REGENERATION STOCKING IN HARVESTED FOREST STANDS

A Thesis in
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by
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ABSTRACT

Stocking equations, normally used to evaluate stands of saw-timber sized trees, were adapted and applied to younger trees in the post-harvest environment of regenerating stands. Using data from regenerating, mixed-oak stands stocking equations based on stem density and stem aggregate height were used to generate stand-level regeneration stocking values and stocking charts, which provided a quantitative view of post-harvest stand conditions. At all intervals following harvest, regeneration stocking levels were significantly different between stands harvested via clearcut versus those harvested by a shelterwood treatment, with few shelterwood stands exhibiting positive regeneration progress at year seven. When stocking values were separated by individual species contributions, oak regeneration stocking was found to be significantly greater in clearcuts than shelterwoods at all stand ages. In addition, while not significant, red maple stocking was higher than oak stocking at all ages in both treatment types. Some non-tree species, such as hay-scented fern and mountain-laurel, were found to have significant negative relationships with regeneration stocking, while Rubus species were found to have a positive relationship with regeneration stocking pre-harvest and one year after harvest. Finally, by extrapolating current regeneration conditions, inferences could be made as to which stands were on a trajectory indicative of regeneration success at a point in the stand’s future. Of the sixteen clearcut treatments in this study, fourteen were projected to be fully stocked when stand quadratic mean diameter reaches 3.7 inches. However, of the nine shelterwood stands, only one was projected to be fully stocked at that point in stand development.
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INTRODUCTION

Charged with managing Pennsylvania’s 2.2 million acres of state forestland, the state Department of Conservation and Natural Resources (DCNR) must provide marketable commodities while maintaining ecological integrity within forest ecosystems before, during, and after harvesting. While the use of proper treatments and harvesting techniques is crucial to preserving forest ecosystems, promoting adequate regeneration in the stand prior to and following a harvest is paramount to silvicultural success (Nyland 1996). To this end, professionals in the field often use regeneration models and guidelines to attempt to create an environment where appropriate forest regeneration occurs (Steiner et al. 2008). Since silviculture varies by forest type and geographical area, these models and guidelines often reflect the species composition and silvicultural goals of the region in which they were developed. These regeneration-level models have the potential to be combined with stand characteristics such as site occupancy or woody and non-woody cover to explore useful predictors of future stand development and benchmarks of regeneration success in the first decade following a harvest.

Given that oaks (*Quercus* spp.) are among the most dominant species in the deciduous forests (Abrams 2002), preserving oak-dominated ecosystems and regenerating new stands with a large oak component is highly desirable, especially in Pennsylvania (Steiner et al. 2008). Species such as white oak (*Quercus alba* L.), northern red oak (*Q. rubra* L.), chestnut oak (*Q. montana* Willd.), black oak (*Q. velutina* Lam.), and scarlet oak (*Q. coccinea* Münchh.) often occur as dominant overstory species in the mixed-oak forests of Pennsylvania. Not only are oak species valuable as a timber
commodity, but their historical and ecological importance as a food source for humans and animals cannot be overstated (McWilliams et al. 2002, Johnson et al. 2002). Without the benefits provided by oak species, the biodiversity in ecosystems once-dominated by oak could suffer. Unfortunately, over the last several decades, regenerating stands across the Eastern United States have shown a decline in oak dominance (Lorimer 1993). This decline has been attributed to a variety of factors, including climate change, animal and insect herbivory, disease, over-harvesting, and suppression of natural fires (Abrams 1992). As a result, foresters in the region must pay close attention to the amount of advance oak regeneration on the ground before harvest and the potential of stands to regenerate oak species after harvest (Gould et al. 2005, Lorimer 1993).

Promoting oak regeneration before and after a harvest has been recognized as critical to the success of timber management plans across the state, but pre-harvest evaluation methods, harvest techniques and post-harvest treatments that improve the proportion of oak regeneration are not always effective. Whereas clearcutting has been widely recognized as the most dependable means of regenerating oak forests, many foresters have been experimenting with shelterwood or single-tree selection treatments at times when its likely that pre-harvest conditions would not favor oaks after a widespread overstory removal (Larsen and Johnson 1998, Johnson et al. 2002). Post-harvest regeneration treatments also help provide the foothold oaks need in developing stands where the proportion of oak species to other, competing tree species is low or where competitive vegetation inhibits oak seedling development. Two common methods for controlling inhibiting vegetation and competition are herbicide treatments or repeated mowing (Engelman and Nyland 2006).
Additional treatments following harvest can also help maintain and improve oak regeneration. Because white-tailed deer (*Odocoileus virginianus* Zimm.) browsing can have profound effects on acorn and oak seedling survival (Steiner 1995), exclusion fences have become commonplace in Pennsylvania forests as a means of protecting oak regeneration in recently harvested stands. While natural regeneration is preferred to artificial regeneration, artificial plantings can also be used to supplement oak seedlings in stands that have low probability of a new seed crop. However, some research suggests that artificial plantings have been less successful in clearcuts than in shelterwoods (Johnson et al. 2002). Because of the variation in regeneration treatment and variable success rates depending on stand conditions, evaluating regeneration in harvested stands is crucial to determine the appropriate regeneration strategy.

Over the last fifteen years, the Oak forest Regeneration Study in Pennsylvania (ORSPA) has provided a wealth of data regarding regenerating stands harvested across Pennsylvania’s state forestland. However, the challenge remains to summarize the data collected into a concise, yet descriptive evaluation of regeneration success or failure as early in a stand’s development as possible. The earlier a stand’s relative abundance of oak regeneration can be described to reflect future stand dynamics, the sooner treatments that further the competitive success of oak seedlings can be initiated if necessary. Stocking charts, like those developed by Gingrich (1967) for mature stands, have long been valuable tools for evaluating stand-level conditions, and recently they have been adapted to describe young, regenerating stands (Fei 2007). In both types of charts, the average level of maximum competition is used as a reference level for the upper bounds of the chart (Gingrich 1967, Reineke 1933), which translates ecologically into the
maximum carrying capacity per plot (Fei 2007). These stocking charts and their associated stocking values, which describe the percentage of a stand’s surface area inhabited by seedlings, provide a concise summary of regeneration development in harvested stands and provide a means to compare stand development in relation to factors such as harvest type, regeneration treatment, or levels of competitive vegetation cover. In addition, ORSPA data collection techniques (Steiner and Finley 2008) enable the creation of multiple stand stocking charts as a means to monitor the progression of stand development. Indeed, the first objective of my study was to evaluate stand regeneration stocking over time for all stands measured through seven years following harvest in an attempt to compare relationships between pre-harvest stand conditions, silvicultural treatments, and regeneration levels at years four and seven at the stand level and plot level within stands.

It was my expectation that calculating stocking values would enable inferences concerning patterns in stand-level growth and development. To permit these inferences, my second objective was to determine the relationship between oak stocking and non-oak stocking, focusing predominately on the impact of red maple stocking on oak regeneration. By determining each species’ contribution to total regeneration stocking, possible connections in terms of competition for site occupancy between competing tree species can be examined. A third research objective was to determine the relationship between tree species’ stocking and woody and non-woody vegetation cover in the stand. Individual stocking values were calculated on a stand and a plot-level basis and used in statistical comparisons between sites and treatment types to better understand the influence of percentage cover of various woody and non-woody species on regeneration.
stocking. The final objective of this study was to use stand characteristics to help predict future regeneration stocking in harvested stands. If year four stand conditions can be used to predict stocking at year seven, well-informed management decisions can be made that might alter stand trajectory toward a more desirable species composition. Quantitative measures of regeneration “success” or “failure” across stands can facilitate management decisions by foresters and land managers in a more timely and cost-effective fashion.
LITERATURE REVIEW

Stand Development and Competition

Early development in oak-dominated forest stands rarely follows a static or regular course of events, but instead is governed by a wide range of dynamic processes and perturbations involving all facets of the forest ecosystem (Gould et al. 2005). Beginning before a harvest, as acorns fall and advance regeneration becomes established, competition for light, water, and growing space influences future stand composition. Once harvesting is complete, vegetative cover and further competition from neighboring plants — oak and non-oak alike—further complicate a seedling’s growing environment and chance for survival. Even if an oak seedling has a competitive advantage over neighboring plants and trees, selective browsing by herbivores such as white-tailed deer can promote a shift in dominance toward species such as red maple (Acer rubrum L.) and black birch (Betula lenta L) (Fei et al. 2005) and negatively affect stand development (Bowersox et al. 1995).

As expected, natural variation of advance regeneration occurs over a wide range of disturbance regimes and moisture gradients; however, oak regeneration can be more competitive on xeric sites than mesic or hydric sites. This is due to the large initial investment in root system growth exhibited by oak species versus the initial investment in height growth exhibited by competitors, which allows for a higher drought tolerance in oak species on xeric sites (Larsen and Johnson 1998). The effects of disturbance are also variable. Windthrow or heavy harvesting may release more non-oak species while frequent burning may increase the potential of oak seedlings to dominate new growing spaces (Johnson et al. 2002). Larsen and Johnson (1998) argue that natural regeneration
is the desired way to retain oak stands, but requires a build-up of seedlings before harvest from multiple cycles of acorn production and favorable growing conditions in the understory. The term “regeneration potential” is often used to describe this ability of tree species throughout their life span to contribute to stand stocking through sexual or vegetative reproduction (Dey 2002). For our purposes, a stand’s “oak regeneration potential” refers to the capacity of oak seedlings (seedlings are conventionally defined as stems less than one inch diameter at breast height, or dbh) and stump sprouts (from cut stems greater than or equal to two inches in diameter at ground level) to obtain and sustain growing space after an overstory removal (Steiner et al. 2008). As forest management techniques become more effective at steering natural regeneration via manipulation of a variety of stand characteristics, foresters play a more important role in stand development — deciding when to harvest a stand and which treatment options to apply as a regenerating stand develops.

A plethora of disturbance events may occur in a forest stand over a wide range of spatial scales. Small-scale canopy disturbances can favor oak regeneration if seedlings grow quickly enough to overcome competition. This type of regeneration termed “gap-phase regeneration” occurs when gaps of varying sizes occur within a forest stand, and is mimicked by the crown gaps in the shelterwood or thinning-style treatments (Veblen 1992). Canopy gaps often favor more shade-intolerant species that prefer disturbance and exhibit fast growth after increased light exposure. However, if sufficient advance oak regeneration exists, it too can exploit these gaps. More catastrophic disturbances (fire, tornado, or timber harvest) often favor regeneration from species of all light tolerances but often more intermediate or shade intolerant species are favored by these events.
(Johnson et al. 2002). However, in these types of large disturbances, at times mid-story, shade tolerant species such as redbud (*Cercis canadensis* L.) and flowering dogwood (*Cornus florida* L.) can exhibit substantial growth and create sub-canopy shade to the detriment of less shade-tolerant regenerating oak seedlings (Veblen 1992). In oak-dominated forest types, high overstory density often prohibits oak recruitment directly into the overstory (Johnson et al. 2002).

While the success of oak regeneration is dependent on a myriad of growing conditions, the degree at which harvested oak trees produce stump sprouts, and the competitive environment within the stand, most oak forests rely on a viable seed crop. The ability of acorns to germinate and develop is the first requirement for establishing sufficient advance regeneration in oak forest ecosystems. Frequency of mast years, in which extremely high acorn numbers are produced, is highly variable and is influenced by both genetic and environmental factors. Mast year cycles can occur every three to five years (Johnson et al. 2002), although some research suggests longer intervals of up to ten years (Dey 2002). Once acorns develop and fall, factors such as drought, insect infestations, and predation by birds and animals can negatively affect acorn germination. In addition, micro-site conditions like light, temperature, hydrology, and interfering vegetation where the acorn lands may or may not promote germination. Dey (2002) reports that acorns buried between one to two inches and in contact with mineral soil are more likely to germinate. A leaf litter layer less than two inches deep serves as a protective layer against desiccation and vast fluctuations in temperature.

Following germination of an acorn crop, oak seedlings enter a forest system where competition for light, water and growing space can often impede successful
growth. Lorimer (1993) suggests that oak seedlings often cannot compete with more shade intolerant species or fast-growing pioneer tree species in any forest type and this could be a fundamental cause of the decline in oak dominance throughout the eastern United States. Non-oak species vying for the same growing space (woody and non-woody alike) often exhibit early leaf-area development, giving competitors an edge in the post-disturbance environment. Extensive shade from competitors can impede oak species, which focus resources on building well-developed root systems before capitalizing on light resources (Hodges and Gardiner 1993). Since oak species invest heavily in root development, xeric sites often support advance regeneration as oak has above average root depth in the seedling stage and thus access to deeper soil water. Unfortunately, even on more xeric sites where oak often exhibits a high root-to-shoot ratio and abundant reproduction, understory vegetation and other tree species can threaten oak seedling success (Dey 2002). Oak seedlings may also show signs of shoot die-back every three to ten years depending on the external environment and the absence of favorable growth conditions. When shoot die-back does occur, oak seedlings simply release dormant buds found at the root collar to re-grow the stem (Larsen and Johnson 1998). This re-sprouting cycle can potentially go on for many years. Tyron and Powell (1984) found root ages of up to fifty years on some upland oak seedlings, with an average root age between 5.7 and 17.4 years for all oak species. This re-sprouting ability enables oak seedlings to simply “wait out” competing species until conditions are favorable to increase height growth.

While developing a more substantial root system can provide a competitive advantage over other species, above-ground height growth still plays a significant role in defining competition following harvest or disturbance. Larsen and Johnson (1998)
suggest that while early oak height growth and competitive advantage may not be substantial beneath dense canopies, rapid height growth (since root systems have already been developed) following overstory release gives an advantage to oaks even though many still succumb to competition from other species. In addition to seed reproduction, stump sprouts may also contribute significantly to oak regeneration, since sprout survival rates are usually high. Even though these sprouts occur more often on stumps of younger oaks as opposed to larger, older stumps they can represent an important portion of total oak stocking (Gould et al. 2006, Johnson et al. 2002). Stump and seedling sprouts can both exhibit increased height growth and success rates due to carbohydrate reserves and previously developed root systems (Hodges and Gardiner 1993).

Competitive exclusion of oaks by other species most often occurs in a short period following harvest or overstory removal (Gould et al. 2004). If oak root systems are sufficiently large, then seedlings can grow in height and increase leaf area at a competitive rate. Focusing on inter-species relations, Gould found that oak seedlings are often competing with red maple seedlings throughout our study area by four years after harvest, and on higher quality sites (site index greater than or equal to 70) blackgum (Nyssa sylvatica Marsh.) and black locust (Robinia pseudoacacia L.) are also competing for resources. Furthermore, competition in the years following harvest is most often occurring between tree seedlings in close proximity to each other and in the case of ORSPA sites, within the milacre subplot (Gould et al. 2004).

The post-harvest environment in any stand is not only contingent on the relationship among newly established individual tree seedlings and tree species composition, but also non-tree vegetation attempting to capitalize on the increased
availability of resources. The ability of oak seedlings to sequester more resources and to colonize a site better than woody and non-woody cover is critical for success of oak regeneration. A wide variety of understory plants can impede oak regeneration in mixed oak stands. Some notable species found throughout the stands in our study area which could interfere with oak regeneration include mountain-laurel (*Kalmia latifolia* L.), *Rubus* species (raspberries and blackberries), hay-scented fern (*Dennstaedtia punctilobula* Michx.), black huckleberry (*Gaylussacia baccata* Wangenh.), and *Vaccinium* species (blueberries). For example, hay-scented fern can impede oak regeneration by creating dense ground cover and reducing the quantity and quality of light reaching seedlings. The fern can shade seedlings on the forest floor, and has been shown to interfere with root growth rate and mycorrhizal infection rates below ground in northern red oak seedlings (Lyon and Sharpe 2003). As root growth rate declines, it is likely that height growth would also slow, limiting the ability of the seedling to increase leaf area and photosynthesis levels. In addition, Lyon and Sharpe found that hay-scented fern can sequester nutrients like potassium and phosphorus better than northern red oak and have “the potential to shift the competitive balance to the detriment of hardwood seedlings” (p.498). Not all competing vegetation adversely affects oak seedlings. *Rubus* species can become dominant vegetation in the years immediately following a harvest or disturbance via rapid vegetative growth and possible allelopathy. However, as *Rubus* plants age, they typically exhibit thinning of leaf area, which then would lower the rate at which these plants compete with oak seedlings. In addition, some evidence suggests that these plants may also protect small tree seedlings from herbivory and moderate soil-level
microclimates (Donoso and Nyland 2006). Thus, it is difficult to definitively describe the level of competitive seedling success relative to competing growth (tree and non-tree).

The variable nature of oak development over time and the decline in oak dominance in Eastern forests does not allow for one appropriate harvesting strategy used in all circumstances. Instead, a variety of management options exist depending on stand characteristics before harvest. Overstory removal treatments or clearcuts are even-aged treatments in which the majority of the overstory basal area in a stand is removed (for the purposes of this study, any stand in which the residual basal area was 20 ft²/ac or less was considered a clearcut). This type of cut allows for regeneration to mostly become established following harvest, with most regeneration in the same cohort growing together at a single canopy level (Smith et al. 1997). Managers can potentially influence species composition in a regenerating clearcut, based on the proportion and species of residual trees left behind as seed sources (Nyland 1996). Critical to this method of harvest is the presence of advance regeneration or seed source prior to harvest (Nyland 1996, Smith et al. 1997). Relatively high densities of advance regeneration enable oaks to gain an early competitive advantage over other early successional or shade intolerant species (Larsen and Johnson, 1996, Sander 1972). Some species in Pennsylvania’s mixed oak forests also exhibit regenerative ability via vegetative means such as stump sprouting or root suckering, which also contributes to the regenerative community following a clearcut treatment (Nyland 1996).

Another commonly used harvest treatment, the shelterwood method, in which a substantial amount of the overstory is left for seed source and to provide light shade and a more cosseted growing environment for regenerating seedlings (Smith et al. 1997). This
method enables managers to provide some timber while waiting for an increase in
advance regeneration of the desired species (often provided by a large seed crop) to
remove the remainder of the overstory. The shelterwood method can be as simple as a
thinning and a final removal cut, or can be a multiple-stage process occurring over a
decade or more (Nyland 1996). Shelterwood treatments are often recommended to
encourage successful oak regeneration (Dey 2002). Not only can a shelterwood
sequence help bolster oak advance regeneration before the final removal cut, but the
regulation of light by remaining overstory trees can help control competing woody
vegetation on higher-quality sites (Loftis 1990, Dey 2002). For shelterwood treatments,
oak regeneration guidelines for Pennsylvania forests developed by Steiner et al. (2008)
recommend that at least 65% of sample plots in a stand contain oak seedlings before any
overstory reductions take place, given the ability of less desirable species to also benefit
from the creation of canopy gaps and increased sunlight. The Steiner et al. (2008)
guidelines normally advise that if oak advance regeneration is insufficient, managers
should defer shelterwood treatment until the oak regeneration potential is acceptable.

If a harvest is prescribed for a stand, the forester must understand and describe
variables that inhibit oak regeneration. If the amount of competing vegetation is high,
herbicide treatments may be necessary. Herbicide treatments carried out after overstory
removal can provide a “window of opportunity” for seedling regeneration if adequate
seed sources are prevalent before species like hay-scented fern can recover (Fei et al.
2008, Johnson et al. 1989). If the oak regeneration could be damaged by herbivory,
exclosure fencing may be necessary to control browsing pressure (Steiner et al. 2008).
The decision to engage in these regeneration treatments is often the result of managers
carefully examining pre-harvest regeneration conditions. However, after a harvest is complete, it often happens that treatments are not prescribed until the dynamic nature of the regenerating stand stabilizes.
Evaluating Oak Regeneration

Due to the ecological factors governing regenerating stands and the myriad management strategies used to promote oak regeneration, attempts to characterize the relative success or failure of individual sites to regenerate oak species following harvests or treatments can be difficult. However, with enough data about early stand development characteristics it may be possible to extrapolate growth forward for an individual or group of individuals to inform management decisions (Loftis 1990). The ability to determine within the first decade following a harvest whether or not regeneration levels are adequate to achieve management goals can be a key towards practicing appropriate silviculture. Given the challenges of regenerating oak stands, the ability to make early evaluations is highly desirable, but evaluating the adequacy of advance oak regeneration before and after a planned overstory treatment or harvest can be difficult.

