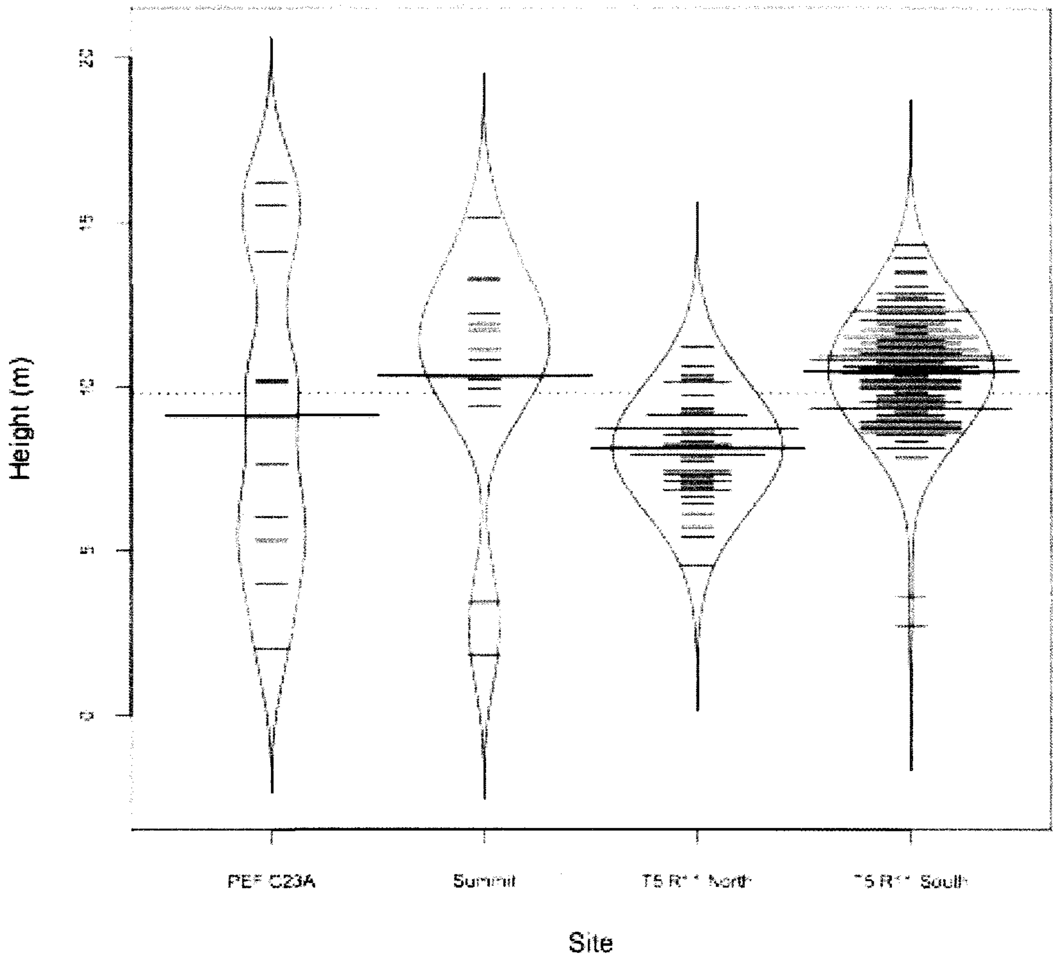

Figure 3.4. Plot of height distribution of eastern white pine of precommercially thinned stands by site.

