Formatted: Header distance from edge: 1"

DOUBLE ECONOMICS & ENVIRONMENTAL STUDIES 610

Allegheny College
Meadville, Pennsylvania
16335

"A Comparison of Worst First Forestry and Diameter Limit Cutting: Long term Yields and Valuations in Northwestern Pennsylvania Forests"

Author: Valerie Lynn Zablotny Hurst
Date: April 6, 2018

Formatted: Right: 0"

"A Comparison of Worst First Forestry and Diameter Limit Cutting: Long term Yields and Valuations in Northwestern Pennsylvania Forests"

by

Valerie Lynn Zablotny Hurst

Submitted to The Department of Economics and The Department of ~~Environmental~~Environmental Studies

Project Advisors: Tomas Nonnenmacher & Richard Bowden

Date: 5~~4~~/1~~6~~/2018

I hereby recognize and pledge to fulfill my responsibilities as defined in the Honor Code and to maintain the integrity of both myself and the College as a whole.

Your Signature:

Your Name: Valerie Lynn Zablotny Hurst

Formatted: Right: 0"

Formatted: Right: 0"

Formatted: Left

Acknowledgements

To my parents…my biggest supporters from 3,000 miles away for whom I ~~deidicate~~dedicate my work to. A special thank you to Annie Sochi and Guy Dunkle from the Foundation for Sustainable Forest~~sry~~ for their help and guidance. Thank you to my advisors Rich Bowden, for introducing me to my love of forestry, and Tomas Nonnenmacher for ushering me through this project with patience and mentorship.

Table of Contents

List of Figures vi

List of Tables vi

Abstract vii

Chapter 1: Introduction 1

Chapter 2: Literature Review ..... 7~~6~~

A. Introduction ..... 7~~6~~

B. Economic Decision Making and Maximizing Net Present Value ..... 7~~7~~

C. Comparisons of Diameter Limit Cutting and Other Harvesting Options ..... 11~~9~~

D. Timber and Logging Industries ..... 14~~1~~

E. Pests and Disease with a Potential to Impact Future Harvests ..... 16~~13~~

F. Conclusion ..... 18~~6~~

Chapter 3: Methods ..... 20~~16~~

A. Study Area ..... 20~~18~~

B. Data Collection ..... 22~~19~~

C. Modeling ..... 22~~0~~

D. Values ..... 23~~0~~

Chapter 4: Results ..... 26~~2~~

Chapter 5: Discussion ..... 38~~32~~

A. Conclusion and Management Implications ..... 42~~35~~

Appendix ..... 44~~36~~

Literature Cited ..... 45~~37~~

Formatted: Right: 0"

Formatted: Font: 16 pt, Font color: Text 1

Formatted: Centered

Formatted: Font: 12 pt

Formatted: Font: 12 pt

Formatted: Font: 12 pt

Formatted: Font: 12 pt

Formatted: Font: 12 pt

Formatted: Right: 0"

Formatted: TOC 3

List of Tables and Figures

Formatted: Font: 16 pt, Font color: Text 1

Formatted: Centered

Formatted: Line spacing: 1.5 lines

Figure 3.1 211

Figure 4.1 3025

Figure 4.2 3125

Figure 4.3 3126

Figure 4.4 3329

~~**Figure 4.5** ..... 29~~

~~**Figure 4.6** ..... 30~~

~~**Figure 4.7** ..... 30~~

Table 3.1 2120

Table 3.2 2421

Table 3.3 25

Table 4.1~~4.1~~ 2624

Table 4.2 2727

Table 4.3 287

Table 4.4 288

Table 4.5 288

Table 4.6 29

Table 4.7 34

Table 4.8 36

Formatted: Normal, Line spacing: single

Formatted: Right: 0"