Quantifying oak advance regeneration prior to harvest is the easiest way to gain insight into a stand’s growth trajectory following a harvest (Dey et al. 1996). Of course, even the presence of oak advance regeneration in a stand doesn’t guarantee oak dominance in the mature stand (Loftis 1990) and even an early height advantage with oak seedlings may not be enough to dominate competitors (Sander et al. 1984). Similarly, the probability of regeneration via stump sprouting can be estimated based on the size of mature oak stems (Gould et al. 2007). Dey (1996) suggests considering oak advance seedling regeneration and post-harvest oak stump sprouts collectively when quantifying oak advance regeneration. This strategy is exhibited by Steiner et al. (2008) when predicting third decade oak stocking based on advance seedling regeneration and stump sprouting.
Size and density of oak advance regeneration relative to competitors (tree and non-tree) are considered important factors in predicting regeneration success (Johnson et al. 2002). Aggregate height, the cumulative seedling height of tree seedlings for a given unit area, is easily measurable in the field and can be translated into a useful predictor of stand density and a species’ likelihood of success in a mature stand (Fei et al. 2006). In addition, Fei et al. (2006) explain that since aggregate height is a combination of the number of seedlings and mean size it more accurately represents stand density (in this case, percent of stand surface area covered by tree regeneration), and it provides a more meaningful evaluation of relative competition and the ability for individuals to succeed as a stand matures. A metric based on seedling density and basal diameter has previously been suggested as a means to predict whether or not seedlings will attain prevailing competitive position after overstory removal (Loftis 1990).

Often a stand’s tendency to accumulate oak seedling regeneration over time can be determined by examining oak reproduction density and its anticipated trajectory during stand development (Johnson et al. 2002). In a forest stand, “stocking” can be an elusive term, but it can be used to describe the adequacy of a stand to achieve a desired regeneration density (Gingrich 1967). A common measure of stocking, relative density, compares the amount of growing space occupied by individuals to the amount of growing space available to all species in a given stand. It follows logically that competition also plays a large role in the development of stocking values and stocking charts (Fei 2004). Underlying all comparisons is the assumption that the structural and compositional status of a future stand can be predicted by careful study of the initial state of the stand (Dey et al. 1996).
While there is a wealth of literature discussing relative site-occupancy, stocking equations, and stocking charts for mature stands, there has been little commitment to understanding regeneration stocking early in stand development. As a forest stand matures, growing conditions and stand composition become more stable and are described fairly accurately using stocking charts (Nyland 1996). However, during stand initiation and into the stem exclusion phase, fluctuations in stand composition and total biomass can make characterizations difficult. Fei et al. (2007) demonstrated that by using aggregate height and stem density per milacre, dynamic stand conditions are comparable over time. During early development stand variables may be in constant flux, but trends can be derived by comparative studies of stands with similar conditions. Regeneration stocking charts may provide a definitive interpretation of the regeneration conditions in a forest over time.

In order to develop regeneration stocking charts, Fei (2007) used the maximum and minimum aggregate heights and stem densities across stands to establish the maximum level of competition across the sites. Once this maximum level is determined, it can be used as a first benchmark, A-level stocking. Fei’s (2004) stocking charts (Figure 1) follow those of Gingrich’s (1967) and use this average maximum competition value as the reference level for regeneration stocking charts. A-level stocking (100% stocking) is exhibited by the nearly horizontal line near the top of the graph. Stocking models developed by McGill et al. (1999) call this value average maximum stand density, or the level of stocking at which all stems have the minimum amount of space needed for positive growth rates.
In developing stands, the primary objective is to achieve stocking at about the B-level or higher (Figure 1), which is defined as full site occupancy by tree regeneration with little or no competition between seedlings (Gingrich 1967; McGill et al. 1999 and Fei 2004 and 2007). We can say that a plot has successfully regenerated to trees when it reaches B-level stocking. It is important to note that the B-level stocking for regenerating stands is only 5 to 30 percent of full (A-level) stocking (Fei 2007), as opposed to 55 to 60 percent of full stocking in charts developed by Gingrich (1967) to chart mature stands. The objective of the research presented here was to describe regeneration in stands assessed within the ORSPA project and compare this measure of tree regeneration to other stand conditions to better predict tree regeneration in harvested stands.

Figure 1. Fei (2007) regeneration stocking chart.
METHODS

Study Sites

Seventy stands comprise the ORSPA study sites, 55 in mixed-oak forests, 13 in northern hardwood forests and 2 in unclassified forest types. They are distributed across central Pennsylvania in the Ridge and Valley and Allegheny Deep Valleys ecological provinces on lands managed by the Pennsylvania DCNR in 8 of the 20 state forest districts. The twenty-five stands used for this analysis can be found mapped in Figure 2. Each stand was measured at least once before the harvest, and then each site was re-measured one year following harvest, four years following harvest and seven years following harvest. As of the 2007 field season, all 70 stands had been measured before harvest, 53 had been re-measured one year after harvest, 47 had been measured again four years following harvest and 25 had been re-measured seven years following harvest. My analysis focused on the 25 mixed-oak stands measured up to seven years following harvest; see Table 1 for general information about these stands.
Figure 2. 25 Mixed-oak forest sites\(^1\) measured up to seven years following harvest and their locations.

\(^1\) In Figure 2, stands are labeled by ORSPA assessment ID number.
Table 1. Stand identification number (PSU ID), location, stand area, silvicultural treatments, site index, pre-harvest stand stocking, and basal area (BA) before and after harvest.

<table>
<thead>
<tr>
<th>PSU ID#</th>
<th>State Forest District</th>
<th>Stand Area t</th>
<th>Silvicultural Treatment t</th>
<th>Additional Treatment³</th>
<th>Deer Exclusion⁴</th>
<th>Site Index⁵</th>
<th>Stocking⁶</th>
<th>BA (ft²/ac) Pre</th>
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Table 1 (cont). Stand identification number (PSU ID), location, stand area, silvicultural treatments, site index, pre-harvest stand stocking, and basal area (BA) before and after harvest.

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<th>PSU ID#</th>
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<th>Stand Area</th>
<th>Harvest Treatment</th>
<th>Regeneration Treatment</th>
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1 In acres
2 Clearcut stands had residual basal area of 10 to 19 ft²/ac, shelterwood stands 20 to 83 ft²/ac. Year harvest completed in parentheses.
3 The year of treatment in parenthesis. When trees were planted within the stand, the number reported is seedlings per acre.
4 Where fences were used, only 6- or 7-strand fences were electrified
5 Height in feet at age 50
6 Pre-harvest Gingrich (1967) mature stand stocking
Measurements

Data on overstory and understory tree species composition as well as woody and non-woody plant cover were taken on all sites by field crews one year prior to harvest, then one, four, and seven years following harvest based on ORSPA protocols (Steiner et al. 2008). During the first measurement of each stand, permanent plots were systematically established using a square grid, with plots usually 200 to 300 feet apart. Depending on stand size, the number of plots per stand varies from 15 to 40. These plots are 1/20th of an acre in size, with a radius of 26.3 ft. The plot centers were marked and recorded via GPS to aid in relocation during subsequent measurements. Within each 1/20th acre plot, four milacre subplots (1/1000th of an acre) with a radius of 3.72 ft were established on centers located 16.5 ft from plot center in each of the four cardinal directions.

At the stand level, data was collected regarding site conditions both prior to harvest and following harvest. Data on soils, slope, aspect, and site index were recorded during the pre-harvest measurement. Some data were collected on the plot level (1/20th of an acre), while others were only taken on the subplot (milacre) level. Within the plot following harvest, species and dbh (diameter at breast height) of all residual overstory trees greater than 2 inch dbh were taken and standing overstory snags were recorded. The majority of regeneration data suitable for my analysis was taken at the milacre, subplot level. Surface conditions were recorded at the subplot level (stratum 0) and expressed as a percentage of total subplot area. These surface conditions included percent coverage of road, dead and down woody debris, stumps, stones, water, skid trails, moss, mineral soil and leaf litter recorded hierarchically in that order. At the 0-5 ft level
(stratum 1) cover was similarly estimated and recorded in five percent intervals and recorded by species. These evaluations included both vegetative cover and tree regeneration where applicable. Dominant non-tree vegetation height was also recorded. Cover in the 5-20 ft intermediate level (stratum 3) was recorded in the same manner as stratum 2. Within the milacre subplot, regeneration tallies were also made of all regenerating tree seedlings (less than 2 inch dbh) and both species and height class (0 to 2 inches, 2.01 to 6 inches, 6.01 inches to 1 foot, 1.01 to 2 feet, 2.01 to 3 feet, 3.01 to 4 feet, 4.01 to 5 feet, and greater than 5.01 feet) were tallied. Diameter at breast height was also recorded by species for stems greater than 5 feet in height. Height of dominant oak and non-oak stems was also recorded for each subplot. The species of the cut stump closest to the plot was recorded and the number of stump sprouts, if any, was counted. In addition, the height, dbh and basal diameter of the dominant sprout for each stump were recorded. Brief descriptions of the regenerative conditions on the twenty-five sites as recorded from 1996 to 2007 follow.
Site Conditions

9601 – Shingle Path\(^1\). This stand is located in Rothrock State Forest in the Northern Ridge and Valley ecological province and underwent a seed tree harvest in 1996 in which the basal area in the stand was reduced from approximately 82 ft\(^2/\)ac to 20 ft\(^2/\)ac. Prior to harvest, the overstory was dominated by chestnut oak, which had a basal area of 55 ft\(^2/\)ac. Other species comprising the majority of the overstory included northern red oak, black oak, and red maple. This stand exhibited moderate gypsy moth-induced defoliation prior to the pre-harvest measurement in 1996 and, as a result, had many standing dead trees and poor advance regeneration. Residual basal area after harvest was comprised mostly of chestnut, scarlet, black and red oak. One year following harvest, the understory was composed mostly of oak stump sprouts, mountain-laurel and blueberry species. Beginning four years following harvest and into the seventh year following harvest, the oak regeneration improved dramatically. However, blueberry, huckleberry and hay-scented fern were heavy in some parts of the stand.

9602 – Shingle Path 2. Located in the Northern Ridge and Valley ecological province in Rothrock State Forest, this stand underwent a shelterwood cut in 1996 during which the basal area in the stand was reduced from approximately 106 ft\(^2/\)ac to 56 ft\(^2/\)ac. The final removal cut was completed in 2002, dropping the residual basal area to 15 ft\(^2/\)ac. Prior to harvest, the overstory was dominated by northern red oak, with a basal area of 38 ft\(^2/\)ac.

\(^1\) Stand names were chosen by DCNR foresters managing each stand.
Other species comprising the majority of the overstory included red maple (26 ft²/ac),
chestnut oak (25 ft²/ac), and white oak (19 ft²/ac). This stand exhibited heavy gypsy
moth defoliation in 2000 and 2001, which reduced the basal area available for final
removal cut significantly. Abundant red maple and minimal oak regeneration existed
throughout this stand one year following harvest. Much of the red maple regeneration is
comprised of stump sprouts, which reached 10 feet in height at year four and grew to 20
feet in height at year seven. Abundant Japanese stiltgrass (*Microstegium vimineum* Trin)
growth on the ground floor severly inhibits seedling regeneration.

9603 – Barrville Road. This stand is located in Rothrock State Forest in the Northern
Ridge and Valley ecological province, and underwent a clearcut in 1997 during which the
basal area in the stand was reduced from approximately 116 ft²/ac to 16 ft²/ac. Prior to
harvest, the overstory was dominated by northern red oak (54 ft²/ac) and chestnut oak (23
ft²/ac), which continued to dominate the residual overstory in the regenerating stand.
Across the site, red maple and chestnut oak stump sprouts are abundant and contribute
significantly to the amount of regeneration.

9604 – Barrville Road 2. Located in the Northern Ridge and Valley ecological province
in Rothrock State Forest, this stand underwent a clearcut in 1998 which the basal area in
the stand was reduced from approximately 116 ft²/ac to 16 ft²/ac. Prior to harvest, the
overstory was overwhelmingly composed of chestnut oak (52 ft²/ac). Beginning four
years after harvest, tall black birch regeneration dominated the understory across the
stand with only a few areas with oak, red maple and black gum (*Nyssa sylvatica*)
Marsh.) seedlings. Following a harvest and up to the latest measurement, competing woody and non-woody vegetation had little impact on tree regeneration.

9606 – Thunder Mountain. This stand is located in Elk State Forest in the Allegheny Deep Valleys ecological province, and underwent a shelterwood cut in 1997 during which the basal area in the stand was reduced from approximately 135 ft²/ac to 45 ft²/ac. Prior to harvest, the overstory was almost entirely comprised of chestnut oak (60 ft²/ac) and red maple (31 ft²/ac). Since year four, this has stand had very dense, diverse regeneration comprised of red maple, northern red oak, black birch, yellow-poplar (*Liriodendron tulipifera* L.), black cherry (*Prunus serotina* Ehrh.), and pin cherry (*Prunus pensylvanica* L.). Some areas of this stand are densely covered with *Rubus* (26% at both years 4 and 7).

9607 – Stever. Located in the Northern Ridge and Valley ecological province in Rothrock State Forest, this stand underwent a clearcut in 1997 during which the basal area was reduced from approximately 108 ft²/ac to 12 ft²/ac. Prior to harvest, the overstory was composed of chestnut oak (29 ft²/ac), white oak (25 ft²/ac), and other species in lesser amounts. Due to the type of cut, white oak, chestnut oak, scarlet oak and red maple were left as residual trees. Immediately after harvest, abundant oak advance regeneration and stump sprouts contributed significantly to the composition of the developing stand. Other regenerating species included red maple, black gum and black locust. At seven years after harvest, the stand had a great deal of diverse, competing vegetative cover (an average of 50% cover) dominated by blueberry species (16% cover).
9611 – Between the Gaps. Located in the Northern Ridge and Valley ecological province in Rothrock State Forest, this stand underwent a shelterwood cut in 1996 during which the basal area was reduced from approximately 92 ft$^2$/ac to 50 ft$^2$/ac with the final removal cut in 2002, reducing the basal area to 20 ft$^2$/ac. Prior to harvest, the overstory was dominated by red maple (36 ft$^2$/ac) and northern red oak (33 ft$^2$/ac). Advance regeneration before the harvest was comprised mostly of red maple and white pine (*Pinus strobus* L.). Heavy deer browsing was evident from one year after to seven years after harvest. In addition, heavy vegetative cover consisting predominately of hay-scented fern (25% cover at year 7) further inhibits oak regeneration, which remained at low levels over time.

9612 – Ario’s Road. This stand is located in Bald Eagle State Forest in the Northern Ridge and Valley ecological province, and underwent a clearcut in 1997 during which the basal area in the stand was reduced from approximately 92 ft$^2$/ac to 10 ft$^2$/ac. Prior to harvest, the overstory was dominated by chestnut oak (34 ft$^2$/ac), scarlet oak (22 ft$^2$/ac) and white oak (22 ft$^2$/ac). Other species comprising the majority of the pre-harvest overstory included red maple and white pine. The best regeneration in this site comes from red maple and oak stump sprouts. Some chestnut oak and red maple regeneration is present from seed, but interfering vegetation at year 4 (63% cover) and year 7 (57% cover) are hampering regeneration in this stand.

9614 – Lonely Trail. Located in the Allegheny Deep Valleys ecological province in Sproul State Forest, this stand underwent a clearcut in 1999 during which the basal area
in the stand was reduced from approximately 52 ft²/ac to 10-20 ft²/ac (depending on area within the stand). Prior to harvest, the overstory was overwhelmingly dominated by red maple (49 ft²/ac), with only one other species, white pine, having more than 10 ft²/ac in basal area. Immediately following the harvest, 5000 white pine and 5000 red oak seedlings were planted to help bolster advance regeneration. One year following harvest, black birch was observed as the dominant tree regeneration species and this dominance persisted through year seven. Little oak regeneration exists in this stand except for the planted oak seedlings, unfortunately some mortality in the planted seedlings was found at year four, and deer browsing at the tops of the tree tubes was observed at year seven.

9701 – Deep Hollow. This stand is located in Bald Eagle State Forest in the Northern Ridge and Valley ecological province and underwent a clearcut in 1999 during which the basal area in the stand was reduced from approximately 85 ft²/ac to 13 ft²/ac. Prior to harvest, the overstory was dominated by northern red oak (32 ft²/ac), chestnut oak (23 ft²/ac), and black oak (17 ft²/ac). Throughout subsequent measurements at years one, four, and seven, oak regeneration was abundant across the site with the primary species being chestnut oak, withstanding abundant gypsy moth defoliation in 2000 and deer browsing observed in 2003. By year seven, red maple and yellow-poplar regeneration was also plentiful in addition to the large chestnut oak component.

9706 – Brooks Tower. Located in Elk State Forest in the Allegheny Deep Valleys ecological province, this stand underwent a clearcut in 1999, which reduced the basal area from approximately 107 ft²/ac to 19 ft²/ac. Prior to harvest, the overstory was
dominated by northern red oak (57 ft²/ac) and red maple (18 ft²/ac). Early in the stand’s development, hay-scented fern inhibited regeneration growth (61% fern cover during year 1 and 56% during year four). However, over time oak regeneration eventually was able to take hold and the density of northern red oak and chestnut oak seedlings improved dramatically.

**9711 – Big Spring South.** This stand is located in Tiadaghton State Forest in the Allegheny Deep Valleys ecological province and underwent a clearcut in 1998 during which the basal area was reduced from approximately 67 ft²/ac to 20 ft²/ac. Prior to harvest, the overstory was dominated by red maple (27 ft²/ac) and chestnut oak (22 ft²/ac). Following harvest, this site exhibited moderate northern red oak and chestnut oak regeneration through year seven. Non-tree vegetation cover was observed to be high across the stand (53% cover at year four and 66% cover at year seven).

**9715 – Mumper Springs.** Located in Tuscarora State Forest in the Northern Ridge and Valley ecological province, this stand was clearcut with residual retention in 1998. The basal area in the stand was reduced from approximately 90 ft²/ac to 15 ft²/ac. Prior to harvest, the overstory was dominated by red maple (29 ft²/ac), northern red oak (26 ft²/ac) and chestnut oak (24 ft²/ac). Overall, this site is regenerating well with dense pockets of desirable regeneration including northern red oak, chestnut oak and white oak. There is also ample black locust regeneration across the stand with some red maple, black birch and striped maple.
9716 – Owl Gap. Located in the Northern Ridge and Valley ecological province in Rothrock State Forest, this stand underwent a shelterwood harvest in 1999 during which the basal area was reduced from approximately 79 ft$^2$/ac to 16 ft$^2$/ac in the first stage. Because the residual was lower than most shelterwood stands, no further removals were scheduled. Prior to harvest, the overstory was dominated by chestnut oak (23 ft$^2$/ac) and red maple (19 ft$^2$/ac). Moderate levels of oak regeneration occurred in this stand, and both stump sprouts and seed origin trees were observed. A decline in inhibiting vegetation was observed at year four (predominantly hay-scented fern), which may have promoted higher oak regeneration levels found at year seven.