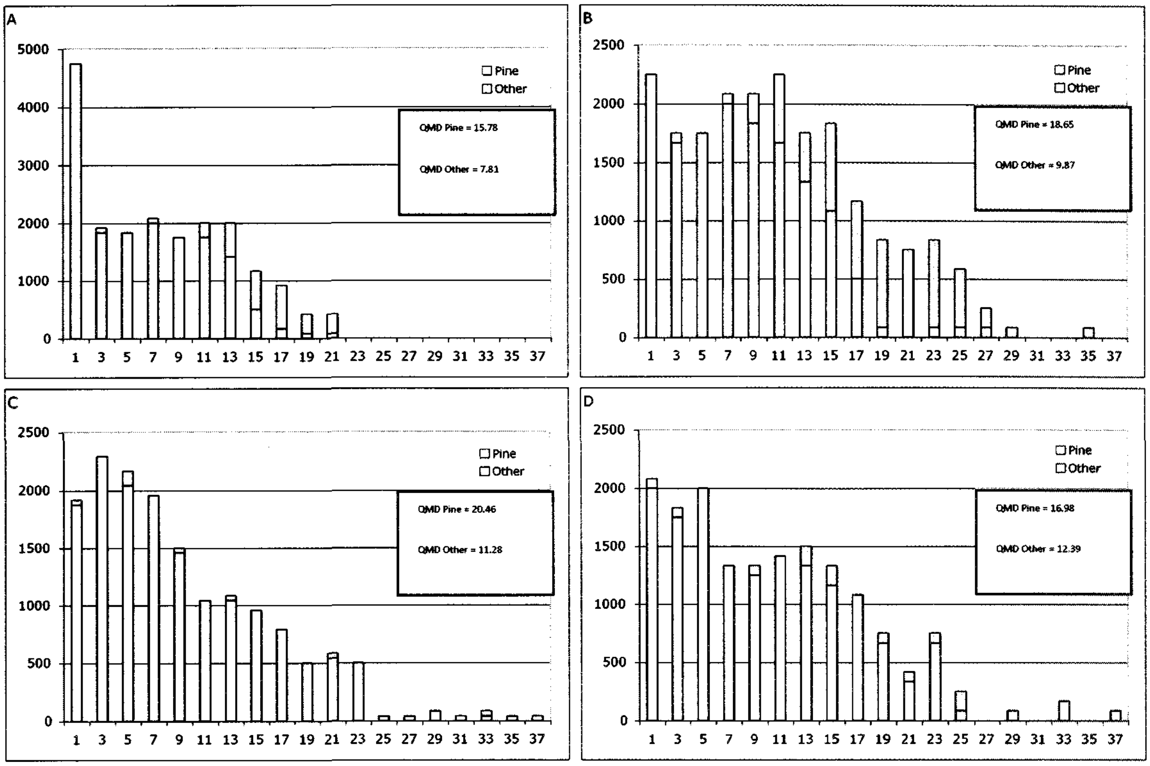

Figure 3.5. Diameter distribution in two centimeter diameter classes, and quadratic mean diameter (QMD) of precommercially thinned stands by site; A= T5 R11 N, B= T5 R11 S, C= PEF C23A, D= Summit.

Mean proportion of eastern white pine trees in the regeneration stratum experiencing weevil attack ranged from 0 ± 0 to 0.51 ± 0.11 across all two-aged stands. The mean number of attacks per tree ranged from 0 ± 0 to 2.61 ± 0.26. The maximum weevil caused offset per tree ranged from 0 ± 0 cm to 8.5 ± 0 cm, and the index of weevil caused offset per tree ranged from 0 ± 0 to 1.85 ± 1.06 (Table 3.7). The largest measured branch diameter (≤ 2 meters high) of eastern white pine stems in the regeneration stratum ranged from 0.85 ± 0.12 cm to 1.38 ± 0.19 cm across all two-aged stands (Table 3.8), and the proportion of eastern white pine trees with evidence of blister rust ranged from 0 to 0.09, with several stands displaying no evidence of blister rust infection on the investigated stems (Table 3.9).

Mean proportion of eastern white pine trees experiencing weevil attack ranged from 0.67 ± 0.17 to 0.89 ± 0.04 across all precommercially thinned stands. The mean number of attacks per tree ranged from 1.73 ± 0.19 to 3.17 ± 0.65. The maximum weevil caused offset per tree ranged from 5.13 ± 0.36 cm to 13.51 ± 4.83 cm, and the index of weevil caused offset per tree ranged from 0.40 ± 0.01 to 0.57 ± 0.10 (Table 3.10). The largest measured branch diameter (≤ 2 meters high) of eastern white pine stems ranged from 1.25 ± 0.19 cm to 2.58 ± 0.22 cm across all precommercially thinned stands (Table 3.11), and the proportion of eastern white pine trees with evidence of blister rust ranged from 0 ± 0 to 0.32 ± 0.10 (Table 3.12).

Table 3.7. Quality of eastern white pine regeneration of two-aged stands in relation to white pine weevil injury.