Formatted: Font: +Body (Cambria), 12 pt, Bold

Abstract

Formatted: Font: 14 pt

Formatted: Line spacing: Double

Worst first (WF) forestry is a single-tree selection management approach~~appraoch~~ that ~~strategicly~~strategically removes undesirable species and cull trees to allow other desirable crop trees to reach financial maturity. Diameter limit cutting (DLC) is a common practice in northwestern Pennsylvania forests that removes trees above a certain diameter. Using a modeled 16 inch diameter limit cut and input from a local expert forester in worst first forestry, this study modeled cuts to three northwestern Pennsylvania mixed hardwood stands over a 40 year period. SILVAH 7.0 computer growth simulations modeled long term volume and value ~~yields.This~~yields. This study treated diameter limit cutting and worst first forestry as mutually exclusive investments so as to compare revenues from harvests and net present value (NPV). The empirical results reveal that at 2, 4 and 6% discount rates WF generally ~~outpreforms~~outperforms DLC for NPV when all study plots are combined, but prior stand characteristics impact individual stand response. Worst first ~~registared~~registered

total harvest revenues in two of the three stands and greater residual stand volume and value.

Formatted: Right: 0"

1

Formatted: Right: 0"

Formatted: Font: 11 pt, Not Bold

Formatted: Left, Line spacing: Multiple 1.15 li

Formatted: Right: 0"

Formatted: Header distance from edge: 1"

Commented [VH1]: Start chapters at beginning of page

Formatted: Line spacing: Double

Chapter 1: Introduction

Forests are important ecosystem service providers. Approximately 22-30% of Eearth's surface is covered in forests, which provide habitat for 70% of plant and animal species (Matthews, 2000). In Pennsylvania's forests alone, 1.2 billion tons of carbon are stored and 5 percent of the state's greenhouse gas emissions are absorbed and retained each year (McCaskill, 2013). Ecosystem goods, like timber, derive from nature's capital stocks. Other services include biodiversity maintenance, water cycling, carbon sequestration, biofuel, in addition to amenity, recreational and social benefits (Wang, 2013). Forests offset the effects of climate change through cycling carbon dioxide out of the atmosphere and thereby generating oxygen. Proper cycling of nutrients and water through soils are directly impacted by forest health. The value of forests' contribution to human welfare in the form of ecosystem services cannot purely be valued within the context of economics (Costanza, 1997). Due to difficulties in assigning valuation to services, society has historically placed less importance on conserving forest ecosystem services. Instead we have been incentivized by pricing structures to extract goods, like timber, from the land at high rates. Discriminating administration of forests through sustainable management techniques promotes the health and integrity of forest services in response to human demands.

Worst first forestry is an type approach toof sustainable forestry management approach that considers the forest and surrounding ecosystem as one. It emphasizes future stand development through single tree selection and the strategic removal of undesirable species and cull trees that allow other desirable crop trees to reach

Formatted: Right: 0"

financial maturity. Worst first tree selection focuses on cutting unhealthy or undesirable trees, but removes no more than 30% of the stand per cut, thereby leaving behind the healthiest and highest quality specimens (Rutledge, 2013). Instead of one entry into a stand every 20 years to harvest the large classes of timber, worst first foresters enter stands every 5 to 10 years to harvest moderate amounts of varied classes of timber. Managers retain the best trees for future development while creating a new age class of trees in the understory (Nyland, 2003). Also taken into consideration when planning for improvement forestry, is the removal of trees susceptible to pest and/or disease and the removal of trees to create or enlarge regeneration openings (Kenefic, 2005). For example, to allow for the highest productivity, managers will implement strategies like spacing so sunlight may filter through. This can be done by walks through ~~s of~~ the forest, marking specific trees for cutting and allowing others to flourish.

Identifying harvestable trees through the worst first approach may yield a small profit from the initial cut. But the remaining trees will continue to compound in value and mature for fifteen or thirty years, whereas a diameter limit plot won't have enough commercially viable trees (Hetzler, 2015). Salable lumber per acre revenue increases under worst first since more quality, defect-free trees have been encouraged to grow. Worst first is economically profitable when landowners take a long run perspective in generating income from forests, particularly in mixed hardwood, oak and hickory forests (Rutledge, 2013).