9717 – PSU Watershed 3. This stand is located in Rothrock State Forest in the Northern Ridge and Valley ecological province, and underwent a clearcut treatment in 1999. The basal area in the stand was reduced from approximately 71 ft$^2$/ac to 16 ft$^2$/ac. Prior to harvest, the overstory was predominately comprised of chestnut oak (30 ft$^2$/ac). By year four, evidence of deer browsing on regeneration was evident and extreme in some areas. Despite the herbivory, oak regeneration was good across the site except for some rocky areas. The oak regeneration by year seven consisted mostly of chestnut oak, with small pockets of black oak and northern red oak. Interfering vegetation is not a problem at this site (66% bare ground in year seven) and has done little to inhibit regeneration.

9718 – Bartley Gap. Located in Rothrock State Forest in the Northern Ridge and Valley ecological province, this stand underwent a clearcut in 1999 during which the basal area was reduced from approximately 95 ft$^2$/ac to 20 ft$^2$/ac. Prior to harvest, almost half the
overstory basal area was comprised of chestnut oak (50 ft$^2$/ac), with significant amounts of white pine (25 ft$^2$/ac) and northern red oak (18 ft$^2$/ac). During the harvest, most overstory oaks were removed, and oak regeneration was sparse through year four. During the fourth year measurement the most abundant regeneration was ten-foot-tall stump sprouts of chestnut and northern red oak and red maple. Vegetation cover was moderate (between 35% and 65% in most plots) throughout the stand at both years four and seven. The most abundant seed source regeneration by year seven was black birch, red maple and some chestnut oak.

9803 – “C” Dorm. This stand is located in Rothrock State Forest in the Northern Ridge and Valley ecological province and underwent a clearcut in 1999 during which the basal area in the stand was reduced from approximately 102 ft$^2$/ac to 10 ft$^2$/ac. Prior to harvest, the overstory was dominated by white oak (48 ft$^2$/ac), with no other species having over 15 ft$^2$/ac basal area in the stand. One year following harvest, a diverse mix of species was found regenerating despite high grass and sedge cover. As the stand developed, a great deal of gypsy moth damage was found; however, by year seven there were areas of abundant red maple, white pine, black birch, white oak and black oak regeneration. At year seven, this site continued to have a high diversity of both tree species and woody and non-woody cover species.

9804 – Horseshoe Bend. Located in the Northern Ridge and Valley ecological province in Bald Eagle State Forest, this stand underwent a clearcut in 1999. The basal area was reduced from approximately 90 ft$^2$/ac to 15 ft$^2$/ac. Prior to harvest, the overstory was
dominated by chestnut oak (67 ft²/ac), with no other species having over 17 ft²/ac basal area. One year following harvest, 300 white pine seedlings per acre (10,500 total seedlings) were planted to improve regeneration density across the stand. Following harvest, blueberry and mountain-laurel contributed significantly to the understory (both species contributed approximately 25% cover). As the stand developed, the planted white pine seedlings remained healthy and vigorous. From the onset of stand development following harvest, black gum and red maple regeneration was very abundant with some chestnut oak, northern red oak and black birch.

9806 – Potter Run. This stand is located in Bald Eagle State Forest in the Northern Ridge and Valley ecological province, and underwent a clearcut in 1999 in which the basal area in the stand was reduced from approximately 129 ft²/ac to 13 ft²/ac. Prior to harvest, the overstory was dominated by chestnut oak (71 ft²/ac), with black oak (13.5 ft²/ac) being the only other species contributing significantly to the overstory. This stand is located on a steep south-facing slope. Immediately following harvest, chestnut oak was the predominant regeneration species with some northern red oak, black oak, red maple and black gum. At year seven these species continued to dominate the regenerating stand. Very little woody or non-woody, competing vegetation occurred at any time in this stand’s development, further enhancing the stand’s ability to regenerate desirable tree species.

9807 – Pioneer Cemetery. Located in Tuscarora State Forest in the Northern Ridge and Valley ecological province, this stand was shelterwood cut in 1999 during which very
few trees were removed and the basal area was reduced from 118 ft$^2$/ac to 83 ft$^2$/ac. The final cut has not been made. Prior to harvest, the overstory was dominated by yellow poplar (34 ft$^2$/ac), chestnut oak (13 ft$^2$/ac) and red maple (13 ft$^2$/ac). Following harvest, many large yellow-poplar, northern red oak and white oak remained standing. The stand was described one year following harvest as a diverse stand with diverse tree regeneration. At years four and seven, oak regeneration was moderate to low; however, striped maple regeneration was dominant with some patches of very dense, diverse regeneration.

9902 – McHenry. This stand is located in Tiadaghton State Forest in the Allegheny Deep Valleys ecological province and underwent a salvage shelterwood cut in 1999 during which the basal area in the stand was reduced from approximately 72 ft$^2$/ac to 44 ft$^2$/ac. Prior to harvest, the overstory was dominated by a mixture of northern red oak (30 ft$^2$/ac) and red maple (30 ft$^2$/ac). Elm spanworm defoliation in 1994 and drought-related oak mortality resulted in many dead or dying trees in the overstory before the salvage harvest. Following harvest very little regeneration was present except for conifers planted in the 1970s. By year four, northern red oak seedlings were observed growing well on former skid trails and roads. Northern red oak regeneration remained abundant through year seven with patches of chestnut oak, black oak and small red maple seedlings.

9903 – Manor Fork. Located in Tiadaghton State Forest in the Allegheny Deep Valleys ecological province, this stand underwent a salvage shelterwood harvest in 2000 during which the basal area in the stand was reduced from approximately 85 ft$^2$/ac to 55 ft$^2$/ac.
The final removal cut has not been implemented. Prior to harvest, mountain-laurel cover was high (51% cover) and very little oak advance regeneration was present. The overstory was dominated by red maple (27 ft²/ac), white oak (17 ft²/ac) and black oak (11 ft²/ac) before treatment. Oak regeneration throughout the first seven years after harvest remained poor, with the only improvement coming in 2002 when some white oak seedlings were artificially planted. Mountain-laurel cover was especially high before harvest (51% cover) and could have led to the low levels of advance regeneration. Unfortunately, at years four and seven the overall inhibiting vegetation cover was approximately 65% of the cover on the stand floor.

**9905 – Headwaters Regeneration.** This stand is located in Tuscarora State Forest in the Northern Ridge and Valley ecological province and was clearcut in 2000. The basal area in the stand was reduced from approximately 74 ft²/ac to 13 ft²/ac. Prior to harvest, the overstory was dominated by chestnut oak (31 ft²/ac) and northern red oak (18 ft²/ac). One year following harvest oak regeneration was excellent and included chestnut, northern red and black oak. Inhibiting vegetation in this stand never gained much dominance on the ground level and was covering only 7% of the forest floor by year seven. Excellent chestnut oak and black oak regeneration persisted through year seven.

**9907 – New Gas Well.** Located in Elk State Forest in the Allegheny Deep Valleys ecological province, this stand harvested via shelterwood, following herbicide treatment in 2001, during which the basal area in the stand was reduced from approximately 112 ft²/ac to 50 ft²/ac during the first stage. The second stage of this prescription has not taken
place. Prior to harvest, the overstory was comprised predominantly of northern red oak (62 ft²/ac) and red maple (27 ft²/ac). By year seven oak seedlings between one and two feet tall were the dominant regeneration despite high evidence of deer browsing inside the fenced stand. Only *Rubus* species appeared to be overtopping regeneration at year seven, covering approximately 49% of the forest understory.

9908 – Ridge Trail. This stand is in Elk State Forest in the Allegheny Deep Valleys ecological province, and was shelterwood cut following herbicide treatment in 2000. The harvest reduced the basal area from approximately 123 ft²/ac to 73 ft²/ac. The second cut in the shelterwood sequence has yet to take place. Prior to harvest, the overstory was predominantly northern red oak (53 ft²/ac) and red maple (24 ft²/ac). One year following harvest very little regeneration was found on this site with the exception of six-inch tall red maple seedlings. As the stand developed, oak seedlings began to compete for growing space in the understory. During the fourth year after harvest, one-foot tall northern red oak seedlings were present along with the red maple regeneration. By the seventh year following harvest, tree regeneration became more diverse, but northern red oak and red maple continued to be the dominant species in the understory. Hay-scented fern was the most abundant inhibiting type of non-woody vegetation on the site.
Data Analysis

The principal stand attribute of interest in this study was tree regeneration stocking, expressed as a percentage of total surface area of the stand occupied by tree regeneration. To generate stocking values for each stand and age measured, two calculations were needed: stem density (stems/milacre) and aggregate height (cumulative feet of seedling height/milacre). Aggregate height can be defined as “the total height of all individuals of a species or species group per unit area” (Fei et al. 2006, p.337). It is important to note that both seed origin regeneration as well as stump sprout regeneration were included in this calculation, since both types would ultimately contribute to total regeneration levels. Once stem density and aggregate height were compiled, these values were used to calculate the percentage stocking per subplot using the regeneration stocking equation developed by Fei (2007):

\[
S = 0.016N^*\left(\sum H / N\right)^{1.0032} \quad \text{(for plots with an average height of} \ < 9 \ \text{feet)}
\]

\[
S = 0.01N^*\left(\sum H / N\right)^{2.3667} \quad \text{(for plots with an average height of} \ \geq 9 \ \text{feet)}
\]

\[N = \# \text{Seedlings per milacre and} \ \sum H = \text{Aggregate Height (in ft/milacre)}\]

Stocking values were then plotted on a standard regeneration stocking chart (Figure 1). The stocking values calculated by this method can be considered as the percentage of maximal stand density occupied by regeneration (Fei 2007).

While there are other ways to summarize stand conditions in early stand development following harvest, e.g., probabilistic models based on basal stem diameter as proposed by Loftis (1990), stocking values provide a basis for additional comparisons in relation to regeneration success. In the ORSPA study, the trajectory of regeneration development through time can be easily observed in a concise fashion by comparing...
stocking values (Appendix 2 contains stocking charts for all data collected through the 2007 field season). To determine these relationships, I first calculated the stand mean level of stocking for each year of development, which permitted comparisons among stands grouped by harvest treatment (clearcut or shelterwood). After these stocking values were split by treatment type, the change in aggregate height and density at varying intervals were compared to the change in regeneration stocking. This comparison provided insight into stand dynamics and whether the number or height of seedlings was the driver of regeneration stocking over time. Besides separating by harvest type, I also differentiated stands based on presence or absence of deer exclosure fencing, herbicide treatments, and pre-harvest overstory stocking values (Gingrich 1967). T-tests were then conducted for the pre-harvest and one, four and seven years following harvest to determine differences in regeneration stocking between harvest type, presence or absence of deer exclosure fencing, herbicide treatment or lack thereof, and between high and low levels of pre-harvest overstory stocking. Comparisons between herbicide treatments, and pre-harvest stocking values (Gingrich 1967) were not significant and were not included in further analyses.

In addition, stocking values could be averaged and compared not only by stand age or harvest type, but also by species class. These values were allocated into three species classes: red maple, all Quercus species, and all other tree species. Contribution to total stocking in each stand was used as a way to assess oak regeneration success in each stand over time, with the predominant comparison being Quercus species versus red maple, since red maple often has been shown to be assuming dominance over oak species in regenerating forest stands (Fei and Steiner 2007). These stocking levels were also
compared across stands to determine whether the dominant oak component that characterized pre-harvest stands was successfully regenerating. The contribution of each species class to total regeneration stocking was shown graphically as well as examined statistically. Species level stocking comparisons were also categorized in terms of harvest type and examined using T-tests. Again, the change in aggregate height and density of individual species’ classes over time was compared to change in stocking in order to better understand stand dynamics over time.

Two other regeneration stocking calculations were made for use in regression analyses and comparisons between regeneration stocking and stand characteristics. The first, the mean ratio of oak species to red maple stocking, provided a way to describe the competitive position of desired oak species regeneration compared to red maple regeneration. Unfortunately, this ratio did not yield significant comparisons or results and was not included in subsequent analyses. The final regeneration stocking calculation considered was the relative increase in stocking from one year to seven years following harvest. A stand could still be considered successfully regenerating if it had an above average relative increase in stocking, which would signal positive, improving regeneration conditions. In this case, year one was used as opposed to the pre-harvest values to provide a more stable baseline for regenerating conditions. The relative increase in stocking from year one to year seven was calculated in this fashion:

\[
\text{Relative Increase in Stocking} = \frac{(S_7 - S_1)}{S_1} \times 100\%
\]

where \( S_7 \) = year 7 stocking value & \( S_1 \) = year 1 stocking value

The effect of woody and non-woody plant cover on stand stocking was also examined. First, mean percentage cover values of all species combined were calculated.
at stratum 1 (0 to 5 feet) and stratum 2 (5 to 20 feet). These values were again compared between harvest type and presence or absence of fencing. Next the effect of stratum 1 total percentage cover was compared to mean total regeneration stocking and mean oak regeneration stocking values, each at years four and seven using regression analysis. The average percentage cover by individual species contribution was calculated at the subplot and plot levels and then averaged to determine a stand level percentage cover by species for all 25 stands in the study.

Calculations expressing the relationships between total non-tree vegetation cover and regeneration stocking provided a foundation for investigating these impacts on an individual species level. The prominent woody and non-woody plant cover species examined were hay-scented fern, Vaccinium species, black huckleberry, mountain-laurel, and Rubus species (predominately R. alleghaniensis Porter and R. occidentalis L.). In addition, the combined percentage cover by all species in stratum 2 (5 to 20 feet in height) was used as a vegetative cover variable. In later comparisons, species groups which were less common in regenerating stands, like sedge species, were also included. Multivariate ordination techniques were attempted with PC-Ord software to further understand individual contributions of both woody and non-woody plant cover to stand stocking at years four and seven; however, no significant relationships were found that would aid in relating cover levels to stand stocking over time.

Using regression analysis, the effects of individual understory plant species cover levels were compared at years one, four and seven to regeneration stocking. These analyses were split first into two groups, clearcut and shelterwood stands, and then predictive relationships were investigated; however, stand level analyses yielded few
significant results. The same regression analyses were done at the plot level, dramatically increasing the sample size and precision of all comparisons. These predictive relationships involved using predominantly woody and non-woody plant species cover levels to predict future regeneration stocking conditions. Three predictive relationships were examined: predicting regeneration stocking at year four based on year one vegetation, predicting regeneration stocking at year seven based on year one vegetation, and predicting regeneration stocking at year seven based on year four vegetation. Mean total regeneration stocking and mean oak regeneration stocking were used for comparisons at the stand level. The best positive and negative relationships between mean cover levels and regeneration stocking were recorded for all categories. For this set of analyses, stand was treated as a class variable, which helped account for categorical differences in regenerative conditions among stands. Once again, predictive comparisons were conducted for clearcut and shelterwood stands at years one, four and seven. These comparisons were then tested for significance and depicted on scatterplots. Once the assumption that high levels of advance regeneration lead to high levels of regeneration following harvest was upheld, oak advance regeneration stocking could be included; along with woody and non-woody plant species cover values in predicting future regeneration stocking. It is important to note that oak stump sprout regeneration was not included in calculations involving advance regeneration, but was included in all stocking calculations.

As another means to predict mature stand conditions, year seven regeneration stocking levels were extrapolated to mature stand conditions based on the Gingrich (1967) mature stand stocking charts (Figure 3). To predict a stand’s progress toward
maturity, the percentage of milacre plots above the B-level on regeneration stocking charts (Appendix 2), as well as the percentage of plots with at least one tree of $\geq 5$ feet in height that were below B-level stocking were used to estimate the percent of plots expected to be fully stocked in the future. It was assumed that if a certain percentage of regeneration subplots have reached a stocking value above the B-level by year seven, they will contribute an equivalent number of trees per acre, and thus mature stand stocking, at a point when A-level stocking would be achieved by a density of 1000 trees per acre. I also assumed that even if a milacre plot was below B-level stocking at age seven, if the plot had at least one tree that was greater than or equal to 5 feet in height at age seven, that particular plot would also be occupied by at tree when A-level stocking was 1000 trees per acre. Using the tree area equation from Gingrich (1967), it was determined that at 100% stocking with 1000 trees per acre the quadratic mean diameter would be approximately 3.7 inches. This diameter was then used to calculate the percentage of mature stand stocking estimated as present in the regenerating stands at age seven (Table 8). This minimum projected stocking value equates to a condition in which no trees contribute to mature stand stocking other than one tree from each “stocked” subplot at age seven. In a similar fashion, an equation presented by Gingrich (1967) that calculated the maximum amount of area that trees in a mature stand could occupy was used to determine how many trees/acre would need to be present at a quadratic mean diameter of 3.7 inches to achieve B-level stand stocking at maturity, this target was approximately 570 trees per acre. As a means to combine these future stocking projections with non-tree vegetation data, mean cover levels prior to harvest and one year following harvest for all successful and unsuccessful plots were calculated and tested for
significant differences in successful clearcut stands and unsuccessful shelterwood stands (Tables 9 and 10).

Binary logistic regression analysis using SAS statistical software was carried out in order to further evaluate which factors may contribute more directly to successful regeneration stocking at year seven. Pre-harvest regeneration stocking levels and vegetative cover prior to harvest and one year following harvest were evaluated to determine their effect on year seven regeneration stocking in both clearcut and shelterwood stands (Table 11). Significant factors included pre-harvest advance regeneration (A), pre-harvest hay-scented fern cover (H₀), pre-harvest mountain-laurel cover (K₀), hay-scented fern cover one year following harvest (H₁), Rubus species cover one year following harvest (R₁), and sedge species cover one year following harvest (S₁). Odds ratios for the significant variables were also calculated and interpreted.

Figure 3. Mature stand stocking charts from Gingrich (1967).
RESULTS

Harvest and Regeneration Treatment Effects

Stocking values of regenerating stands prior to harvest and at years one, four and seven after harvest are shown for clearcut stands in Figure 4 and shelterwood stands in Figure 5. As both demonstrate, regeneration stocking typically (but not always) increased with time. By age seven, only six clearcut stands and none of the shelterwood stands accumulated over 20% regeneration stocking, while three clearcut stands and eight shelterwood stands had less than 10% stocking.

Figure 4. Average percent regeneration stocking of all tree species from one year before harvest to seven years following harvest for clearcut stands.
Figure 5. Average percent regeneration stocking of all tree species from one year before harvest to seven years following harvest for shelterwood stands

Clearcut stands had approximately twice as much mean total regeneration stocking as shelterwood stands at all ages (Table 2). This difference was reflected prior to harvest (4.7% versus 1.6% stocking, p = 0.009) and continued through year four (10.7% vs. 5.6%, p = 0.016) and year seven (17.1% vs. 8.0%, p = 0.001). The relationship between fencing and regeneration stocking was found to be statistically significant (p≤0.05) only prior to harvest.
Table 2. Summary of average stand regeneration stocking per milacre split by stand type and years following harvest (t-test probability for difference between treatment means: H₀: μ = 0).