Site	PEF C2A	PEF C2B	T 39	Topsfield	Long Pond	T4 R12	T5 R12	T3 R12	Dead River
Proportion of Trees with Weevil Injury									
Mean	0.44	0.12	0.51	0.17	0.22	0.21	0	0.47	0.25
Std. Error	0.09	0.05	0.11	0.17	0.11	0.12	0	0.13	0.16
Minimum	0	0	0	0	0	0	0	0	0
Maximum	1	0.43	1	1	1	1	0	1	1
Attacks per Tree									
Mean	1.11	1.75	2.61	1	1	1.5	---	1.71	1
Std. Error	0.06	0.25	0.26	---	0	0.29	---	0.24	0
Minimum	1	1	1	1	1	1	---	1	1
Maximum	2	3	6	1	1	2	---	3	1
Maximum Offset per Tree (cm)									
Mean	2.66	3.81	6.48	8.5	3.73	1.77	---	3.67	2.9
Std. Error	0.83	1.13	1.76	0	1.00	0.91	---	0.69	0.1
Minimum	0.5	1	1.5	8.5	2.4	0	---	1.58	2.8
Maximum	13	6.17	17.6	8.5	6.7	3	---	6.6	3
Index of Offset per Tree									
Mean	1.01	0.58	1.85	8.5	0.78	0.21	---	0.55	0.78
Std. Error	0.19	0.11	1.06	0	0.27	0.11	---	0.13	0.22
Minimum	0.5	0.33	0.21	8.5	0.48	0	---	0.19	0.56
Maximum	2.84	0.81	10.12	8.5	1.6	0.33	---	1.03	1

Table 3.8. Quality of eastern white pine regeneration of two-aged stands in relation to branch shedding ability.

Site	PEF C2A	PEF C2B	T 39	Topsfield	Long Pond	T4 R12	T5 R12	T3 R12	Dead River
Largest Branch Diameter (cm)									
Mean	1.07	1.22	1.27	0.91	1.21	1.10	0.85	0.90	1.38
Std. Error	0.09	0.18	0.26	0.16	0.12	0.18	0.12	0.14	0.19
Minimum	0.5	0.65	0.2	0.6	0.7	0.4	0.45	0.4	0.5
Maximum	1.9	2.1	3.3	1.7	1.63	2.1	1.5	1.5	2.4

Table 3.9. Quality of eastern white pine regeneration of two-aged stands in relation to blister rust infection.

Site	**PEF C2A**	**PEF C2B**	**T 39**	**Topsfield**	**Long Pond**	**T4 R12**	**T5 R12**	**T3 R12**	**Dead River**
Proportion of Trees with Evidence of Blister Rust									
Mean	0.09	0	0.06	0	0	0.04	0	0.05	0.04
Std. Error	0.06	0	0.04	0	0	0.04	0	0.05	0.04
Minimum	0	0	0	0	0	0	0	0	0
Maximum	1	0	0.50	0	0	0.33	0	0.50	0.33

Table 3.10. Quality of eastern white pine regeneration of precommercially thinned stands in relation to white pine weevil injury.

Site	T5 R11 N	T5 R11 S	PEF C23A	Summit
Proportion of Trees Experiencing Weevil Injury				
Mean	0.89	0.77	0.67	0.86
Std. Error	0.04	0.09	0.17	0.14
Minimum	0.71	0.16	0	0
Maximum	1	1	1	1
Attacks per Tree				
Mean	2.63	2.27	3.17	1.73
Std. Error	0.22	0.12	0.65	0.19
Minimum	1	1	1	1
Maximum	6	5	5	3
Maximum Offset per Tree (cm)				
Mean	5.13	6.56	13.51	5.78
Std. Error	0.36	0.54	4.83	0.89
Minimum	3	4.8	2.5	3.83
Maximum	7.5	11	28	9.5
Index of Offset per Tree				
Mean	0.47	0.40	0.57	0.50
Std. Error	0.42	0.01	0.10	0.07
Minimum	0.24	0.33	0.19	0.25
Maximum	0.71	0.49	0.72	0.65

Table 3.11. Quality of eastern white pine regeneration of precommercially thinned stands in relation to branch shedding ability.

Site	T5 R11 N	T5 R11 S	PEF C23A	Summit
Largest Branch Diameter (cm)				
Mean	2.58	2.08	2.23	1.25
Std. Error	0.22	0.07	0.57	0.19
Minimum	1.8	1.74	0.9	0.45
Maximum	4.7	2.43	4.65	1.87

Table 3.12. Quality of eastern white pine regeneration of precommercially thinned stands in relation to blister rust infection.