Diameter limit cutting (DLC) is defined as the removal of trees that measure at or above a certain diameter at breast height (Helms,1998). A tree is considered financially mature when the trees' value increases comparatively less than what a landowner could

Formatted: Right: 0"

earn in an alternative investment (Merker, 2016). However, in ~~diameter limit cutting~~DLC trees considered undesirable are left behind based on their smaller size class. DLC can be used to positively influence future stand development under certain conditions such as releasing understory trees or promoting specific shade tolerant species.

Private landowners of the northeastern United States have a deeply ingrained culture of diameter limit cutting to harvest timber (Nyland, 1992). From the perspective of a landowner, diameter limit cutting serves as an appealing tool for raising funds in a short amount of time (Jacobson, 2017 Forest Finance 1). After the first entry to a stand a landowner can expect to receive high yields and a large lump sum of cash (Nyland, 2005). A diameter is selected based on regional tradition, the financial needs of a landowner, tree species, cost of harvesting, implementation and local sawmill demand (Merker, 2016). Northwest Pennsylvania has a culture of 16 or 18 inch diameter cuts. ~~The misconception of tree diameter as an accurate representation of age persists within forester and logger ideology (Keefer et al., 2002).~~

Pennsylvania's forests are predominantly even aged, a situation where large trees and small trees are the same age (Jacobson, 2017 Forest Finance 1). Therefore, from an ecological standpoint, the notion of “take the best and leave the rest” that DLC uses results in poor species composition and slow growing, poor quality trees. The misconception of tree diameter as an accurate representation of age persists within forester and logger ideology (Keefer et al., 2002). Removing only the most commercially valuable, high quality trees tends to create genetically inferior future generations of species that ultimately command less commercial value. Additionally, profit maximization over many decades will experience diminishing returns as, with each

Formatted: Right: 0"

successive DLC cut, the forest experiences a heightened inability to "earn its keep" (Merker, 2016).

Since private hardwood stands in the Northeast are harvested with DLC, these practices foreseeably pose an ethical dilemma to future forest stewardship (Lockhart et al, 2004). Foresters perpetuate poor land stewardship by ignoring potential short and long term effects of exploiting natural resources. Ecological and ecosystem health are sacrificed to meet the immediate financial needs of landowners.

Pennsylvania's forests contain an estimated 86 million board feet of standing timber valued at $24 billion dollars. ~~(Jacobson, 2017) . In Pennsylvania T~~the Pennsylvania government controls only 3 out of every 10 acres, mainly managed by the Department of Conservation and Natural Resources (DCNR) Bureau of Forestry, the PA Game Commission and the US Forest Service (Jacobson, 2017). Remaining forest land, about 12 million acres or 70% of forests, is controlled by ~~a~~ half a million private landowners (Jacobson, 2017). As demand for timber related products grows and timber harvesting on public lands fades, there's ~~even~~ increasingly more potential for private owners to capitalize on supplying timber (Beach, 2005). This means that private Pennsylvania landowners have potentially complicated decisions to make based on their preferences for whether their land will be forested, how it will be managed and what type of, if any, harvesting will be allowed (Butler, 2013). From existing research we know that family and non-~~-~~industrial private forest landowners are a heterogeneous group of individuals (Raunikar 202, Brubaker 2006). Additionally, private landowners take non-market values, such as aesthetics and environmental ~~values~~conservation, into consideration just as much as profit maximization when making decisions about forest

Formatted: Right: 0"

management (Atmadja et al, 2013). A 2006 survey by the US Department of Agriculture and the Forest Service of private family forest landowners illustrated that owners valued their land to enjoy beauty, to protect nature, to use for hunting or fishing, and other recreation (McCaskill, 2009). Southern landowners (Raunikar et al, 2005) were willing to incur an opportunity cost of managing a stand as a plantation to continue to receive forest amenities in the form of naturally regenerating loblolly stands. However, even though those landowners may indicate concern for "stewardship", real life dilemmas like health care costs intercede, often pushing a landowner towards employing diameter limit cutting for a lump sum to cover costs.