<table>
<thead>
<tr>
<th>Stand Type (n)</th>
<th>Pre-harvest Stocking</th>
<th>p-value</th>
<th>Year 1 Stocking</th>
<th>p-value</th>
<th>Year 4 Stocking</th>
<th>p-value</th>
<th>Year 7 Stocking</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clearcut (16)</td>
<td>4.71</td>
<td>0.009</td>
<td>4.77</td>
<td>0.059</td>
<td>10.68</td>
<td>0.016</td>
<td>17.07</td>
<td>0.001</td>
</tr>
<tr>
<td>Shelterwood (9)</td>
<td>1.57</td>
<td></td>
<td>2.38</td>
<td></td>
<td>5.57</td>
<td></td>
<td>8.00</td>
<td></td>
</tr>
<tr>
<td>Fenced (15)</td>
<td>2.29</td>
<td>0.045</td>
<td>3.01</td>
<td>0.127</td>
<td>7.81</td>
<td>0.304</td>
<td>12.42</td>
<td>0.295</td>
</tr>
<tr>
<td>Unfenced (10)</td>
<td>5.52</td>
<td></td>
<td>5.26</td>
<td></td>
<td>10.37</td>
<td></td>
<td>15.87</td>
<td></td>
</tr>
</tbody>
</table>

Clearcut sites 9905, 9806, and 9717 had the highest average regeneration stocking per milacre (32.1%, 25.1%, and 23.2% respectively) and had the highest proportion of oak stocking relative to other tree species (49.0%, 67.3%, and 45.1%, Figure 6). In addition, although 9614 and 9604 had high total regeneration (14.1% and 21.5% stocking), virtually none of the seedlings were oak species. Other clearcut sites with especially low oak stocking components relative to total stocking included 9803, 9701, 9804, 9606 and 9612. The oak component of shelterwood stands was quite low, less than 3.4% across all stands (Figure 7).

The relative influence on regeneration stocking of two of its components, stem density and aggregate height, was examined by plotting incremental change in stocking over a time interval against incremental change in either component (Figures A1 to A30). It is clear that changes in regeneration stocking are primarily driven by changes in aggregate height, and this was equally true of shelterwoods and clearcuts as well as maples and oaks. However, in some stands the regeneration cohort was augmented by additional regeneration after harvest, especially of red maple, and the resulting increase in
density was always accompanied by a positive (though usually small and not proportional) increase in stocking. The relationship between the change in aggregate height to change in total stocking was found to be statistically significant at all intervals in both clearcut and shelterwood stands. This indicates that in nearly all cases, stocking is strongly driven by height growth and over time an increase in height contributes more than an increase in density to regeneration stocking. This is illustrated in clearcut stands 9905 and 9806, which had among the highest changes in aggregate height from year one to year seven, 60.1 and 66.9 respectively, and also had high total regeneration stocking. By contrast, stand 9718, which was amongst the lowest in total regeneration stocking at year seven, exhibited a larger increase in total stem density from year one to year seven, but a lower change in aggregate height.

Figure 6. Average percent regeneration stocking per milacre from one year before harvest to seven years following harvest for clearcut stands, split by species or species group.
Average red maple regeneration stocking was higher than oak species stocking in all stand age classes in both clearcuts and shelterwoods (Table 3). The oak component of regeneration did increase over time, but was never higher than red maple stocking when averaged across all stands in either clearcut or shelterwood treatments. Both red maple and oak species had significantly higher stocking in clearcut versus shelterwood stands before harvest, illustrating why their respective harvest treatments were selected. In addition, the oak stocking was significantly higher in clearcut vs. shelterwood stands in all years of stand development (Table 3). Both oak and red maple had equal or higher stocking in unfenced vs. fenced stands in all years of measurement, but the differences were never quite statistically significant (p = 0.052). A directly proportional relationship was seen between change in aggregate height and change in stocking at all intervals when stocking for both oak species and red maple stocking in both treatment types.
Table 3. Summary of mean stand regeneration stocking per milacre based on stand type, split into contribution to total stocking by species class: red maple (ACRU), all oak species combined (Oak) or all other species combined (Other). (t-test probability for difference between treatment means: $H_0: \mu = 0$).

<table>
<thead>
<tr>
<th>Stand Type (n)</th>
<th>Pre-harvest Stocking</th>
<th>Year 1 Stocking</th>
<th>Year 4 Stocking</th>
<th>Year 7 Stocking</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ACRU</td>
<td>Oak</td>
<td>Other</td>
<td>ACRU</td>
</tr>
<tr>
<td>Clearcut (16)</td>
<td>2.03</td>
<td>1.34</td>
<td>1.34</td>
<td>1.88</td>
</tr>
<tr>
<td>t-test p-value</td>
<td>0.037</td>
<td>0.032</td>
<td>0.097</td>
<td>0.088</td>
</tr>
<tr>
<td>Shelterwood(9)</td>
<td>0.98</td>
<td>0.33</td>
<td>0.26</td>
<td>0.99</td>
</tr>
<tr>
<td>Fenced(15)</td>
<td>1.16</td>
<td>0.77</td>
<td>0.35</td>
<td>1.22</td>
</tr>
<tr>
<td>t-test p-value</td>
<td>0.052</td>
<td>0.294</td>
<td>0.127</td>
<td>0.246</td>
</tr>
<tr>
<td>Unfenced(10)</td>
<td>2.38</td>
<td>1.29</td>
<td>1.85</td>
<td>2.07</td>
</tr>
</tbody>
</table>

Table 4 shows the relative increase in regeneration stocking between measurement ages one and seven for clearcuts versus shelterwood stands, as well as between fenced and unfenced stands. Although the increase in stocking between years one and seven was slightly higher in shelterwoods vs. clearcuts for all species categories, and in fenced vs. unfenced stands, none of the differences were statistically significant.
Table 4. Comparison of relative regeneration stocking increase from year one to year seven by stand type.

<table>
<thead>
<tr>
<th>Stand Type</th>
<th>Total Mean</th>
<th>SE</th>
<th>Red maple Mean</th>
<th>SE</th>
<th>Oak species Mean</th>
<th>SE</th>
<th>All Other Species Mean</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clearcut (16)</td>
<td>4.25</td>
<td>1.2</td>
<td>3.01</td>
<td>0.5</td>
<td>2.46</td>
<td>0.6</td>
<td>6.81</td>
<td>1.9</td>
</tr>
<tr>
<td>Shelterwood (9)</td>
<td>4.72</td>
<td>1.1</td>
<td>3.49</td>
<td>1.2</td>
<td>3.97</td>
<td>1.4</td>
<td>7.74</td>
<td>3.1</td>
</tr>
<tr>
<td>Fenced (15)</td>
<td>4.70</td>
<td>1.3</td>
<td>3.82</td>
<td>0.8</td>
<td>3.55</td>
<td>0.9</td>
<td>7.73</td>
<td>2.3</td>
</tr>
<tr>
<td>Unfenced (10)</td>
<td>3.19</td>
<td>0.9</td>
<td>2.23</td>
<td>0.5</td>
<td>2.20</td>
<td>0.8</td>
<td>6.28</td>
<td>2.1</td>
</tr>
</tbody>
</table>
Regeneration Stocking and Pre-harvest Advance Regeneration

Since oak advance regeneration was very low in shelterwood stands, and only slightly higher in clearcut stands (less than 8% stocking on average), the effect of oak advance regeneration on year seven stocking levels was difficult to quantify when the harvest types were compared. When regression analysis was used for clearcut stands with oak regeneration before harvest as a predictor of oak species regeneration stocking at year seven (Figure 8), a statistically significant positive relationship was found \( (p<0.001, r^2 = 0.199) \). Surprisingly, stands 9717, 9806 and 9905 had some subplots with high levels of oak stocking at year seven, despite the low levels of advance oak regeneration present prior to harvest. The same statistically significant relationship was obtained for the relationship between oak advance regeneration and the mean stocking change from years one to seven in clearcut stands. It is important to note that oak stump sprout regeneration in clearcut stands, overall, had little impact on year seven oak regeneration stocking totals and was not included in the calculation of mean oak regeneration stocking at year seven. In clearcut subplots where oak stump sprout regeneration was present at year seven, these sprouts constituted an average of 65.7% of the total oak regeneration on these subplots, but over all clearcut subplots with oaks present at year seven (1111 subplots), stump sprouts constituted an average of only 3.3% to total oak stocking per subplot.

The relationship between oak advance regeneration stocking and mean oak regeneration stocking at year seven in shelterwood stands was not significant. Similarly, the relationship between oak advance regeneration and mean stocking increase from years one to seven was not statistically significant. In shelterwood subplots where oak
stump sprout regeneration was present at year seven, these sprouts constituted an average of 71.7% of the total oak regeneration on these subplots, but over all shelterwood subplots with oaks present at year seven (727 subplots), stump sprouts constituted an average of only 1.6% to total oak stocking per subplot.

Figure 8. Relationship of mean oak advance regeneration stocking\(^1\) and year seven oak regeneration stocking\(^1\) at the plot level for clearcut stands (n=292).

\(^1\) For this comparison, stocking calculations exclude any stump sprout origin regeneration present at the study plot.
Relationships between Regeneration Stocking and Non-tree Vegetation Cover

Relationships with Total Cover

Characterizing non-tree vegetation cover is critical to understanding the post-harvest competitive environment in which tree regeneration develops. Table 5 shows that at year one stratum 1 vegetation levels were significantly higher \((p = 0.023)\) in clearcut than in shelterwood \((56.8\% \text{ versus } 35.9\%)\) harvests, but differences diminished in subsequent years and were not statistically significant. By contrast, stratum 2 non-tree vegetation cover levels were almost identical between between clearcut and shelterwood treatments in year one and these levels became significantly higher in subsequent years. In year one, this vegetation consisted mainly of witch-hazel \((Hamamelis virginiana L.)\) and mountain-laurel, with species such as devil’s walking stick \((Aralia spinosa L.)\), \(Vitis\) species, \(Rubus\) species, and \(Smilax\) species present at years four and seven. Mean cover levels were generally similar between fenced and unfenced stands.

Table 5. Total mean percent vegetation cover (woody and non-woody species) in stratum 1 \((0-5 \text{ feet in height})\) and stratum 2 \((5-20 \text{ feet in HT})\) by stand category at years 1, 4 and 7.

<table>
<thead>
<tr>
<th>Stand Type (n)</th>
<th>Year 1</th>
<th>Year 4</th>
<th>Year 7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stratum 1</td>
<td>Stratum 2</td>
<td>Stratum 1</td>
</tr>
<tr>
<td>Clearcut (16)</td>
<td>56.8</td>
<td>6.9</td>
<td>44.8</td>
</tr>
<tr>
<td>t-test p value</td>
<td>0.023</td>
<td>0.473</td>
<td>0.188</td>
</tr>
<tr>
<td>Shelterwood(9)</td>
<td>35.9</td>
<td>5.5</td>
<td>49.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fenced(15)</td>
<td>44.9</td>
<td>5.1</td>
<td>41.0</td>
</tr>
<tr>
<td>t-test p value</td>
<td>0.118</td>
<td>0.291</td>
<td><strong>&lt;0.001</strong></td>
</tr>
<tr>
<td>Unfenced(10)</td>
<td>57.2</td>
<td>8.4</td>
<td>58.1</td>
</tr>
</tbody>
</table>

53
Mean total regeneration stocking values, by stand (Figure 9), were negatively related to the stratum 1 percentage cover at year four (p-value = 0.004, $r^2 = 0.277$); however, when separated by harvest type this relationship was significant only for clearcut stands ($p = 0.007$, $r^2 = 0.379$). Despite the statistical results, the shelterwood data seems similar to the clearcut data in Figure 9, which may indicate no discernable difference in the effect of stratum 1 non-tree cover on regeneration stocking between harvest types. With both harvest types, there does appear to be a threshold of 40-50% mean stratum 1 vegetation cover beyond which total regeneration stocking is low in all stands.

Figure 9. Year four mean total regeneration stocking compared to mean stratum 1 vegetation cover per stand for both clearcut and shelterwood stands.
Carrying out the same analysis for stands seven years following harvest, a significant negative relationship (p = <0.001, r² = 0.489) was again observed when all stands were combined (Figure 10). Similar to year four data, when separated by harvest type the relationship between stratum 1 cover and regeneration stocking was only significant in clearcut stands (p = <0.001, r² = 0.624). One stand, 9607, has a mean stratum 1 percentage vegetation cover of 61%, but reached over 20% total mean regeneration stocking by year seven. This stand’s stratum 1 vegetation consists predominantly of *Vaccinium* species, which typically by year seven had been over-topped by tree regeneration. Looking at all stands, again at a threshold of 40-50% mean non-tree vegetation percentage cover, the year seven total regeneration stocking seems to decrease substantially and rarely achieves 15% total regeneration stocking. There was no relationship between the mean ratio of oak to maple stocking with mean stratum 1 non-tree vegetation cover levels at year four or year seven after harvest.

Figure 10. Year seven mean total regeneration stocking compared to mean stratum 1 vegetation cover per stand for both clearcut and shelterwood stands.
Figures 11 and 12 show analogous comparisons for oak regeneration only. At age 4 (Figure 11) there was a weak, statistically significant negative relationship between oak regeneration stocking and vegetation cover levels near ground level (p = 0.032, $r^2 = 0.149$) when both harvest types were combined. While a low percentage cover of non-tree plant species did not guarantee relatively high oak species regeneration stocking, a high level of non-tree cover was always associated with low oak stocking — 17 of 18 stands with greater than 30 % cover had less than 4 % oak regeneration stocking.

Figure 11. Year four mean oak species regeneration stocking compared to mean stratum 1 vegetation cover per stand for both clearcut and shelterwood stands.
At age 7 (Figure 12) there was a statistically significant negative relationship between oak stocking and stratum 1 cover ($p = 0.004$, $r^2 = 0.283$) when all stands were combined. Again, there appears to be a clear threshold emerging; when the non-tree vegetation cover levels are greater than 30%, oak species regeneration stocking is almost always less than 4% (16 out of 18 stands).

Figure 12. Year 7 mean oak species regeneration stocking compared to mean stratum 1 vegetation cover per stand for both clearcut and shelterwood stands.
Relationships between Individual Species and Species Groups

Mean vegetation cover levels were split by species type and compared to future mean total regeneration stocking and oak species regeneration stocking. Three predictive relationships were examined: regeneration values at year four and seven as a function of vegetation cover at year one, and regeneration values at year seven as function of vegetation cover at year four. At the stand level, these regressions were weak (r² values ≤ 0.10), so the same predictive relationships were examined at the plot level, increasing the sample size and clarity of the relationships. For this analysis, stand was considered a class variable, but stands were still split between clearcut and shelterwood treatments and sample sizes varied between stand ages and vegetation type. Only plots with a non-zero percentage cover values for the non-tree vegetation species in question were included in the analysis.

Comparisons with mean total regeneration stocking provided the most significant relationships in clearcut stands, although oak regeneration followed the same patterns (Table 6). All categories of cover had a negative influence on tree regeneration, although not all comparisons were consistently significant. The only exception to this was cover by *Rubus* spp. in year one, which had a positive and generally statistically significant effect on regeneration of oaks and all species combined. At year four, this positive relationship continued, but was only statistically significant for all species combined.
Table 6. Plot-level predictive comparison results (regression p-values) between mean vegetation cover levels and mean total regeneration stocking per milacre and mean oak stocking per milacre for 16 clearcut stands (significant relationships at the 0.05 level in boldface).

<table>
<thead>
<tr>
<th></th>
<th>Black Huckleberry</th>
<th>Hay-scented Fern</th>
<th>Mountain-laurel</th>
<th>Rubus Spp</th>
<th>Vaccinium Spp</th>
<th>Sedge Spp</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Regen Stocking</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 1 vs. Year 4</td>
<td>0.073</td>
<td>0.071</td>
<td>0.059</td>
<td><strong>0.007</strong></td>
<td>0.076</td>
<td>0.601</td>
</tr>
<tr>
<td>Year 1 vs. Year 7</td>
<td><strong>0.016</strong></td>
<td>0.164</td>
<td>0.083</td>
<td><strong>0.044</strong></td>
<td><strong>0.001</strong></td>
<td>0.669</td>
</tr>
<tr>
<td>Year 4 vs. Year 7</td>
<td>0.016</td>
<td>&lt;0.001</td>
<td><strong>0.021</strong></td>
<td>0.056</td>
<td><strong>0.001</strong></td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>Mean Oak Stocking</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 1 vs. Year 4</td>
<td>0.841</td>
<td><strong>0.010</strong></td>
<td>0.274</td>
<td><strong>0.047</strong></td>
<td>0.493</td>
<td>0.466</td>
</tr>
<tr>
<td>Year 1 vs. Year 7</td>
<td>0.759</td>
<td>0.100</td>
<td>0.476</td>
<td>0.123</td>
<td>0.294</td>
<td>0.797</td>
</tr>
<tr>
<td>Year 4 vs. Year 7</td>
<td>0.472</td>
<td>&lt;0.001</td>
<td>0.092</td>
<td>0.201</td>
<td><strong>0.005</strong></td>
<td>0.839</td>
</tr>
</tbody>
</table>

1 (sign of slope coefficient, degrees of freedom)

*Scatterplots of these relationships can be found in Tables A-31 through A-43, in Appendix I.

For shelterwood stands, the results were almost identical in the direction of the relationship (e.g., Rubus spp. cover in year one had a significantly positive influence on total regeneration at both ages one and seven), but sample sizes were smaller and fewer relationships were statistically significant. Notable significant negative relationships were found between hay-scented fern (p < 0.001) and mountain-laurel (p = 0.001) cover at year four and regeneration at age seven. Total stratum 2 cover at age one, which did not appear as a significant factor in any regressions for clearcut stands, had a significant positive relationship with total regeneration stocking at age 4 (p < 0.001) and a weaker relationship with total stocking at age seven. However, stratum 2 cover at age four
appeared to have a negative effect on regeneration stocking at age seven, an effect that was statistically significant for oak regeneration (p=0.021).

Table 7. Plot-level predictive comparison results (regression p-values) between mean vegetation cover levels and mean total regeneration stocking per milacre and mean oak stocking per milacre for 9 shelterwood stands (significant relationships at the 0.05 level in boldface).