Site	T5 R11 N	T5 R11 S	PEF C23A	Summit
Proportion of Trees with Evidence of Blister Rust				
Mean	0.32	0.22	0	0
Std. Error	0.10	0.04	0	0
Minimum	0	0	0	0
Maximum	1	0.50	0	0

Basal area (m^2 ha^{-1}) of pine reserves was not correlated with weevil injury in either the presence versus absence model ($p = 0.3721$) or the abundance model ($p = 6950$) (Table 3.13). The random effects of the presence versus absence model differed greatly between sites, suggesting that other factors influenced the presence or absence of weevil injuries at different sites (Table 3.14). Similarly, the lack of significance in the abundance model combined with larger random effects associated with the intercept, indicate that differences in site influence abundance of weevil attacks more than basal area (m^2 ha^{-1}) of pine reserves (Tables 3.15, 3.16, Figure 3.6).

Table 3.13. Presence/absence of weevil injury logistic model [Equation 1], parameter estimates and fit statistics. AIC-Akaike's Information Criteria; BIC-Bayesian Information Criteria; $\widehat{OR}$-Odds Ratio.

	Value	**Std. Error**	**P value**	**AIC**	**BIC**	**LogLik**	$\widehat{OR}$
α	-0.788	0.385	0.0434	550.10	564.04	-270.05	----
β	0.191	0.213	0.3721				

Table 3.14. Random effects for presence/absence logistic regression [Equation 1].

	α_{site}
PEF C2A	0.901
PEF C2B	0.088
T 39	1.245
Topsfield	-0.839
Long Pond	0.127
T4 R12	-0.535
T5 R12	-1.269
T3 R12	0.752
Dead River	-0.470

Table 3.15. Mean number weevil injuries model [Equation 2], parameter estimates, and fit statistics. AIC-Akaike's Information Criteria; BIC-Bayesian Information Criteria; RMSE-Root mean squared error; R^2-Generalized coefficient of determination.

	Value	**Std. Error**	**P value**	**AIC**	**BIC**	**LogLik**	**RMSE**	**R^2**
β_0	0.870	0.220	0.0004	120.29	130.57	-54.14	0.70	0.19
β_1	0.017	0.044	0.6950					

Table 3.16. Random effects mean number weevil injuries linear mixed effects model [Equation 2].

	b_0	b_1
PEF C2A	-0.163	-0.032
PEF C2B	-0.117	-0.023
T 39	0.275	0.054
Topsfield	0.011	0.002
Long Pond	-0.139	-0.027
T4 R12	-0.058	-0.011
T3 R12	0.175	0.034
Dead River	0.015	0.003