Financial analysis and comparison of forestry management techniques helps forest owners make informed decisions about the best investment option available. We assume forest owners exist as economic actors who want to maximize their wealth, which within the field of economics is a good indicator of how people will behave. Worst first forestry involves a much longer timeline between the periods of investment and payoff. Therefore, worst first forestry must pay out higher returns on investment through higher rates of growth, a tree's "interest rate", for landowners to decide that they will invest their time in this management technique. Landowners therefore need an accurate and objective valuation of their natural resource to base management decisions on. The difference between current resource value and expected future value of a forest is a prime determinant of when a forest landowner decides to harvest mature stands (Mcketta, 1992). Since forests can be considered a capital asset to a landowner, management decisions levied on forests are the result of long term investment evaluations. Those evaluations take into consideration how management regimes will

Formatted: Right: 0"

impact the valuation of a natural resource. By manipulating a forest through either a DLC or a worst first forestry cut, we could expect different valuation results in the future.

The objective of the following research is to conduct a long term yield comparison between the two management practices of worst first forestry and diameter limit cutting. Due to sporadic record keeping by institutions using worst first forestry, there has been a lack of formal evidence presented that verifies claims of superior revenue streams over longer periods of time. I hypothesize that the practice of worst first forestry will provide greater returns on investment through higher volume and value as well as demonstrate better overall residual stand quality when modeled over a 40 year period.

I partnered with the Foundation for Sustainable Forestsry (FSF), a 501(c)(3) non-profit land trust that manages forests with the Worst First approach. Through their management they place importance on "conserving intact forested ecosystems…to highlight sustainable forestry practices" (Foundation for Sustainable Forests, 2017). FSF wants to cultivate long term management plans where forests maintain or restore species, height and functional diversity. The Foundation therefore has a distinct need to establish a comparison of yields between worst first forestry and other management approaches, such as diameter limit cutting, to verify their field based intuition that Worst First is superior for forest landowners.

Formatted: Line spacing: Double

Formatted: Right: 0"

Chapter 2: Literature Review

Formatted: Font: Bold

A. Introduction

Formatted: Indent: First line: 0.5"

The purpose of this review is to provide a summary of previous growth and yield comparison models within forestry economics as they relate to diameter limit cutting. Research is localized to the United States, focusing on ~~north-eastern~~Northeastern forests. This research generally finds that diameter limit cutting results in residual stands of poorer quality than comparable selection system stands. Additionally, this chapter provides a summary of current topics in the timber industry and a summary of pests and diseases that threaten current timber stocks. These include changes in consumer preferences in timber products and the spread of pests across the East coast, like emerald ash borer, that threaten future timber stock viability.

Formatted: Indent: First line: 0.5"

B. Economic Decision Making and Maximizing Net Present Value

The typical experimental design used to evaluate two alternative management strategies is to harvest stands using each strategy and review the growth of the residual stand. Growth within a stand is then analyzed to determine which management plan gives the greatest net financial returns as measured by net present value (NPV), a benefit/ costs ratio or an internal rate of return (Wagner, 2003). In a net present value calculation all costs and revenues are discounted back to the present time by an investors' rate of return (Timber Tax, 2012). Whichever harvesting method has the highest net present value is considered the landowner's best financial investment. While no~~No~~ benchmark for accepting or rejecting investments is perfect, ~~however~~ the

Formatted: Right: 0"

generally accepted standard for doing so is net present value (Rideout and Hesseln, 2001). The net present value approach is an important aspect of forestry yield analysis, which aims to answer how future levels of forest production will affect an owner's bottom line (Holopainen, 2010). Yield models can take the form of computer programs such as SILVAH or other stand simulators (Nyland 2005, Brubaker et al 2006). These tools help inform researchers' estimations by providing patterns of growth responses of ~~by~~ different tree species with varying growth rates after ~~a~~ different management cuts. Present value calculations are estimated with forest planning software systems as well, based on the above production predictions (Holopainen, 2010).