<table>
<thead>
<tr>
<th></th>
<th>Black Huckleberry</th>
<th>Hay-scented Fern</th>
<th>Mountain-laurel</th>
<th>Rubus Spp</th>
<th>Vaccinium Spp</th>
<th>Stratum 2 Cover</th>
<th>Sedge Spp</th>
<th>Grass Spp</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Regen Stocking</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 1 vs. Year 4</td>
<td>0.941</td>
<td>0.551</td>
<td>0.679</td>
<td><strong>0.032</strong></td>
<td>0.063</td>
<td>&lt;<strong>0.001</strong></td>
<td>0.472</td>
<td>0.658</td>
</tr>
<tr>
<td></td>
<td>(-.50)</td>
<td>(-.144)</td>
<td>(-.91)</td>
<td>(+.66)</td>
<td>(-.166)</td>
<td>(+.129)</td>
<td>(-.106)</td>
<td>(-.131)</td>
</tr>
<tr>
<td>Year 1 vs. Year 7</td>
<td>0.645</td>
<td>0.784</td>
<td>0.455</td>
<td>&lt;<strong>0.001</strong></td>
<td>0.312</td>
<td>0.136</td>
<td><strong>0.011</strong></td>
<td>0.455</td>
</tr>
<tr>
<td></td>
<td>(-.50)</td>
<td>(-.144)</td>
<td>(-.91)</td>
<td>(+.66)</td>
<td>(-.166)</td>
<td>(+.129)</td>
<td>(-.106)</td>
<td>(-.131)</td>
</tr>
<tr>
<td>Year 4 vs. Year 7</td>
<td>0.899</td>
<td>&lt;<strong>0.001</strong></td>
<td><strong>0.011</strong></td>
<td><strong>0.005</strong></td>
<td>0.424</td>
<td>0.669</td>
<td>0.508</td>
<td><strong>0.007</strong></td>
</tr>
<tr>
<td></td>
<td>(-.28)</td>
<td>(-.183)</td>
<td>(-.85)</td>
<td>(-.127)</td>
<td>(-.171)</td>
<td>(-.68)</td>
<td>(-.156)</td>
<td>(-.187)</td>
</tr>
<tr>
<td><strong>Mean Oak Stocking</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 1 vs. Year 4</td>
<td>0.569</td>
<td>0.309</td>
<td>0.146</td>
<td>0.336</td>
<td>0.869</td>
<td>0.302</td>
<td>0.399</td>
<td>0.230</td>
</tr>
<tr>
<td></td>
<td>(-.50)</td>
<td>(-.144)</td>
<td>(-.91)</td>
<td>(+.66)</td>
<td>(-.166)</td>
<td>(-.129)</td>
<td>(-.106)</td>
<td>(-.131)</td>
</tr>
<tr>
<td>Year 1 vs. Year 7</td>
<td>0.380</td>
<td>0.485</td>
<td>0.674</td>
<td>0.475</td>
<td>0.858</td>
<td>0.057</td>
<td>0.248</td>
<td>0.094</td>
</tr>
<tr>
<td></td>
<td>(-.50)</td>
<td>(-.144)</td>
<td>(-.91)</td>
<td>(+.66)</td>
<td>(-.166)</td>
<td>(+.129)</td>
<td>(-.106)</td>
<td>(-.131)</td>
</tr>
<tr>
<td>Year 4 vs. Year 7</td>
<td>0.276</td>
<td>0.024</td>
<td>0.541</td>
<td>0.943</td>
<td>0.188</td>
<td><strong>0.021</strong></td>
<td>0.144</td>
<td>0.478</td>
</tr>
<tr>
<td></td>
<td>(-.28)</td>
<td>(-.183)</td>
<td>(-.85)</td>
<td>(-.127)</td>
<td>(-.171)</td>
<td>(-.68)</td>
<td>(-.156)</td>
<td>(-.187)</td>
</tr>
</tbody>
</table>

*(sign of slope coefficient, degrees of freedom)*
*Scatterplots of these relationships can be found in Tables A-44 through A-52, in Appendix I.*
Projected Stocking

The ability of regeneration stocking to predict a stand’s progress toward mature stand stocking was calculated using the percentage of milacre plots above B-level regeneration stocking as well as the percentage of plots below B-level stocking with at least one tree ≥ 5 feet in height as estimates of the number of plots within a stand that would reach full stocking at maturity. As was expected, clearcut stands showed, on average, further progress toward the desired mature stand stocking levels than shelterwood stands (Table 8). This minimum projected stocking value equates to a condition in which no plots with less than current B-level stocking and no tree >5 feet in height contribute to stocking at the reference future condition. When using only the number of milacre plots above the B-level stocking, the minimum projected stocking in clearcut stands ranged from 5.5% (9711) to 86.1% (9905) with a 42.6% average projected stocking. However, the minimum projected stocking in shelterwood stands averaged 12.0%, with only one stand having a projected stocking level of over 20% (9716, 47.8% projected minimum stocking). As Table 8 demonstrates, adding milacre plots with at least one tree ≥ 5 feet in height at age seven that were below B-level stocking greatly increased the minimum projected stocking in both clearcuts and shelterwood stands. This addition nearly tripled the projected stocking in shelterwood stands, increasing from 12.0% to 34.9%, and nearly doubled the clearcut stand average projection from 42.6% to 74.3%. Using the combined minimum projection, it appears that all but two clearcut stands have over 50% predicted future stocking (stands 9711 and 9612). The combined estimate allows for 5 out of the 9 shelterwood stands to be over 30% stocked. A similar method can be used to estimate progression toward mature stand stocking using the
Gingrich (1967) maximum area calculation. When this calculation is performed using the quadratic mean diameter of 3.7 inches and a fully occupied tree area (1000 milacres), it tells us that the target is 570 trees/acre. If this density is anticipated based on year seven stand conditions, then the stand is on the correct trajectory to be “fully stocked” at maturity. Based on the combined projected estimates from Table 8, only three clearcut stands are below this target: stand 9603, with approximately 559 trees/acre; stand 9612 with 469 trees/acre; and stand 9711 with approximately 264 trees/acre. Only one shelterwood stand, 9716, reached this target with approximately 803 trees/acre. It is clear from these projections that at year seven, the majority of clearcut stands are on the right trajectory to achieve full stocking at maturity, while very few shelterwood stands have reached this point and are failing to reach a fully stocked condition by year seven.
Table 8. Status of year seven regeneration progress toward fully-stocked mature stands.

<table>
<thead>
<tr>
<th>Stand</th>
<th>% Subplots above B-level</th>
<th>% Subplots with at least 1 tree ≥ 5 ft in height</th>
<th>Minimum Projected Stocking (^2) (at DBH=3.7 in.)</th>
<th>Likely Additional Stocking (^4) (at DBH=3.7 in.)</th>
<th>Combined Projected Stocking (^5) (at DBH = 3.7 in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clearcut</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9603</td>
<td>23.2</td>
<td>32.1</td>
<td>23.4 %</td>
<td>32.5 %</td>
<td>55.9 %</td>
</tr>
<tr>
<td>9604</td>
<td>38.1</td>
<td>33.3</td>
<td>38.5 %</td>
<td>33.7 %</td>
<td>72.2 %</td>
</tr>
<tr>
<td>9606</td>
<td>32.1</td>
<td>47.4</td>
<td>32.5 %</td>
<td>47.9 %</td>
<td>80.4 %</td>
</tr>
<tr>
<td>9607</td>
<td>56.7</td>
<td>19.6</td>
<td>57.4 %</td>
<td>19.8 %</td>
<td>77.2 %</td>
</tr>
<tr>
<td>9612</td>
<td>8.9</td>
<td>37.5</td>
<td>9.0 %</td>
<td>37.9 %</td>
<td>46.9 %</td>
</tr>
<tr>
<td>9614</td>
<td>35.1</td>
<td>41.4</td>
<td>35.5 %</td>
<td>41.9 %</td>
<td>77.4 %</td>
</tr>
<tr>
<td>9701</td>
<td>47.4</td>
<td>29.5</td>
<td>47.9 %</td>
<td>29.8 %</td>
<td>77.7 %</td>
</tr>
<tr>
<td>9706</td>
<td>30.3</td>
<td>38.6</td>
<td>30.6 %</td>
<td>39.0 %</td>
<td>69.6 %</td>
</tr>
<tr>
<td>9711</td>
<td>5.4</td>
<td>20.7</td>
<td>5.5 %</td>
<td>20.9 %</td>
<td>26.4 %</td>
</tr>
<tr>
<td>9715</td>
<td>33.6</td>
<td>43.5</td>
<td>34.0 %</td>
<td>44.0 %</td>
<td>78.0 %</td>
</tr>
<tr>
<td>9717</td>
<td>68.5</td>
<td>21.6</td>
<td>69.3 %</td>
<td>21.8 %</td>
<td>91.1 %</td>
</tr>
<tr>
<td>9718</td>
<td>17.0</td>
<td>40.2</td>
<td>17.2 %</td>
<td>40.7 %</td>
<td>57.9 %</td>
</tr>
<tr>
<td>9803</td>
<td>55.0</td>
<td>26.0</td>
<td>55.6 %</td>
<td>26.3 %</td>
<td>81.9 %</td>
</tr>
<tr>
<td>9804</td>
<td>59.2</td>
<td>38.3</td>
<td>59.9 %</td>
<td>38.7 %</td>
<td>98.6 %</td>
</tr>
<tr>
<td>9806</td>
<td>74.0</td>
<td>23.0</td>
<td>74.9 %</td>
<td>23.3 %</td>
<td>98.2 %</td>
</tr>
<tr>
<td>9905</td>
<td>85.1</td>
<td>12.8</td>
<td>86.1 %</td>
<td>12.9 %</td>
<td>99.0 %</td>
</tr>
<tr>
<td>MEAN</td>
<td></td>
<td></td>
<td>42.6 %</td>
<td>31.9 %</td>
<td>74.3 %</td>
</tr>
<tr>
<td>Shelterwood</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9601</td>
<td>19.1</td>
<td>32.1</td>
<td>19.3 %</td>
<td>32.5 %</td>
<td>51.8 %</td>
</tr>
<tr>
<td>9602</td>
<td>10.5</td>
<td>22.4</td>
<td>10.6 %</td>
<td>22.7 %</td>
<td>33.3 %</td>
</tr>
<tr>
<td>9611</td>
<td>7.8</td>
<td>10.3</td>
<td>7.9 %</td>
<td>10.4 %</td>
<td>18.3 %</td>
</tr>
<tr>
<td>9716</td>
<td>47.3</td>
<td>32.1</td>
<td>47.8 %</td>
<td>32.5 %</td>
<td>80.3 %</td>
</tr>
<tr>
<td>9807</td>
<td>2.6</td>
<td>23.3</td>
<td>2.6 %</td>
<td>23.6 %</td>
<td>26.2 %</td>
</tr>
<tr>
<td>9902</td>
<td>8.3</td>
<td>7.5</td>
<td>8.4 %</td>
<td>7.6 %</td>
<td>16.0 %</td>
</tr>
<tr>
<td>9903</td>
<td>0.0</td>
<td>10.8</td>
<td>0.0 %</td>
<td>10.9 %</td>
<td>10.9 %</td>
</tr>
<tr>
<td>9907</td>
<td>4.0</td>
<td>35.0</td>
<td>4.0 %</td>
<td>35.4 %</td>
<td>39.4 %</td>
</tr>
<tr>
<td>9908</td>
<td>7.0</td>
<td>30.7</td>
<td>7.1 %</td>
<td>31.1 %</td>
<td>38.2 %</td>
</tr>
<tr>
<td>MEAN</td>
<td></td>
<td></td>
<td>12.0 %</td>
<td>23.0 %</td>
<td>34.9 %</td>
</tr>
</tbody>
</table>

1 Milacre subplots below B-level regeneration stocking with at least 1 tree ≥ 5 ft in ht.
2 Quadratic mean diameter at breast height. Stocking calculated using an estimate of trees/ac from the percentage of subplots above B-level regeneration stocking at age seven.
3 Estimated contribution from subplots with at least one tree ≥ 5 feet in height at age seven but below B-level regeneration stocking.
4 Stocking levels below B-level stocking (57%) when stand quadratic mean DBH is 3.7 in. (Gingrich 1967) are underlined.
Determining a means to project future stand stocking from current regenerative conditions, I investigated non-tree vegetation cover levels in subplots deemed to be successfully regenerating and compare these values to subplots which were unsuccessful at year seven. In successful clearcut stands, hay-scented fern cover levels pre-harvest and one year following harvest were significantly different (p < 0.001) between successfully and not successfully regenerating subplots by year seven (Table 9). Successful and unsuccessful clearcut subplots had a statistically significant difference in mountain-laurel (p = 0.049), Rubus species (p = 0.005), and sedge species cover (p = 0.048) one year following harvest.

A similar comparison was carried out in shelterwood stands classified as unsuccessful in regenerating by year seven (Table 10). Combined cover levels for all non-tree vegetation pre-harvest was significantly different between successful and unsuccessful shelterwood plots prior to harvest (p = 0.001) and nearly so one year following harvest (p = 0.064). When evaluating cover levels by species prior to harvest, hay-scented fern (p = 0.005), mountain-laurel (p = 0.020), and Vaccinium species (p = 0.004) all had significantly different cover levels in successful versus unsuccessful subplots. This significant difference in mean percentage cover continued on year following harvest for mountain-laurel (p = 0.018), and Vaccinium species (p = 0.009).
Table 9. Comparison between mean non-tree vegetation cover levels before harvest and year 1 (standard error of the mean in parentheses) in successful vs. unsuccessful subplots within 13 successfully regenerating clearcut stands (at year seven).

<table>
<thead>
<tr>
<th>Cover Type</th>
<th>Mean % Cover</th>
<th>Successful Subplots</th>
<th>Unsuccessful Subplots</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Stratum 1 Cover (Pre-harvest)</td>
<td>45.0% (0.8)</td>
<td>45.9% (1.7)</td>
<td>0.644</td>
<td></td>
</tr>
<tr>
<td>Stratum 1 Cover (Year 1)</td>
<td>56.4% (0.7)</td>
<td>54.3% (1.5)</td>
<td>0.220</td>
<td></td>
</tr>
<tr>
<td>Stratum 2 Cover (Pre-harvest)</td>
<td>32.8% (0.7)</td>
<td>30.3% (1.4)</td>
<td>0.097</td>
<td></td>
</tr>
<tr>
<td>Stratum 2 Cover (Year 1)</td>
<td>8.3% (0.4)</td>
<td>8.8% (0.8)</td>
<td>0.530</td>
<td></td>
</tr>
<tr>
<td>Hay-scented fern (Pre-harvest)</td>
<td>10.3% (0.7)</td>
<td>17.0% (1.7)</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Hay-scented fern (Year 1)</td>
<td>8.9% (0.6)</td>
<td>17.3% (1.7)</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Black huckleberry (Pre-harvest)</td>
<td>9.4% (0.5)</td>
<td>9.4% (1.1)</td>
<td>0.987</td>
<td></td>
</tr>
<tr>
<td>Black huckleberry (Year 1)</td>
<td>4.2% (0.3)</td>
<td>4.0% (0.6)</td>
<td>0.873</td>
<td></td>
</tr>
<tr>
<td>Mountain-laurel (Pre-harvest)</td>
<td>6.5% (0.5)</td>
<td>5.1% (0.8)</td>
<td>0.126</td>
<td></td>
</tr>
<tr>
<td>Mountain-laurel (Year 1)</td>
<td>2.6% (0.2)</td>
<td>1.8% (0.3)</td>
<td>0.049</td>
<td></td>
</tr>
<tr>
<td>Vaccinium species (Pre-harvest)</td>
<td>11.7% (0.5)</td>
<td>9.2% (0.7)</td>
<td><strong>0.003</strong></td>
<td></td>
</tr>
<tr>
<td>Vaccinium species (Year 1)</td>
<td>12.4% (0.4)</td>
<td>10.8% (0.8)</td>
<td>0.086</td>
<td></td>
</tr>
<tr>
<td>Rubus species (Pre-harvest)</td>
<td>0.7% (0.1)</td>
<td>0.8% (0.2)</td>
<td>0.707</td>
<td></td>
</tr>
<tr>
<td>Rubus species (Year 1)</td>
<td>3.5% (0.3)</td>
<td>2.3% (0.3)</td>
<td><strong>0.005</strong></td>
<td></td>
</tr>
<tr>
<td>Sedge species (Pre-harvest)</td>
<td>1.0% (0.1)</td>
<td>1.0% (0.2)</td>
<td>0.793</td>
<td></td>
</tr>
<tr>
<td>Sedge species (Year 1)</td>
<td>3.2% (0.4)</td>
<td>4.9% (0.8)</td>
<td><strong>0.048</strong></td>
<td></td>
</tr>
</tbody>
</table>

1. Regeneration stocking levels above B-level stocking or occupied by at least one tree ≥ 5 feet in height
2. Regeneration stocking levels below B-level stocking nor occupied by at least one tree ≥ 5 feet in height
3. Total combined cover of all non-tree vegetation from 0 to 5 feet in height.
4. Total combined cover of all non-tree vegetation from 5 to 20 feet in height.
Table 10. Comparison between mean non-tree vegetation cover levels before harvest and at year 1 (standard error of the mean in parentheses) in successful vs. unsuccessful subplots within 8 unsuccessfully regenerating shelterwood stands (at year seven).

<table>
<thead>
<tr>
<th>Cover Type</th>
<th>Successful Subplots</th>
<th>Unsuccessful Subplots</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stratum 1 Cover(^3) (Pre-harvest)</td>
<td>44.7% (1.4)</td>
<td>50.2% (1.0)</td>
<td>0.001</td>
</tr>
<tr>
<td>Stratum 1 Cover(^3) (Year 1)</td>
<td>32.7% (1.7)</td>
<td>29.1% (1.0)</td>
<td>0.064</td>
</tr>
<tr>
<td>Stratum 2 Cover(^4) (Pre-harvest)</td>
<td>22.7% (1.3)</td>
<td>21.7% (0.8)</td>
<td>0.509</td>
</tr>
<tr>
<td>Stratum 2 Cover(^4) (Year 1)</td>
<td>3.7% (0.5)</td>
<td>4.3% (0.3)</td>
<td>0.304</td>
</tr>
<tr>
<td>Hay-scented fern (Pre-harvest)</td>
<td>16.8% (1.5)</td>
<td>22.2% (1.2)</td>
<td>0.005</td>
</tr>
<tr>
<td>Hay-scented fern (Year 1)</td>
<td>3.3% (0.4)</td>
<td>3.2% (0.3)</td>
<td>0.765</td>
</tr>
<tr>
<td>Black huckleberry (Pre-harvest)</td>
<td>2.6% (0.6)</td>
<td>2.9% (0.5)</td>
<td>0.762</td>
</tr>
<tr>
<td>Black huckleberry (Year 1)</td>
<td>2.1% (0.5)</td>
<td>2.5% (0.3)</td>
<td>0.460</td>
</tr>
<tr>
<td>Mountain-laurel (Pre-harvest)</td>
<td>10.1% (1.1)</td>
<td>13.4% (0.9)</td>
<td>0.020</td>
</tr>
<tr>
<td>Mountain-laurel (Year 1)</td>
<td>3.1% (0.4)</td>
<td>4.3% (0.3)</td>
<td>0.018</td>
</tr>
<tr>
<td>Vaccinium species (Pre-harvest)</td>
<td>15.0% (1.0)</td>
<td>11.6% (0.6)</td>
<td>0.004</td>
</tr>
<tr>
<td>Vaccinium species (Year 1)</td>
<td>9.7% (0.6)</td>
<td>7.9% (0.4)</td>
<td>0.009</td>
</tr>
<tr>
<td>Rubus species (Pre-harvest)</td>
<td>0.6% (0.1)</td>
<td>0.5% (0.1)</td>
<td>0.138</td>
</tr>
<tr>
<td>Rubus species (Year 1)</td>
<td>0.8% (0.1)</td>
<td>0.5% (0.1)</td>
<td>0.003</td>
</tr>
<tr>
<td>Sedge species (Pre-harvest)</td>
<td>1.2% (0.2)</td>
<td>1.6% (0.1)</td>
<td>0.067</td>
</tr>
<tr>
<td>Sedge species (Year 1)</td>
<td>4.7% (0.6)</td>
<td>3.1% (0.3)</td>
<td>0.012</td>
</tr>
</tbody>
</table>

\(^1\) Regeneration stocking levels above B-level stocking or occupied by at least one tree \(\geq 5\) feet in height

\(^2\) Regeneration stocking levels below B-level stocking nor occupied by at least one tree \(\geq 5\) feet in height

\(^3\) Total combined cover of all non-tree vegetation from 0 to 5 feet in height.

\(^4\) Total combined cover of all non-tree vegetation from 5 to 20 feet in height.
Logistic Regression Relationships

Binary logistic regression was used to further differentiate the effects of non-tree vegetation levels prior to harvest and one year following harvest on the success or failure of plots to become fully stocked by tree seedlings by year seven (Table 11). In all analyses, stand was treated as a class variable. Advance regeneration had a significant positive influence on regeneration outcome at year seven (p<0.001): when holding vegetation levels fixed, there was an average 9% increase in the odds of stocking success at year seven for every 1% increase in advance regeneration stocking. Pre-harvest hay-scented fern (p=0.002) and mountain-laurel cover (p=0.024) were both found to have significant negative effects on regeneration success. The odds ratios for these effects were nearly identical (0.986 for hay-scented fern and 0.984 for mountain-laurel) and indicate that for every 1% in the cover of these species prior to harvest, regeneration at year seven is 2% less likely to succeed. Hay-scented fern cover levels one year following harvest still had a significant negative effect (p<0.001) on year seven regeneration outcome. Similarly, year one sedge species cover also had significant negative effect (p=0.019), while Rubus species one year following harvest was found to have a positive effect (p=0.042) on year seven regeneration outcome. The odds ratio for Rubus cover one year following harvest was 1.035, indicating that if other variables were fixed, there is a 3.5% increase in the odds of stocking success at year seven for every 1% increase in year one Rubus cover in clearcut stands.