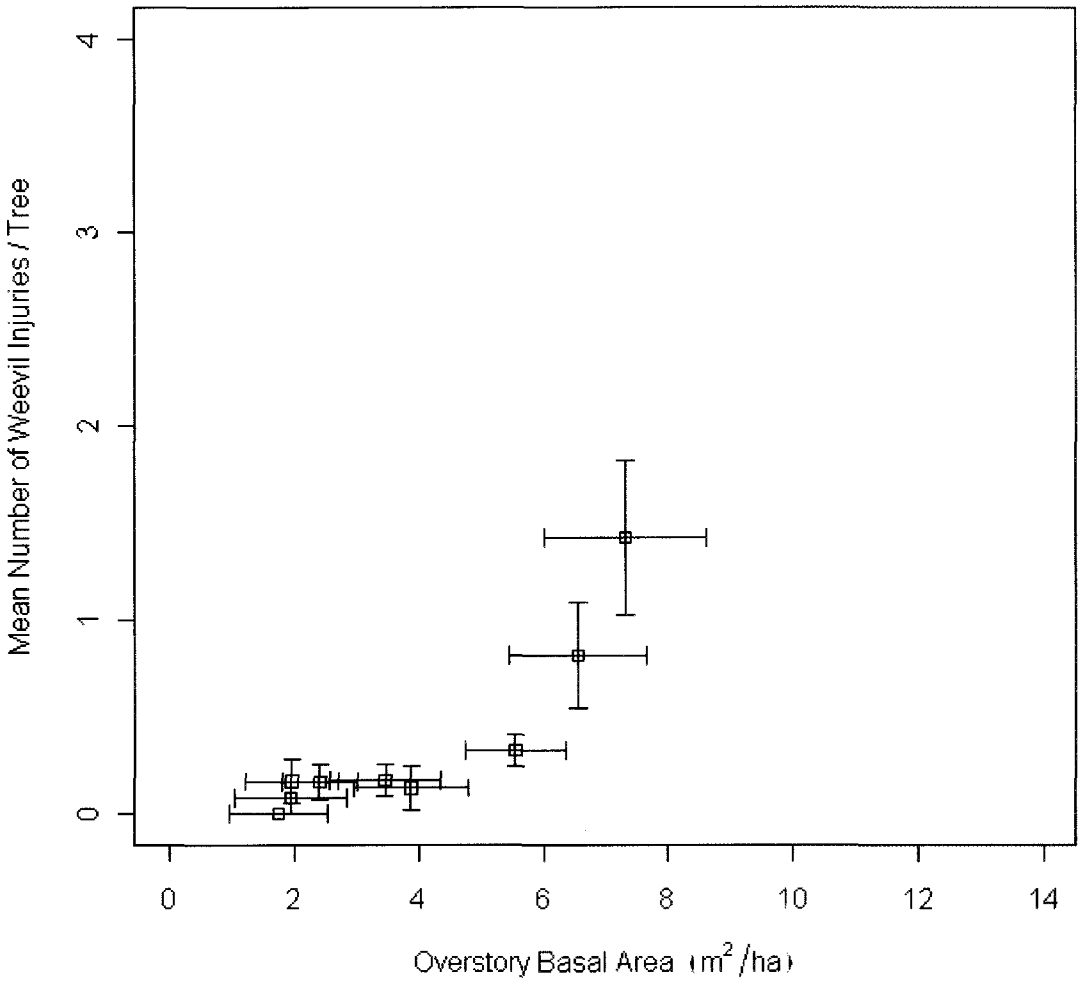

Figure 3.6. Scatterplot of mean number of weevil injuries vs basal area (m^2 ha^{-1}) of pine reserves. Grey circles represent plot observations, open squares represent site means with standard error bars.

Results of the chi-square test for independence indicated that the number of weevil attacks observed on eastern white pine stems was dependent on stand type ($p < 0.0001$), with those stands having a history of precommercial thinning experiencing almost double the incidence of white pine weevil attack (Table 3.17). The results of the non-parametric Kruskal Wallis tests indicated significant differences between stand type with regard to every variable tested. The proportion of trees with weevil injury was greater ($p < 0.0001$) in the precommercially thinned stands than in the two-aged stands. Precommercially thinned stands had larger maximum weevil caused offset per tree than that of two-aged stands ($p < 0.0001$). The index of weevil caused offset was greater ($p = 0.0007$) in the two-aged stands than in the precommercially thinned stands. Largest branch diameter was found to be greater in precommercially thinned stands than in two-aged stands ($p < 0.0001$) (Table 3.18).

Table 3.17. Results of chi-square test for independence showing number of weevil attacks is dependent upon stand type.

Statistic	DF	Value	Pr(>|z|)
Chi-square	5	116.7958	<0.0001
Stand Type	**Mean**	**SE**	
Two-aged	1.30	0.24	
Precommercially thinned	2.45	0.30	

Table 3.18. Results of Kruskal Wallis tests showing effect of stand type on eastern white pine quality variables.

Variable	**χ^2 Statistic**	**DF**	***P* value**	**TA Mean**	**TA SE**	**PCT Mean**	**PCT SE**
PTI	7.71	1	0.0055	0.26	0.06	0.80	0.05
MOT	4.02	1	0.0449	3.72	0.83	7.75	1.94
IOT	1.93	1	0.1649	1.58	0.88	0.48	0.04
LBD	6.09	1	0.0136	1.10	0.06	2.04	0.28

PTI= Proportion of trees with weevil injury, MOT= Maximum offset per tree, IOT= Index of offset per tree, LBD= Largest branch diameter, TA= two-aged stand type, PCT= precommercially thinned stand type

DISCUSSION

Our results indicated that growing eastern white pine in two-aged stands resulted in smaller branch diameters, therefore limiting the need to prune. Eastern white pine grown in this manner also had smaller branch diameters than the precommercially thinned counterparts. This finding is important, as the financial value of eastern white pine lies in the recovery of high grade, defect-free lumber. Grading of eastern white pine lumber is based on the maximum allowable defects of the best face. These defects include the frequency and size of knots, with the highest grade of D select and better allowing for one knot up to ½ inch in diameter, per surface foot (NeLMA 1952). Based on the results of this study, the two-aged stands will yield more D select trees. Currently, lumber that is D select and better is worth approximately 2.4 times the value of premium grade lumber, which is the next highest grade (Random Lengths 2008). As log grade increases, so does value (Hibbs and Bentley 1987), placing the greatest importance on the ability to grow clear, knot-free lumber.