Methodology in the forestry economics field is informed through the application of finance theory. For example, landowners must choose between mutually exclusive investments, in which the choice of one investment precludes the selection of the other, when selecting a harvesting regime that fits their management objectives. In a 100 year study by Nyland (2005) modeling growth and yields, the net present value of selection system cutting was found to outperform DLC ~~diameter limit cutting net present value~~ at interest rates of 4%, 6% and 8%. Although a forest is clearly not a stock, bond or mutual fund, an investment in timber acts very similarly. Landowners often use financial instruments to benchmark their discount rate ~~(Wagner, 2003), which. The discount rate~~ refers to the interest rate used to determine the present value of cash flows (Wagner, 2003). A landowner's real discount rate depends on time preference, management objectives, alternative uses of capital and degree of risk aversion (Lu 1993). Over a longer investment horizon the risks of pests and disease, adverse weather conditions, changes in the valuations of species, and shifts in timber markets become exacerbated.

Formatted: Right: 0"

When Brubaker et al. (2006) tested Pennsylvania landowners' ability to estimate the present value of their forestland and the future value of their forestland in 10 years, the authors found landowners made accurate estimates of present value but much less accurate future value estimates. The participants were less aware of the relative impacts that price trends had on timber value, instead opting to explain timber value increases through biological growth of trees. This gap in knowledge about long term economic trends may be why land owners typically opt for management that typically offers short term gains, such as DLC. Landowners don't have a universal risk premium (Klemperer 1996). A risk premium is the additional return an investor receives in excess of the risk free rate of return an investment is expected to yield. Risk premiums compensate investors who can tolerate extra risk or uncertainty in their investment. For landowners who decide to wait longer between harvests, they may be rewarded with higher returns for tolerating additional risk.

In Lake states such as New York, Pennsylvania and West Virginia DLC is thought of as the only way to achieve high short term financial gains from the harvesting of trees (Wagner, 2003). Historical factors shaped the widespread application of diameter limit cutting in the northeastern United States. Diameter limit cutting was advocated for in the early twentieth century, even by environmental luminaires like Gifford Pinchot, as an alternative to widespread clearcutting (Kenefic, 2006). During the 1930's-50's the U.S. Forest Service began advising private landowners to use diameter limit cutting through marketing names like "economic selection". Governmental policy and forestry management norms played a large role in forming path dependence for Pennsylvanian foresters decision making into the 21st century.

Formatted: Superscript

Formatted: Right: 0"

Private landowners and foresters must make decisions about which cutting strategy to use on their forests using reason based on information about their financial objectives, time preferences and personal objectives. In the bounded rationality model, economic actors act in a space in which their rational decision making is bounded by limited available information, limited processing capabilities of the human mind and limited time to make decisions (Hoogstra, 2008). Conversely, the neo-classical rational choice model assumes actors will weigh costs and benefits to arrive at an action that maximizes personal utility. In this model, actors are guided by the 'invisible hand', not by culture, society or institutions in their decision making process The actors are a group of homogenous, rational agents whose preferences are static (Kant, 2003). There are also zero transaction costs to obtain information about alternatives. No one model fully encompasses decision making due to forestry's inherent complexities (Schlüter, 2007). Forest management in the last two decades has transitioned from "sustained timber yield management" to sustainble forest management" (Kant, 2003). Forestry as an industry is evolving from being yield driven to balancing ecological, economic and socio-cultural goals for the present and future generations. Applying the rational model approach in forestry draws criticism for its inability to explain the full process of decision making, especially as the field of forestry evolves in respect to management decisions (Oliveira, 2007).