The same analyses were carried out for stands which received a shelterwood treatment. Advance regeneration again had a significant positive influence on regeneration outcome at year seven (p=0.004), but pre-harvest hay-scented fern
(p=0.012) was found to have a negative effect and was the only vegetation cover species prior to harvest to have a significant effect on regeneration outcome in shelterwood stands in year seven. Similar to clearcut stands, the odds ratio for the pre-harvest hay-scented fern cover levels was 0.987, which indicates that for every 1% in the cover of these species prior to harvest, regeneration at year seven about 1.3% less likely to succeed. No non-tree vegetation one year following harvest was found to have a statistically significant effect on regeneration outcome in shelterwood stands in year seven, but again advance regeneration again had a significant positive influence (p<0.001). Advance regeneration was calculated from pre-harvest stocking levels, but also included in the year one analysis.

Table 11. Binary logistic regression equations for mean total regeneration stocking success seven years after harvest versus stand attributes prior to harvest and at year one in clearcut and shelterwood stands.

<table>
<thead>
<tr>
<th>Equation #</th>
<th>Clearcut Stands</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A¹</td>
<td>07 Stocking = 24.94 + 0.088(A) – 0.014(H₀) – 0.016(K₀)</td>
</tr>
<tr>
<td>1B²</td>
<td>07 Stocking = 24.77 + 0.092(A) – 0.019(H₁) + 0.034(R₁) - 0.016(S₁)</td>
</tr>
<tr>
<td>Schoerwood Stands</td>
<td></td>
</tr>
<tr>
<td>2A¹</td>
<td>07 Stocking = 0.262 + 0.131(A) – 0.013(H₀)</td>
</tr>
<tr>
<td>2B²</td>
<td>07 Stocking = -0.563 + 0.157(A)</td>
</tr>
</tbody>
</table>

¹ Year seven regeneration stocking (success or failure) predicted by pre-harvest conditions.
² Year seven regeneration stocking (success or failure) predicted by pre-harvest and year one conditions.
DISCUSSION AND MANAGEMENT IMPLICATIONS

There are few metrics that can be referenced to determine whether or not a stand is successfully regenerating the desired species composition based on management objectives. By calculating regeneration stocking values, foresters can gain a sense of how well their stands are doing relative to one another, expressed as a single, numeric value (Figures 4 and 5). One objective of this calculation is to compare stands to each other temporally, by harvest type, or by species contribution to total regeneration stocking in a straightforward manner.

Clearcut treated stands, on average, had significantly greater regeneration stocking values than shelterwoods at three of four stand ages sampled: 4.7% vs 1.6% (p = 0.009) before harvest, 4.8% vs. 2.4% (p = 0.059) one year after harvest, 10.7 % vs. 5.6% (p = 0.016) at age four, and 17.1% vs. 8.0% (p = 0.001) at age seven (Table 2). However, these results do not necessarily indicate that clearcutting stands were more effective in promoting regeneration than shelterwood treatments. Instead, it reflects the decision by management foresters to prescribe shelterwood techniques in stands with lower levels of advance regeneration in the hope that the residual overstory would supply additional regeneration in the early stages of stand development. A great deal of research and published guidelines have indicated that shelterwood treatments can be a reliable way to enhance oak advance regeneration before a full overstory removal cut (Loftis 1990b, Marquis et al. 1984, Steiner et al. 2008). Unfortunately, the results indicate that this goal was generally unrealized in the stands under study here. Four years following harvest, only a few shelterwood stands had reached pre-harvest clearcut stand stocking levels. Similarly, at year seven, regeneration stocking levels in shelterwood stands were only
half that of clearcut-treated stands. Sander (1972) found similar results with monitored oak advance regeneration twelve years after harvest that developed very slowly in harvest treatments similar to a shelterwood cut versus more complete overstory removal twelve years after harvest. The one exception of this trend was stand 9716, which had 10.6% regeneration stocking at year four and 16.6% stocking at year seven, levels nearly equal to the average regeneration stocking values of clearcut stands at these ages. This stand was noted as having no oak regeneration prior to harvest, despite high acorn production in the previous year. However, after the harvest was conducted and light levels increased on the forest floor, high oak regeneration levels were found at year one and year four. Cover data indicated a decline in inhibiting vegetation in year four, which may have helped improve regeneration levels at year seven. This type of response was predicted by Marquis et al. (1984) when interfering non-tree vegetation in shelterwood stands is controlled, and could also apply under more natural conditions as vegetation levels decrease. This stand (9716) exhibited the highest regeneration levels among shelterwood stands for species other than oak and red maple, such as tulip-poplar and black birch.

Although total regeneration stocking was higher in unfenced stands in all years sampled, the difference was never statistically significant except prior to harvest. Forest managers typically made the choice to erect fences in stands where the pre-harvest advance regeneration levels were low and protection from over browsing would be necessary to achieve acceptable levels of regeneration. These fences were not used where high advance regeneration levels indicated that excessive browsing would not be a problem after harvest. In general, results indicated that decisions to fence or not fence
were probably appropriate, and it appears that fencing helped bring regeneration levels up to those of their unfenced counterparts.

Seven clearcut stands had over 20% total regeneration stocking per milacre by year seven, while six other stands failed to achieve even 15% regeneration stocking per milacre by year seven (Figure 4). Incremental increases in stocking over time were observed in most stands. However, stand 9604 showed a rapid expansion in stocking between years four and seven 8.7% stocking to 21.5% stocking at year seven. This is likely due to the high black birch component in this stand, which exhibited rapid height growth and development in this early successional environment. Almost all shelterwood stands demonstrated an incremental increase in stocking over time, with the exception of 9602 and 9908, which both exhibited a dramatic increase in stocking from year one to year four (Figure 5). In the case of 9602, this rapid increase was due mostly to the high densities of red maple stump sprouts found throughout the site. At 9908, only six-inch red maple seedlings were found during the year one assessment, but by year four red oak seedlings were present on site. This could be due to the exclosure fence erected following the year one assessment.

As a means to summarize the progress of all stands in this study, Table 12 illustrates the most successful clearcut and shelterwood stands in terms of total regeneration stocking. While regeneration “success” or “failure” is difficult to define for these stands, they can be compared to each other in terms of the average regeneration stocking levels. This comparison between stands offers insight into which stands offer the best example of growing conditions that promote regeneration or management techniques to mimic to improve regeneration in harvested stands. Although stands may
have below-average stocking at year four or year seven, they may still be moving along a positive trajectory. After examining the regeneration stocking charts for these stands, some stands with below average stocking (9603, 9611, 9706, 9907) appear to be moving incrementally toward the B-line and full regeneration stocking (Appendix 2) which indicates they may become “successful” in the future. Three clearcut stands (9606, 9614 and 9715) had above average stocking levels at year four, but fell below average by year seven. In all three cases, stocking barely increased (by at most 3%) from year four to year seven, while other stands had much larger increases, driving the year seven average stocking level too high for these stands which gained very little to reach. It was also important to investigate the driving force behind increases or decreases in regeneration stocking. Across almost all intervals, in clearcut and shelterwood stands, the change in aggregate height was nearly directly proportional to the change in regeneration stocking (Figures A1-A11). This clearly indicates that recruitment of new seedlings rarely drives regeneration stocking and that once a stand begins regenerating, the seedlings present at the site either as advance regeneration prior to harvest or immediately following harvest (year one) will make up the majority of total regeneration stocking at year seven. The success or failure of a site to reach acceptable stocking levels may in a large part be reliant on how well seedlings can compete with and how soon they can over-top competing non-tree vegetation.
Table 12. Summary of regeneration successes and failures among clearcut and shelterwood stands four and seven years following harvest.

<table>
<thead>
<tr>
<th></th>
<th>Below Average Stocking</th>
<th>Mean Stocking Level</th>
<th>Above Average Stocking</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Clearcut</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 4</td>
<td>9603, 9604, 9612,</td>
<td>10.7</td>
<td>9606, 9607, 9614, 9701, 9715,</td>
</tr>
<tr>
<td></td>
<td>9706, 9711, 9718, 9803</td>
<td></td>
<td>9717, 9803, 9806, 9905</td>
</tr>
<tr>
<td>Year 7</td>
<td>9603, 9606, 9612, 9614,</td>
<td>17.1</td>
<td>9604, 9607, 9701, 9717, 9803,</td>
</tr>
<tr>
<td></td>
<td>9706, 9711, 9715, 9804,</td>
<td></td>
<td>9806, 9905</td>
</tr>
<tr>
<td></td>
<td>9718</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Shelterwood</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 4</td>
<td>9602, 9611, 9807,</td>
<td>5.6</td>
<td>9601, 9716</td>
</tr>
<tr>
<td></td>
<td>9902, 9903, 9907, 9908</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 7</td>
<td>9611, 9807, 9902,</td>
<td>8.0</td>
<td>9601, 9602, 9716</td>
</tr>
<tr>
<td></td>
<td>9903, 9907, 9908</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figures 6 and 7 illustrate the components of each stand’s regeneration stocking, grouping the stands by treatment with the regeneration stocking split into three categories: all oak species, red maple, and all other tree species combined. The sites with the best average regeneration stocking per milacre: 9905, 9806 and 9717 also had the highest proportion of oak stocking relative to other tree species (Figure 6). This seems to clearly indicate that management strategies currently employed are correctly targeted towards improving oak regeneration and are often just as beneficial to other species in the stand. Conversely, while 9614 and 9604 had very high total regeneration stocking, virtually none of the seedlings were oak species. This is due to very high black birch components in both stands. At some sites, if fast-growing, early successional species like black birch, pin cherry, or even red maple, jump to an early competitive advantage, it could already be too late for oak seedlings to establish successfully (Hodges & Gardiner 1993). Other sites with especially low oak stocking components relative to total stocking...
included 9803, 9701, 9804, 9606 and 9612. Often site factors such as competing vegetation were the main reason that oak stocking was so low. Once again, at all intervals the driving force in oak stocking levels was the change in oak aggregate height. Oak species’ slow height growth relative to root growth often put the seedlings at a disadvantage compared to faster-growing non-tree vegetation like hay-scented fern. Lyon and Sharpe (2003) also found that hay-scented fern acquires nutrients like potassium and phosphorus better than red oak seedlings, slowing growth of red oaks and other hardwood species and possibly exacerbating further stresses such as herbivory or drought. Averaged across clearcut stands, oak regeneration stocking was never higher than red maple stocking at any age (1.3% vs. 2.0% before harvest, 1.6% vs. 1.9% one year following harvest, 3.4% vs. 4.1% at year four, and 4.8% vs. 5.4% at year seven), but was higher than other species stocking at one year (1.6% vs. 1.3%) and four years (3.4% vs. 3.3%) following harvest (Table 3). All other species average stocking was higher than oak stocking at year seven (6.9% vs. 4.8%). This again reflects the increased early height growth of species like black birch and tulip poplar relative to oak species.

Similarly, a positive relationship was found between mean oak advance regeneration and mean oak regeneration stocking at year seven (p= <0.001, r^2 = 0.195).

In shelterwood stands, even the best sites, 9716 and 9907, have very low oak regeneration levels (see Figure 7). This clearly illustrates the importance of following a natural timeline as opposed to a man-made timeline for initiating timber harvests. Steiner et al. (2008) highly recommend that stands harvested via the shelterwood method should be harvested immediately after a large acorn crop is produced in the stand, and that these stands often do little to supplement oak advance regeneration without a heavy acorn crop.
in the first year or two after harvest. Without the appropriate oak mast crop, the shelterwood system cannot be very effective. While the growing conditions in the shelterwood sites may have been appropriate, the seed crops were not sufficient. Despite having equivalent oak stocking and other species stocking prior to harvest, oak stocking in shelterwood stands was lower than other species stocking one year (0.4% vs. 1.0%), four years (1.0% vs. 1.9%), and seven years (1.3% vs. 3.1%) following harvest (Table 3). Oak stocking was never higher than red maple stocking levels averaged across all shelterwood stands. In addition, the low levels of oak regeneration in shelterwood stands contributed to insignificant relationships being found with advance oak regeneration in shelterwood plots. This analysis may simply be a numerical assertion of the decision that foresters in the field made regarding the decision to carry out a clearcut versus a shelterwood in their stands.

Mean oak regeneration stocking across all stands was significantly different in clearcut and shelterwood stands at all stand ages (Table 3). This again is mostly a reflection of the pre-harvest regenerative environment that dictated which harvest type would take place, rather than one of clearcut treatments being more beneficial for oak regeneration. The mean other species stocking levels seven years following harvest was also significantly different between clearcut and shelterwood treatments (p = 0.037). Many of the other species besides maple and oaks that are present in these stands develop much better in the open conditions provided by clearcut stands than the shaded environment of the shelterwood. Only the most successful shelterwood stand, 9716, has reached the pre-harvest oak regeneration stocking levels of the majority of clearcut stands at year seven. While additional time for sufficient regeneration levels to develop in
shelterwoods is expected (Atwood, et al. 2009), it was anticipated that more than one shelterwood stand in this study would be successful at year seven. Presence or absence of exclosure fencing does not seem have affected stocking for any of the three species groups. However, fencing was used where evidence suggested that heavy browsing was present, so presumably the fences were effective in preventing regeneration loss.

The relative stocking increase from year one to seven was also calculated and compared between harvest and regeneration treatment types (Table 4). When the relative increase of total regeneration stocking was calculated, the relative increase from year one to seven was higher in shelterwood than in clearcut stands (4.72 versus 4.25). This is also true when relative stocking increase is split into species categories, the increase was higher for red maple stocking (3.49 versus 3.01), oak (3.97 versus 2.46), and other species (7.74 versus 6.81) in shelterwood stands than clearcut stands. Despite the lower relative increase in stocking over time the quality of regeneration was usually superior in clearcut stands by year seven, both in density and aggregate height (Table A-1). These differences in relative stocking increase from year one to year seven were not found to be statistically significant, and it is probable that regardless of which treatment type is chosen, the stocking increase is positive. When comparing fenced versus unfenced stands, the relative total stocking increase as well as the relative red maple, oak and other species stocking increases were all higher in fenced stands than in unfenced stands; however, these differences were not statistically significant.

The next objective was to attempt to determine the relationship between regeneration stocking and woody and non-woody vegetation cover in the stands. When looking at total vegetation cover levels (Table 5), significant differences between clearcut
and shelterwood stands were seen in year one stratum 1 cover (56.8% vs. 35.9%, p = 0.023). This is likely due to the differences in light levels and growing space available between the two treatment types following harvest. However, this vegetation cover was only found to have a statistically significant negative relationship with regeneration stocking at year four (p = 0.007) and at year seven (p <0.001) in clearcut stands. Since regeneration levels were so low in shelterwood stands, a statistically significant relationship could not be established between inhibiting vegetation and tree regeneration. However, no stand of either treatment type with greater than 40% non-tree cover levels in stratum 1 had stocking levels over 10% at year four or over 15% at year seven (Figures 9 and 10). In fact, average non-tree cover levels in excess of 30% seem to negatively impact the development of oak regeneration by (Kaeser et al. 2008) and is used as a threshold in the guidelines for oak regeneration set forth by (Steiner et al. 2008).

Mean oak regeneration levels also exhibited clear negative relationships with total stratum 1 cover levels (Figures 11 and 12). Four years following harvest, no shelterwood stands and only one clearcut stand (9607) had mean oak stocking over 4% when vegetation cover was greater than 40%. Non-tree vegetation at the clearcut site consisted predominantly of *Vaccinium* species cover, with very few other species present in the understory. Similarly, at year seven only two stands (both clearcuts, 9706 and 9803) had greater than 4% oak stocking when vegetation levels were over 30%. With only two-thirds of a site available for oak seedlings, an already competitive post-harvest environment becomes even more so. In both stands that overcame high vegetation levels, *Rubus* species stocking contributed the highest proportion of non-tree vegetation cover. In the case of 9706, *Rubus* species overtook hay-scented fern as the dominant vegetation
by year seven and in 9803, forb and grass species dominated in year four, only to be replaced by *Rubus* species by year seven. This co-existence of *Rubus* species and oak regeneration is not uncommon. Donoso and Nyland (2006) found that *Rubus* species do not interfere with hardwood regeneration on upland sites and argue that *Rubus* species could enhance regeneration by providing protection from herbivory and balancing the microclimate (i.e. temperature and light conditions) near the forest floor.

Regression analysis showed no statistically significant relationships between the mean ratio of oak to maple stocking and vegetation levels in stands of either harvest type. Seven years following harvest may be too early to discuss the ratio of oak to maple stocking with any certainty. Also, non-tree vegetation could be inhibiting red maple and oak seedlings and saplings equally, resulting in small changes in the ratio of oak to maple stocking in maturing stands.

The most significant predictive comparisons at the plot level in clearcut stands were found when examining mean total regeneration stocking (Table 6). When using year one non-tree species cover as the independent variable, a significant positive relationship was found with *Rubus* species cover and mean total regeneration stocking at years four (p = 0.007) and seven (p = 0.044). This result further verifies the findings of (Donoso and Nyland 2006). Mean black huckleberry (p = 0.016) and *Vaccinium* species (p =0.001) cover values one year following harvest had a significant negative relationship with total regeneration stocking at year seven. Although *Vaccinium* species are often an associated understory species in Ridge and Valley oak forests, in some plots, dense patches of *Vaccinium* species may leave limited growing space available to seedlings attempting to germinate. When using four year non-tree vegetation cover levels as
predictors, mean black huckleberry, hay-scented fern, mountain-laurel, *Vaccinium* species and sedge species cover levels all had significant negative relationships on year seven mean total regeneration cover.

Predicting future tree regeneration in shelterwood stands based on vegetation cover levels may only be possible when examining mean total regeneration stocking (Table 7). The low levels of regeneration stocking in the nine shelterwood stands examined in this study most likely contribute to the difficulty of attempting to separate regeneration stocking by species and finding relevant relationships with vegetation in developing shelterwood stands. Validating other regression results, *Rubus* species cover levels at year one had a significantly positive relationship with year four (*p* = 0.032) and year seven (*p* < 0.001) mean total regeneration stocking. Additionally, a negative relationship with year seven mean regeneration stocking was predicted by hay-scented fern (*p* < 0.001), mountain-laurel (*p* = 0.011), and grass species cover (*p* = 0.007) at year four in developing shelterwood stands. Hay-scented fern was expected to show a negative relationship with tree regeneration based on its ability to colonize large contiguous stand areas (Fei, et al. 2010, George & Bazzaz 1999). Marquis et al. (1984) explained that mountain-laurel has a high potential to interfere with the establishment of tree regeneration and can be detrimental to the growth of existing seedlings. If mountain-laurel cover exists one year following harvest, the potential for this plant species to suppress small seedlings for light and growing space is very high. Similarly, hay-scented fern cover can limit the stand surface area available to tree regeneration, and can acquire nutrients, such as potassium, from the forest more efficiently and at a higher rate than oak species seedlings, negatively affecting the competitive balance in a stand (Lyon and
Sharpe 2003). Even without statistical analysis, it is evident as one walks though the stands that both species are noticeably affecting tree regeneration in many ORSPA shelterwood sites.