It is important to note that eastern white pine is a poor natural branch shedder. Foster (1957) found that natural branch shedding of the butt log is rarely achieved within the lifespan of an eastern white pine, with dead branches persisting on the bole from 25 to 73 years. With an average of 60 limbs found in a given butt log, loose black knots become an obstacle to recovering valuable lumber (Foster 1957, Wendel and Smith 1990).

Our results indicate that growing eastern white pine in two-aged stands with large isolated pine reserves may also negate the need for white pine weevil control methods such as pruning and insecticide use. It is likely that the large isolated reserve pine create enough shade to limit weevil activity, as the two-aged stands had significantly lower incidence of weevil injury compared to the precommercially thinned counterparts. Trees most susceptible to weevil attack are those with leaders that exhibit thick phloem and are growing in sunlight (Dirks 1964, Droska et al. 2003, Wilkinson 1982). Also, the higher densities found in the regenerating matrix of two-aged stands leads to pine stems that are maintaining smaller diameter leaders, which are not preferred by the white pine weevil. The higher densities found in the two-aged stands also likely contribute to the significantly smaller stem offsets found in these stands, by forcing a more rapid upturn of the new leader on weevil-damaged trees.

In the precommercially thinned white pine stands and other situations with little shade, control of the white pine weevil is centered on pruning damaged trees, as well as insecticide treatments. Persisting dead terminal shoots act as a point of entry for red-rot (Ostrander and Foster 1957). Therefore, pruning of affected leaders is essential. In sapling stands, it is wise to prune before adults emerge in the spring, as a method to reduce the population. Pruning of lateral branches can help to maintain a straight bole (Hamid et al. 2005). Insecticide use can be effective against adult weevils. Dixon and Houseweart (1982) found that the population trends of the white pine weevil are strongly determined by survival of overwintering adults, with the highest numbers of adult weevils found on host trees in the spring (Dixon and Houseweart 1983). This suggests that suppression efforts such as insecticide use should be executed in the spring, as a means of limiting the adult weevil population, thus preventing attack. Diflubenzuron (Dimilin) is the insecticide currently registered for white pine weevil control in Maine (MDOC 2003). It acts as an insect growth regulator by interfering with the development of chitin, thereby interfering with the development of the insect shell. To be effective diflubenzuron must be applied to leaders prior to buds opening (MDOC 2003).

Our results indicate that white pine blister rust had little impact on the quality of both the two-aged and precommercially thinned stand types, with the exception of two of the precommercially thinned stands. This may be attributed to the lack of *Ribes* present, as we encountered this alternate host species only four times across the time span of data collection. Ostrofsky et al (1988) found that the *Ribes* eradication program had significantly reduced incidence of white pine blister rust throughout the state of Maine. However, those areas that were treated during the *Ribes* eradication program represent only a small portion of Maine, with the sites investigated in this study falling outside of that range. Indeed, two of the precommercially thinned stands in this study exhibited blister rust incidence up to three times as high as those findings of Ostrofsky et al (1988), leading to concern regarding the potentially increased susceptibility of pine in precommercially thinned stands to blister rust infection.

The two-aged with reserves stand type exhibited eastern white pine stems of higher quality than those of the precommercially thinned stands, relative to all quality variables investigated in this study, and thus leads to the belief that white pine in these stands can exhibit a higher value than the precommercially thinned counterparts. These benefits are amplified, when considering that the two-aged with reserves stand type also leaves the forest manager with the option to thin out poorer quality pine stems, while still maintaining enough pine stems. This is contrary to the precommercially thinned stands, in which every pine stem is already deemed a crop tree, thus limiting the ability to retain high quality pine within these stands during pest or pathogen outbreaks.

CONCLUSION

Neither weevil injury, branch shedding ability, or blister rust incidence were found to be of major concern in two-aged stands. Management of forest stands throughout the spruce-fir region of Maine as two-aged stands with a substantial component of large isolated reserve pines growing above the regenerating mixed species conifer matrix was found to be a viable silvicultural option. We recommend treating potential eastern white pine crop trees as an invisible species when carrying out precommercial thinning regimes, allowing nearby spruce and fir stems to remain around the pine until a later thinning. Treating potential eastern white pine crop trees in this manner will allow for higher quality pine crop trees, with smaller branch diameters, less weevil attacks, and more rapid turn up of lateral branches, thus limiting pruning investments, while still allowing for the stand to be precommercially thinned.

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