The final objective of this study was to attempt to find a way to use stand characteristics to help predict future regeneration stocking. Using binary logistic regression, I was able to develop prediction equations which indicated which stand characteristics may be contributing to the ability of a subplot to successfully regenerate by age seven (Table 11). For these analyses, I only used the successful subplots in clearcut stands and the unsuccessful plots in shelterwood stands. Among both treatment types, the only consistent stand characteristic that had a significant effect on regeneration stocking was advance regeneration. This further underscores the importance of obtaining regeneration (oak or otherwise) prior to any type of harvest, especially shelterwoods. In concurrence with other results of my study, hay-scented fern cover pre-harvest and at year one was found to have a negative effect on year seven regeneration success in clearcut stands. Once again, *Rubus* species one year following harvest was found to have a significant positive effect on the potential for regeneration success at year seven in clearcut stands. In shelterwood stands, the only non-tree vegetation type to have a significant effect on regeneration potential at year seven was hay-scented fern prior to harvest. However, the lack of significant effects from other species could be due partially to the lack of appropriate growing conditions at the site for most vegetation, not just tree seedlings.

Overall, the accuracy of predictions was higher when examining clearcut than shelterwood stands. This may be a testament to the growth factors affecting regeneration
in shelterwood stands. In clearcut stands, all tree seedlings and vegetative cover are released at once, mostly uniformly; however, in shelterwood stands, more intricate thinning patterns and patches develop (Nyland 1996). This may lessen the effect of individual species on predicting future tree regeneration. A wide variety of stand conditions, which could heavily influence seedling regeneration in harvested stands, are not included in ORSPA data collection protocols. These factors include but are not limited to: drought occurrence, seed source availability, acorn crop production, gypsy moth defoliation, and soil nutrient availability (Miller and Kochenderfer 1998).

While the prediction equations discussed above provide a possible means to predict future regeneration stocking based on previous stand conditions, there may be a faster, more concise way to quickly assess a stand’s development. When plotted on a stocking chart (Appendix 2), a stand’s progress towards “fully stocked” is quite clear. The larger the proportion of plots above the B-line, the closer the stand is to success. This benchmark may be most appropriate for evaluating a stand’s success or progress towards desired stocking levels over time. Since within-stand conditions are highly varied in this study, and many of the stand characteristics affecting tree regeneration may not be captured in ORSPA protocols, the percentage of plots above the B-line, which can be accurately estimated based on regeneration stocking calculations, may be the best predictor of future stand conditions. The percentage of plots above the B-line also provides a quick and concise calculation to assess regeneration progress based on ORSPA data.

Using Gingrich (1967) mature stand stocking charts as a guide, the percent of milacre plots above B-level stocking in regeneration stocking charts was used as a
predictor for future stand stocking as growing conditions remained unchanged and no additional trees contributing to mature stand stocking (Table 8). Using the current proportion of regeneration plots above the B-level, the minimum projected future stocking of clearcut stands at a quadratic mean diameter of 3.7 inches was 42.6%. For stands receiving a shelterwood treatment, current regeneration provides only 12.0% of desired future stand stocking at the reference condition (quadratic mean diameter of 3.7 inches). When plots with at least one tree greater than or equal to 5 feet in height were added to this projection, clearcut stands gained an average of 31.9% of additional projected future stocking at the reference condition, while shelterwood stands gained 23.0% projected stocking. When these estimates were combined, clearcut stands at age seven were projected to have on average 74.3% of stand stocking at the reference condition already present within the regenerating stand, while shelterwood stands had 34.9%. This again reflects that the goal of the shelterwood treatment, for the most part, has been unrealized by year seven in these stands. By year seven, the residual overstory has yet to supply much additional regeneration.

After projecting future stand conditions, two clearcut stands emerge from others within the treatment group: 9711, which had only 26.4% of future stand stocking at the reference condition present at year seven; and 9612, which had 46.9% of stand stocking at the reference condition present at year seven. Both these stands are identified as having high levels of non-tree interfering vegetation, which would contribute to the lack of B-level regeneration and seedlings greater than 5 feet in height. Conversely, one shelterwood stand far exceeded the mean minimum projected stocking, 9716, which currently has 80.3% of its future stand stocking at the reference condition developing. Of
all shelterwood stands, 9716 had the highest regeneration stocking levels, likely due to a decline in inhibiting non-tree vegetation that occurred four years following initial thinning. Of all shelterwood treatments, 9716 is the only stand which may also have responded well to a clearcut treatment, or it may have been timed accurately to take advantage of a large seed crop from mature, residual overstory trees. When looking at the lower levels of current regeneration available to contribute to future stand stocking in shelterwoods, this estimate further underscores the need for longer timetables for shelterwood stands to develop properly.

Minimum projected stocking predictions offer a helpful means to judge the quality as well as the quantity of regeneration in clearcut and shelterwood stands. With an average of 74.3% of future stand stocking (at a quadratic mean diameter of 3.7 inches) already developing in the clearcut stands, it seems that the treatment type was chosen properly in the case of the 16 clearcut stands. If clearcut stands should have about 75% of their future tree stocking growing by year seven, it only underlines the need for stands like 9711 and 9612 to receive active management immediately. A focused effort to reduce the density of competing non-tree vegetation in 9711 and 9612 may be warranted to help promote tree regeneration before these stands fall further behind the benchmark. If no treatment or management is available; however, the stands could be left to regenerate naturally.

Once successfully and unsuccessfully regenerating subplots at year seven had been determined, the difference in these subplots between vegetation cover levels pre-harvest and one year following harvest within a successful clearcut stand could be evaluated. One year following harvest, hay-scented fern, black huckleberry and
mountain-laurel cover levels were significantly different in successful and unsuccessful subplots (Table 9). These differences in hay-scented fern and mountain-laurel cover were also seen in the logistic regression results, which indicated a significant negative effect from fern and mountain-laurel cover. *Vaccinium* species cover levels on average were lower in unsuccessful clearcut plots (11.7% vs. 9.2% prior to harvest and 12.4% vs. 10.8% one year following harvest). The differences in the pre-harvest levels were in fact statistically significant. This result concurs with Kaeser et al. (2008) which found the highest large oak seedling densities amongst forest understory that was predominately low, ericaceous cover. When comparing non-tree vegetation in successful and unsuccessful shelterwood subplots within unsuccessful shelterwood stands, *Vaccinium* species and hay-scented fern cover levels pre-harvest and one year following harvest were significantly different (Table 10). Rojo and Carson (2006) explain that as deer browse more palatable tree regeneration, hay-scented fern can quickly spread into unoccupied habitat areas forming dense, widespread clumps. These dense patches often limit light reaching the forest floor, potentially limiting new acorn germination. In stands that have already been assessed to have low tree regeneration and are therefore chosen for shelterwood treatment, the selective browsing by deer could be enhancing the ability of hay-scented fern to inhibit new seedling establishment. In both clearcut and shelterwood treatments, it appears that hay-scented fern cover levels early in stand development may exhibit the most significant relationship with future regeneration success or failure at year seven.

Comparing all stands to each other and providing an actual regeneration value for each stand’s seedlings and comparing this value to non-tree vegetation levels provides a
means to compare current stands in the ORSPA study to one another. Those stands regenerating the most oak in terms of stocking can be used as models for other stands. Since data regarding some pre-harvest stand conditions was collected by the ORSPA study, foresters can attempt to emulate these conditions before harvesting new stands. In addition, such data provides average and above average benchmarks which can be applied to non-ORSPA stands to determine how much management must take place to keep the oak component in a developing stand as it ages. It is my belief that as a stand ages and growing conditions stabilize, an intermediate age regeneration stocking value (e.g., stands age 10 to 20) along with oak regeneration guidelines can direct future treatments and management. At this point in stand development, high densities of small seedlings will decline rapidly and variation between stocking values from assessment to assessment will decrease. Since re-entires into any regenerating stand are costly, intermediate regeneration stocking levels can focus attention onto the least successful stands allowing for more effective budgeting.

While many inferences and types of predictions can be made using regeneration stocking values, this metric has some limitations. One of the difficulties in predicting regeneration success or failure early in a stand’s development is the dynamic nature of nearly all growing conditions and plant species colonizing the stand (Dey et al. 1996). The dynamic nature of regenerating stands makes predictions especially difficult although ten years following harvest many stands may start to stabilize in terms of species composition and competitive environment. I believe that regeneration stocking equations developed for ten year measurements will express the significant relationships
between non-tree vegetation cover levels and regeneration stocking will be more conclusive.

Finally, with many ORSPA stands now reaching ten years or more past harvest, there may be an opportunity to implement a new experimental design in which the most successful stands in terms of total regeneration stocking or mean oak regeneration stocking are used as model conditions and treatments are prescribed in order to emulate pre-harvest or year one conditions in these successful stands. Additional data may also significantly improve inferences concerning shelterwood stands and may allow time for an additional acorn crop. After a significant acorn year, studying changes in regeneration stocking could provide insights on the merits of harvesting on a more “natural” schedule as opposed to one that is simply operational. Data could be collected on variables currently not considered in ORSPA protocols such as defoliation by insects, drought, or significant acorn years, and their effect on regeneration could be studied based using pre-disturbance data collected on stands within the ORSPA study. Perhaps another study could focus on stands that had either a very high or very low percent of plots above B-level stocking at year seven. These stands could be split into treatment and non-treatment blocks and management options could be explored to test which methods (such as mowing, herbicide, or supplemental seedling planting) offer the greatest “boost” to stands that may be progressing too slowly. Regeneration stocking captures many variables that could prove useful as these stands age, giving us data over the critical first ten years of development to study once stands reach maturity.
Literature Cited


APPENDIX A

Additional Data Tables and Figures

The following appendix section provides additional tables and figures which are referenced in the results and discussion section. Some data in this study could not be summarized in a straightforward manner without larger data tables. Some supporting figures are included as an addition to data summarized or explained more succinctly in the results and discussion sections.
Table A-1. Average stem density (stems/milacre), average aggregate height (stems/milacre) and average stocking value 25 mixed-oak stands measured up to seven years following harvest

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Table A-2. Mean percent ground cover per milacre values over time for black huckleberry (GABA), hay-scented fern (HAYS), mountain-laurel (KALA), *Rubus* species (RUBU) and Blueberry species (VACC) for all 25 mixed oak stands

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<tr>
<th>Stand ID</th>
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<th>Year 4 Post-harvest</th>
<th>Year 7 Post-harvest</th>
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Figure A-1. Change in stand mean regeneration stocking between year 0 and year 1 vs. change in mean seedling density.

Figure A-2. Change in stand mean regeneration stocking between year 0 and year 1 vs. change in mean seedling aggregate height.
Figure A-3. Change in stand mean regeneration stocking between year 1 and year 4 vs. change in mean seedling density.

Figure A-4. Change in stand mean regeneration stocking between year 1 and year 4 vs. change in mean seedling aggregate height.
Figure A-5. Change in stand mean regeneration stocking between year 4 and year 7 vs. change in mean seedling density.

Figure A-6. Change in stand mean regeneration stocking between year 4 and year 7 vs. change in mean seedling aggregate height.
Figure A-7. Change in stand mean regeneration stocking between year 0 and year 7 vs. change in mean seedling density.

Figure A-8. Change in stand mean regeneration stocking between year 0 and year 7 vs. change in mean seedling aggregate height.
Figure A-9. Change in stand mean regeneration stocking between year 1 and year 7 vs. change in mean seedling density.

Figure A-10. Change in stand mean regeneration stocking between year 1 and year 7 vs. change in mean seedling aggregate height.
Figure A-11. Change in stand mean red maple regeneration stocking between year 0 and year 1 vs. change in mean red maple seedling density.

Figure A-12. Change in stand mean red maple regeneration stocking between year 0 and year 1 vs. change in mean red maple seedling aggregate height.
Figure A-13. Change in stand mean red maple regeneration stocking between year 1 and year 4 vs. change in mean red maple seedling density.

Figure A-14. Change in stand mean red maple regeneration stocking between year 1 and year 4 vs. change in mean red maple seedling aggregate height.
Figure A-15. Change in stand mean red maple regeneration stocking between year 4 and year 7 vs. change in mean red maple seedling density.

Figure A-16. Change in stand mean red maple regeneration stocking between year 4 and year 7 vs. change in mean red maple seedling aggregate height.
Figure A-17. Change in stand mean red maple regeneration stocking between year 0 and year 7 vs. change in mean red maple seedling density.

Figure A-18. Change in stand mean red maple regeneration stocking between year 0 and year 7 vs. change in mean red maple seedling aggregate height.
Figure A-19. Change in stand mean red maple regeneration stocking between year 1 and year 7 vs. change in mean red maple seedling density.

Figure A-20. Change in stand mean red maple regeneration stocking between year 1 and year 7 vs. change in mean red maple seedling aggregate height.
Figure A-21. Change in stand mean oak regeneration stocking between year 0 and year 1 vs. change in mean oak seedling density.

Figure A-22. Change in stand mean oak regeneration stocking between year 0 and year 1 vs. change in mean oak seedling aggregate height.
Figure A-23. Change in stand mean oak regeneration stocking between year 1 and year 4 vs. change in mean oak seedling density.

![Figure A-23](image1)

Figure A-24. Change in stand mean oak regeneration stocking between year 1 and year 4 vs. change in mean oak seedling aggregate height.

![Figure A-24](image2)
Figure A-25. Change in stand mean oak regeneration stocking between year 4 and year 7 vs. change in mean oak seedling density.

Figure A-26. Change in stand mean oak regeneration stocking between year 4 and year 7 vs. change in mean oak seedling aggregate height.
Figure A-27. Change in stand mean oak regeneration stocking between year 0 and year 7 vs. change in mean oak seedling density.

Figure A-28. Change in stand mean oak regeneration stocking between year 0 and year 7 vs. change in mean oak seedling aggregate height.
Figure A-29. Change in stand mean oak regeneration stocking between year 1 and year 7 vs. change in mean oak seedling density.

Figure A-30. Change in stand mean oak regeneration stocking between year 1 and year 7 vs. change in mean oak seedling aggregate height.
Figure A-31. Clearcut plot level predictive positive relationship between year 4 mean total regeneration stocking and mean *Rubus* cover year 1.

Figure A-32. Clearcut plot level predictive negative relationship between year 7 mean total regeneration stocking and mean black huckleberry cover year 1.

Figure A-33. Clearcut plot level predictive negative relationship between year 7 mean total regeneration stocking and mean *Vaccinium* species cover year 1.
Figure A-34. Clearcut plot level predictive positive relationship between year 7 mean total regeneration stocking and mean *Rubus* cover year 1.

Figure A-35. Clearcut plot level predictive negative relationship between year 7 mean total regeneration stocking and mean black huckleberry cover year 4.

Figure A-36. Clearcut plot level predictive negative relationship between year 7 mean total regeneration stocking and mean hay-scented fern cover year 4.
Figure A-37. Clearcut plot level predictive negative relationship between year 7 mean total regeneration stocking and mean mountain-laurel cover year 4.

Figure A-38. Clearcut plot level predictive negative relationship between year 7 mean total regeneration stocking and mean *Vaccinium* species cover year 4.

Figure A-39. Clearcut plot level predictive negative relationship between year 7 mean total regeneration stocking and mean sedge species cover year 4.
Figure A-40. Clearcut plot level predictive negative relationship between year 4 mean oak regeneration stocking and mean hay-scented fern cover year 1.

Figure A-41. Clearcut plot level predictive positive relationship between year 4 mean oak regeneration stocking and mean *Rubus* species cover year 1.

Figure A-42. Clearcut plot level predictive negative relationship between year 7 mean oak regeneration stocking and mean hay-scented fern cover year 4.
Figure A-43. Clearcut plot level predictive negative relationship between year 7 mean oak regeneration stocking and mean *Vaccinium* species cover year 4.

![Plot Level Year 4 Vaccinium Spp Cover vs Year 7 Oak Regeneration Stocking](image)

Figure A-44. Shelterwood plot level predictive positive relationship between year 4 mean total regeneration stocking and mean *Rubus* species cover year 1.

![Plot Level Year 1 Rubus Spp Cover vs Year 4 Total Regeneration Stocking](image)

Figure A-45. Shelterwood plot level predictive positive relationship between year 4 mean total regeneration stocking and mean total stratum 2 cover year 1.

![Plot Level Year 1 Stratum 2 Cover vs Year 4 Total Regeneration Stocking](image)
Figure A-46. Shelterwood plot level predictive positive relationship between year 7 mean total regeneration stocking and *Rubus* species cover year 1.

Figure A-47. Shelterwood plot level predictive negative relationship between year 7 mean total regeneration stocking and sedge species cover year 1.

Figure A-48. Shelterwood plot level predictive negative relationship between year 7 mean total regeneration stocking and hay-scented fern cover year 4.
Figure A-49. Shelterwood plot level predictive negative relationship between year 7 mean total regeneration stocking and mountain-laurel cover year 4.

Figure A-50. Shelterwood plot level predictive negative relationship between year 7 mean total regeneration stocking and grass species cover year 4.

Figure A-51. Shelterwood plot level predictive negative relationship between year 7 mean total regeneration stocking and *Rubus* species cover year 4. 
Figure A-52. Shelterwood plot level predictive negative relationship between year 7 mean oak regeneration stocking and total stratum 2 cover year 4.
*Figures A-53 through A-58 show relationships not found to be significant between vegetation cover prior to harvest and mean total regeneration stocking at year 7 in clearcut stands.

Figure A-53. Clearcut plot level negative relationship between year 7 mean total regeneration stocking and hay-scented fern cover prior to harvest.

Figure A-54. Clearcut plot level negative relationship between year 7 mean total regeneration stocking and black huckleberry cover prior to harvest.

Figure A-55. Clearcut plot level negative relationship between year 7 mean total regeneration stocking and mountain-laurel cover prior to harvest.
*Figures A-53 through A-58 show relationships not found to be significant between vegetation cover prior to harvest and mean total regeneration stocking at year 7 in clearcut stands.

Figure A-56. Clearcut plot level negative relationship between year 7 mean total regeneration stocking and *Vaccinium* species cover prior to harvest.

Figure A-57. Clearcut plot level relationship between year 7 mean total regeneration stocking and *Rubus* species cover prior to harvest.

Figure A-58. Clearcut plot level relationship between year 7 mean total regeneration stocking and sedge species cover prior to harvest.
*Figures A-59 through A-61 show relationships not found to be significant between vegetation cover one year following harvest and mean total regeneration stocking at year 7 in clearcut stands.

Figure A-59. Clearcut plot level negative relationship between year 7 mean total regeneration stocking and hay-scented fern cover one year following harvest.

Figure A-60. Clearcut plot level negative relationship between year 7 mean total regeneration stocking and mountain-laurel cover one year following harvest.

Figure A-61. Clearcut plot level relationship between year 7 mean total regeneration stocking and sedge species cover one year following harvest.
*Figures A-62 through A-66 show relationships not found to be significant between vegetation cover prior to harvest and mean total regeneration stocking at year 7 in shelterwood stands.

Figure A-62. Shelterwood plot level negative relationship between year 7 mean total regeneration stocking and hay-scented fern cover prior to harvest.

Figure A-63. Shelterwood plot level negative relationship between year 7 mean total regeneration stocking and black huckleberry cover prior to harvest.

Figure A-64. Shelterwood plot level relationship between year 7 mean total regeneration stocking and mountain-laurel cover prior to harvest.
*Figures A-62 through A-66 show relationships not found to be significant between vegetation cover prior to harvest and mean total regeneration stocking at year 7 in shelterwood stands.

Figure A-65. Shelterwood plot level negative relationship between year 7 mean total regeneration stocking and *Vaccinium* species cover prior to harvest.

Figure A-66. Shelterwood plot level relationship between year 7 mean total regeneration stocking and sedge species cover prior to harvest.
*Figures A-67 through A-70 show relationships not found to be significant between vegetation cover one year following harvest and mean total regeneration stocking at year 7 in shelterwood stands.

Figure A-67. Shelterwood plot level negative relationship between year 7 mean total regeneration stocking and hay-scented fern cover one year following harvest.

Figure A-68. Shelterwood plot level relationship between year 7 mean total regeneration stocking and black huckleberry cover one year following harvest.

Figure A-69. Shelterwood plot level negative relationship between year 7 mean total regeneration stocking and mountain-laurel cover one year following harvest.
*Figures A-67 through A-70 show relationships not found to be significant between vegetation cover one year following harvest and mean total regeneration stocking at year 7 in shelterwood stands.

Figure A-70. Shelterwood plot level relationship between year 7 mean total regeneration stocking and *Vaccinium* species cover one year following harvest.
APPENDIX B

Regeneration Stocking Charts

The following appendix section provides regeneration stocking charts for all assessments and reassessments of mixed-oak stands completed through the 2007 field season. These charts are organized chronologically by year first assessed and are identified by their unique stand ID (i.e. 9601 is the first site added to the study in 1996). In addition, the last two digits of the number correspond to how many years following the initial harvest a stand was assessed (i.e. 960104 is the reassessment of stand 9601 four years following harvest). Also included with each stocking chart is the average regeneration stocking value per milacre plot, as well as the percent of measured plots in each stand that were found to have regeneration stocking above the B-level.
Regeneration Stocking Chart 960100

Avg. Stocking Value: 0.8%
Subplots above B-line: 0.0%

Regeneration Stocking Chart 960104

Avg. Stocking Value: 7.3%
Subplots above B-line: 14.4%

Regeneration Stocking Chart 960101

Avg. Stocking Value: 2.9%
Subplots above B-line: 0.0%

Regeneration Stocking Chart 960107

Avg. Stocking Value: 9.7%
Subplots above B-line: 19.1%
Regeneration Stocking Chart 960200

Avg. Stocking Value: 0.3%
Subplots above B-line: 0.0%

Regeneration Stocking Chart 960204

Avg. Stocking Value: 5.6%
Subplots above B-line: 4.0%

Regeneration Stocking Chart 960201

Avg. Stocking Value: 0.9%
Subplots above B-line: 0.0%

Regeneration Stocking Chart 960207

Avg. Stocking Value: 9.2%
Subplots above B-line: 10.5%
Regeneration Stocking Chart: 960210

Avg. Stocking Value: 12.1%
Subplots above B-line: 29.0%
Regeneration Stocking Chart 960300

Avg. Stocking Value: 1.9%
Subplots above B-line: 0.0%

Regeneration Stocking Chart 960301

Avg. Stocking Value: 2.7%
Subplots above B-line: 0.0%

Regeneration Stocking Chart 960304

Avg. Stocking Value: 6.2%
Subplots above B-line: 8.9%

Regeneration Stocking Chart 960307

Avg. Stocking Value: 10.9%
Subplots above B-line: 23.2%
Regeneration Stocking Chart 960310

Avg. Stocking Value: 17.3%
Subplots above B-line: 20.0%
Regeneration Stocking Chart 960400

Avg. Stocking Value: 0.8%
Subplots above B-line: 0.0%

Regeneration Stocking Chart 960404

Avg. Stocking Value: 8.7%
Subplots above B-line: 20.5%

Regeneration Stocking Chart 960401

Avg. Stocking Value: 1.1%
Subplots above B-line: 0.0%

Regeneration Stocking Chart 960407

Avg. Stocking Value: 21.9%
Subplots above B-line: 38.1%
Regeneration Stocking Chart 960410

Avg. Stocking Value: 27.3%
Subplots above B-line: 50.0%
Regeneration Stocking Chart 960600

Avg. Stocking Value: 1.5%
Subplots above B-line: 0.0%

Regeneration Stocking Chart 960604

Avg. Stocking Value: 13.6%
Subplots above B-line: 31.3%

Regeneration Stocking Chart 960601

Avg. Stocking Value: 8.7%
Subplots above B-line: 13.8%

Regeneration Stocking Chart 960607

Avg. Stocking Value: 14.2%
Subplots above B-line: 32.1%
Regeneration Stocking Chart 960610

Avg. Stocking Value: 17.9%
Subplots above B-line: 50.4%
Regeneration Stocking Chart 960700

Avg. Stocking Value: 5.2%
Subplots above B-line: 0.8%

Regeneration Stocking Chart 960704

Avg. Stocking Value: 15.1%
Subplots above B-line: 37.5%

Regeneration Stocking Chart 960701

Avg. Stocking Value: 7.3%
Subplots above B-line: 9.5%

Regeneration Stocking Chart 960707

Avg. Stocking Value: 22.9%
Subplots above B-line: 56.7%
Regeneration Stocking Chart: 960710

Avg. Stocking Value: 27.5%
Subplots above B-line: 70.8%
Regeneration Stocking Chart 961100

Avg. Stocking Value: 1.2%
Subplots above B-line: 0.8%

Regeneration Stocking Chart 961101

Avg. Stocking Value: 1.4%
Subplots above B-line: 0.9%

Regeneration Stocking Chart 961104

Avg. Stocking Value: 3.7%
Subplots above B-line: 2.6%

Regeneration Stocking Chart 961107

Avg. Stocking Value: 4.9%
Subplots above B-line: 7.8%
Regeneration Stocking Chart: 961110

Avg. Stocking Value: 7.6%
Subplots above B-line: 10.4%
Regeneration Stocking Chart 961200

Avg. Stocking Value: 1.6%
Subplots above B-line: 0.0%

Regeneration Stocking Chart 961201

Avg. Stocking Value: 1.7%
Subplots above B-line: 0.0%

Regeneration Stocking Chart 961204

Avg. Stocking Value: 5.5%
Subplots above B-line: 5.4%

Regeneration Stocking Chart 961207

Avg. Stocking Value: 7.9%
Subplots above B-line: 8.9%
Regeneration Stocking Chart: 961210

Avg. Stocking Value: 8.0%
Subplots above B-line: 13.8%
Regeneration Stocking Chart 961400

Regeneration Stocking Chart 961404

Regeneration Stocking Chart 961401

Regeneration Stocking Chart 961407

Avg. Stocking Value: 13.7%
Subplots above B-line: 16.4%

Avg. Stocking Value: 7.4%
Subplots above B-line: 14.2%

Avg. Stocking Value: 14.0%
Subplots above B-line: 31.7%

Avg. Stocking Value: 14.9%
Subplots above B-line: 35.1%
Regeneration Stocking Chart 970100

Avg. Stocking Value: 2.9%
Subplots above B-line: 0.0%

Regeneration Stocking Chart 970101

Avg. Stocking Value: 4.7%
Subplots above B-line: 8.4%

Regeneration Stocking Chart 970104

Avg. Stocking Value: 12.2%
Subplots above B-line: 28.9%

Regeneration Stocking Chart 970107

Avg. Stocking Value: 18.0%
Subplots above B-line: 47.4%
Regeneration Stocking Chart 970600

Avg. Stocking Value: 3.3%
Subplots above B-line: 0.0%

Regeneration Stocking Chart 970601

Avg. Stocking Value: 2.3%
Subplots above B-line: 1.0%

Regeneration Stocking Chart 970604

Avg. Stocking Value: 5.8%
Subplots above B-line: 7.0%

Regeneration Stocking Chart 970607

Avg. Stocking Value: 9.3%
Subplots above B-line: 30.3%
Regeneration Stocking Chart 971100

Avg. Stocking Value: 3.3%
Subplots above B-line: 2.2%

Regeneration Stocking Chart 971101

Avg. Stocking Value: 1.5%
Subplots above B-line: 1.1%

Regeneration Stocking Chart 971104

Avg. Stocking Value: 2.2%
Subplots above B-line: 0.0%

Regeneration Stocking Chart 971107

Avg. Stocking Value: 4.3%
Subplots above B-line: 5.4%
Regeneration Stocking Chart 971500

Avg. Stocking Value: 7.4%
Subplots above B-line: 10.7%

Regeneration Stocking Chart: 971504

Avg. Stocking Value: 11.5%
Subplots above B-line: 27.5%

Regeneration Stocking Chart 971501

Avg. Stocking Value: 6.9%
Subplots above B-line: 5.9%

Regeneration Stocking Chart 971507

Avg. Stocking Value: 14.4%
Subplots above B-line: 33.6%
Regeneration Stocking Chart 971600

Avg. Stocking Value: 1.5%
Subplots above B-line: 0.0%

Regeneration Stocking Chart 971601

Avg. Stocking Value: 3.2%
Subplots above B-line: 0.9%

Regeneration Stocking Chart 971604

Avg. Stocking Value: 9.7%
Subplots above B-line: 18.8%

Regeneration Stocking Chart 971607

Avg. Stocking Value: 16.6%
Subplots above B-line: 47.3%
Regeneration Stocking Chart 971700

Avg. Stocking Value: 9.2%
Subplots above B-line: 6.7%

Regeneration Stocking Chart: 971704

Avg. Stocking Value: 20.3%
Subplots above B-line: 57.1%

Regeneration Stocking Chart 971701

Avg. Stocking Value: 12.9%
Subplots above B-line: 25.2%

Regeneration Stocking Chart 971707

Avg. Stocking Value: 23.2%
Subplots above B-line: 68.5%
Regeneration Stocking Chart 971800

Avg. Stocking Value: 0.5%
Subplots above B-line: 0.0%

Regeneration Stocking Chart 971804

Avg. Stocking Value: 2.6%
Subplots above B-line: 0.0%

Regeneration Stocking Chart 971801

Avg. Stocking Value: 0.7%
Subplots above B-line: 0.0%

Regeneration Stocking Chart 971807

Avg. Stocking Value: 7.5%
Subplots above B-line: 17.0%
Regeneration Stocking Chart 980100

Avg. Stocking Value: 6.7%
Subplots above B-line: 8.9%

Regeneration Stocking Chart: 980104

Avg. Stocking Value: 34.2%
Subplots above B-line: 88.2%

Regeneration Stocking Chart 980101

Avg. Stocking Value: 8.4%
Subplots above B-line: 17.3%
Regeneration Stocking Chart 980200

Avg. Stocking Value: 3.3%
Subplots above B-line: 1.7%

Regeneration Stocking Chart 980204

Avg. Stocking Value: 19.2%
Subplots above B-line: 57.5%

Regeneration Stocking Chart 980201

Avg. Stocking Value: 2.4%
Subplots above B-line: 0.0%
Regeneration Stocking Chart 980300

Avg. Stocking Value: 8.2%
Subplots above B-line: 9.0%

Regeneration Stocking Chart 980301

Avg. Stocking Value: 3.9%
Subplots above B-line: 3.0%

Regeneration Stocking Chart 980304

Avg. Stocking Value: 9.2%
Subplots above B-line: 10.1%

Regeneration Stocking Chart 980307

Avg. Stocking Value: 20.2%
Subplots above B-line: 55.0%
Regeneration Stocking Chart 980400

Avg. Stocking Value: 1.1%
Subplots above B-line: 0.0%

Regeneration Stocking Chart: 980404

Avg. Stocking Value: 10.4%
Subplots above B-line: 20.0%

Regeneration Stocking Chart 980401

Avg. Stocking Value: 3.7%
Subplots above B-line: 0.9%

Regeneration Stocking Chart 980407

Avg. Stocking Value: 16.1%
Subplots above B-line: 59.2%
Regeneration Stocking Chart 980600

Avg. Stocking Value: 4.1%
Subplots above B-line: 0.0%

Regeneration Stocking Chart 980601

Avg. Stocking Value: 7.7%
Subplots above B-line: 12.0%

Regeneration Stocking Chart 980604

Avg. Stocking Value: 16.2%
Subplots above B-line: 52.0%

Regeneration Stocking Chart 980607

Avg. Stocking Value: 25.1%
Subplots above B-line: 74.0%
Regeneration Stocking Chart 980700

Avg. Stocking Value: 2.1%
Subplots above B-line: 0.0%

Regeneration Stocking Chart: 980704

Avg. Stocking Value: 2.7%
Subplots above B-line: 0.9%

Regeneration Stocking Chart 980701

Avg. Stocking Value: 1.9%
Subplots above B-line: 0.0%

Regeneration Stocking Chart 980707

Avg. Stocking Value: 3.7%
Subplots above B-line: 2.6%
Regeneration Stocking Chart 980800

Avg. Stocking Value: 2.8%
Subplots above B-line: 1.6%

Regeneration Stocking Chart: 980804

Avg. Stocking Value: 15.9%
Subplots above B-line: 54.0%

Regeneration Stocking Chart 980801

Avg. Stocking Value: 3.8%
Subplots above B-line: 2.9%

Regeneration Stocking Chart 980807

Avg. Stocking Value: 29.3%
Subplots above B-line: 66.3%
Regeneration Stocking Chart 990100

Avg. Stocking Value: 4.7%
Subplots above B-line: 0.9%

Regeneration Stocking Chart 990101

Avg. Stocking Value: 9.8%
Subplots above B-line: 12.0%

Regeneration Stocking Chart: 990104

Avg. Stocking Value: 26.8%
Subplots above B-line: 64.2%
Regeneration Stocking Chart 990200

Avg. Stocking Value: 3.0%
Subplots above B-line: 0.8%

Regeneration Stocking Chart: 990204

Avg. Stocking Value: 5.0%
Subplots above B-line: 4.2%

Regeneration Stocking Chart 990201

Avg. Stocking Value: 1.6%
Subplots above B-line: 0.0%

Regeneration Stocking Chart 990207

Avg. Stocking Value: 6.6%
Subplots above B-line: 8.3%
Regeneration Stocking Chart 990300

Avg. Stocking Value: 1.0%
Subplots above B-line: 0.0%

Regeneration Stocking Chart 990301

Avg. Stocking Value: 0.7%
Subplots above B-line: 0.0%

Regeneration Stocking Chart 990304

Avg. Stocking Value: 2.0%
Subplots above B-line: 0.0%

Regeneration Stocking Chart 990307

Avg. Stocking Value: 3.1%
Subplots above B-line: 0.0%
Regeneration Stocking Chart 990400

Avg. Stocking Value: 1.9%
Subplots above B-line: 0.0%

Regeneration Stocking Chart 990401

Avg. Stocking Value: 6.7%
Subplots above B-line: 5.8%

Regeneration Stocking Chart: 990404

Avg. Stocking Value: 18.5%
Subplots above B-line: 28.2%
Regeneration Stocking Chart 990500

Avg. Stocking Value: 11.3%
Subplots above B-line: 18.8%

Regeneration Stocking Chart 990501

Avg. Stocking Value: 9.0%
Subplots above B-line: 17.0%

Regeneration Stocking Chart 990504

Avg. Stocking Value: 22.5%
Subplots above B-line: 75.0%

Regeneration Stocking Chart 990507

Avg. Stocking Value: 32.1%
Subplots above B-line: 85.1%
Regeneration Stocking Chart 990600

Avg. Stocking Value: 2.4%
Subplots above B-line: 1.4%

Regeneration Stocking Chart 990601

Avg. Stocking Value: 5.0%
Subplots above B-line: 2.7%

Regeneration Stocking Chart 990604

Avg. Stocking Value: 15.5%
Subplots above B-line: 33.3%
Regeneration Stocking Chart 990700

Avg. Stocking Value: 2.8%
Subplots above B-line: 0.0%

Regeneration Stocking Chart 990704

Avg. Stocking Value: 4.5%
Subplots above B-line: 0.0%

Regeneration Stocking Chart 990701

Avg. Stocking Value: 1.5%
Subplots above B-line: 0.0%

Regeneration Stocking Chart 990707

Avg. Stocking Value: 7.6%
Subplots above B-line: 4.0%
Regeneration Stocking Chart 990800

Avg. Stocking Value: 0.8%
Subplots above B-line: 0.0%

Regeneration Stocking Chart 990801

Avg. Stocking Value: 0.7%
Subplots above B-line: 0.0%

Regeneration Stocking Chart 990804

Avg. Stocking Value: 3.0%
Subplots above B-line: 0.0%

Regeneration Stocking Chart 990807

Avg. Stocking Value: 6.3%
Subplots above B-line: 6.0%
Regeneration Stocking Chart 990900

Avg. Stocking Value: 3.9%
Subplots above B-line: 3.7%

Regeneration Stocking Chart 990901

Avg. Stocking Value: 2.9%
Subplots above B-line: 1.0%

Regeneration Stocking Chart 990904

Avg. Stocking Value: 10.9%
Subplots above B-line: 20.2%

Regeneration Stocking Chart 990907

Avg. Stocking Value: 22.0%
Subplots above B-line: 69.6%
Regeneration Stocking Chart 991000

Avg. Stocking Value: 4.7%
Subplots above B-line: 1.7%

Regeneration Stocking Chart 991001

Avg. Stocking Value: 5.9%
Subplots above B-line: 9.6%

Regeneration Stocking Chart 991004

Avg. Stocking Value: 10.2%
Subplots above B-line: 26.9%
Regeneration Stocking Chart 000100

Avg. Stocking Value: 7.1%
Subplots above B-line: 7.5%

Regeneration Stocking Chart: 000104

Avg. Stocking Value: 13.7%
Subplots above B-line: 39.2%

Regeneration Stocking Chart 000101

Avg. Stocking Value: 2.7%
Subplots above B-line: 0.8%

Regeneration Stocking Chart 000107

Avg. Stocking Value: 31.7%
Subplots above B-line: 55.2%
Regeneration Stocking Chart 000200

Avg. Stocking Value: 2.2%
Subplots above B-line: 0.8%

Regeneration Stocking Chart 000201

Avg. Stocking Value: 3.0%
Subplots above B-line: 0.0%

Regeneration Stocking Chart 000204

Avg. Stocking Value: 3.6%
Subplots above B-line: 0.0%
Regeneration Stocking Chart 000300

Avg. Stocking Value: 2.3%
Subplots above B-line: 0.0%

Regeneration Stocking Chart 000301

Avg. Stocking Value: 2.8%
Subplots above B-line: 0.0%

Regeneration Stocking Chart 000304

Avg. Stocking Value: 26.0%
Subplots above B-line: 56.3%

Regeneration Stocking Chart 000307

Avg. Stocking Value: 34.8%
Subplots above B-line: 75.6%
Regeneration Stocking Chart 000400

Avg. Stocking Value: 8.1%
Subplots above B-line: 3.3%

Regeneration Stocking Chart 000401

Avg. Stocking Value: 6.3%
Subplots above B-line: 5.0%

Regeneration Stocking Chart 000404

Avg. Stocking Value: 9.0%
Subplots above B-line: 15.0%
Regeneration Stocking Chart 020200

Avg. Stocking Value: 7.2%
Subplots above B-line: 10.0%

Regeneration Stocking Chart 020201

Avg. Stocking Value: 4.9%
Subplots above B-line: 0.1%

Regeneration Stocking Chart 020204

Avg. Stocking Value: 11.4%
Subplots above B-line: 10.9%
Regeneration Stocking Chart 020300

Avg. Stocking Value: 5.3%
Subplots above B-line: 7.7%

Regeneration Stocking Chart 020304

Avg. Stocking Value: 13.6%
Subplots above B-line: 24.3%

Regeneration Stocking Chart 020301

Avg. Stocking Value: 6.7%
Subplots above B-line: 2.5%
Regeneration Stocking Chart 020600

Avg. Stocking Value: 3.1%
Subplots above B-line: 0.0%

Regeneration Stocking Chart 020604

Avg. Stocking Value: 36.9%
Subplots above B-line: 86.2%

Regeneration Stocking Chart 020601

Avg. Stocking Value: 11.3%
Subplots above B-line: 13.8%
Regeneration Stocking Chart 060100

Avg. Stocking Value: 3.1%
Subplots above B-line: 4.5%

Regeneration Stocking Chart 060101

Avg. Stocking Value: 4.6%
Subplots above B-line: 8.3%

Regeneration Stocking Chart 060102

Avg. Stocking Value: 4.0%
Subplots above B-line: 5.3%