Formatted: Not Highlight

Formatted: Not Highlight

Formatted: Not Highlight

Formatted: Not Highlight

Formatted: Not Highlight

Until recently however, foresters have had limited information about the long term effects of diameter-limit cutting, especially in even aged stands. When shown the large upfront financial gains possible through diameter-limit cutting, landowners understandably are motivated by the thought "Why shouldn't I take out the best trees

Formatted: Right: 0"

now, if that will give me the most money today?" (Kenefic, 2005, p.6). Using the rational model approach, when a forest owner's objectives are purely economic, they will choose the forest management option that maximizes their utility. However, owners generally aren't behaving as purely economic actors, as shown by a 2006 national survey of family forest owners on reasons for owning forest land (McCaskill, 2009). Owners ranked non-economic benefits like beauty and ability to pass land onto future generations as important. They're aligning more closely with the bounded rationality model that represents actors as heterogeneous. DLC still leaves trees behind which gives a landowners forest the appearance of natural beauty. Coufal (2000, p. 5) stated that "This situation is made complex because the public probably prefers the appearance of a high graded stand to a clear cut, and the high grading often meets the immediate needs of the landowner" (Diameter limit cuts are sometimes referred to as a high grade, given that they both remove the trees of highest quality and value).

C. Comparisons of Diameter Limit Cutting and Other Harvesting Options

Past studies evaluating diameter limit cutting profitability have shown mixed results mainly due to stand conditions differing in terms of species composition, age, structure, density and residual stand growth after a given harvesting option. Studies have implemented varying degrees of diameter limit cuts to compare different thinning regimes which resulted in a wide spectrum of even and uneven age residual stands and ensuing tree growth (Wagner et al, 2003). Even aged stands have trees of roughly the same age and height but sometimes with varying diameters depending on growing conditions (Peng, 2000). Uneven age forests typically have three or more age classes

Formatted: Right: 0"

residing within a stand; young, middle aged and then older aged trees. There are many more younger, smaller trees in uneven age stands that grow in the shade of older, overstory trees (Wittwer et al, 1990). Additionally, each study had variation in stumpage price, stumpage appreciation rates, length of study period, interest rates, associated financial criteria and differed in their decision to estimate volume growth by log grade.

Most literature points to diameter limit cuts resulting in residual stands composed of trees with genetically less desirable characteristics. Over repeated cuts, DLC exerts a dysgenic effect where future seed stocks inherit undesirable traits. As a diameter limit cut becomes more severe the stand quality will proportionally decline (Wilusz, 1974). Maynard et al (1987, pg. 35) argue that “in terms of genetic consequences, diameter-limit cutting is like destroying the first, second, and third place finishers in every horse race, and putting the last place finishers out to stud!”. When diameter limit cutting was compared to a selection system of cutting in uneven age stands, diameter limit cutting was shown to result in less regular and less frequent yields of volume and value (Nyland, 2003). An early study initiated by Eyre and Zillgitt (1953) followed the forests response over 20 years to regimes of selective cutting and diameter limit cutting in northern hardwood forests of the Lake states. Average annual gross growth of board feet per acre per year for the 12 and 20 inch diameter limit cuts both measured lower than the selection system. Selection cutting left healthy trees as residual stock, whereas the 12 inch diameter limit cut ended up on the opposite side of the spectrum with lesser quality trees as residual growing stock. When a 17 inch diameter limit cut on a 15 year cutting cycle was compared to two selection system cuts on 10 year cutting cycles, the authors Miller and Smith (1991) found stand quality improved over time with the

Formatted: Right: 0"

selection system cuts, eliminating lower grade trees and introducing more trees of higher, grade 1 logs. Consistent with other literature, the diameter limit cut produced fluctuating grades of trees over the three entries.

Nowak (1997) investigated diameter limit cuts on even aged Allegheny hardwood stands and found DLC resulted in lower financial returns in younger forests but higher financial returns in older forests. Literature from multi-decade long study periods show higher economic returns when more severe diameter limit cuts are done. When utilizing a 16 inch diameter limit cut in uneven age stands over 22 and 32 year study periods, the DLC recorded higher financial returns compared to eight other cutting treatments (Reed et al, 1996). Smith (1987) concluded that as the minimum diameter of a DLC cut increased, diameter limit cuts became more profitable than a single tree selection over a 30 to 40 year study period. In contrast to Smith, Niese's (1992) 20 year study of an even age stand found that diameter limit cuts had the lowest economic returns and tree quality when compared light, medium and heavy selection treatments. A more recent study by Kenefic et al. (2005) applied both diameter limit cutting and a selection cut at 20 year intervals since the 1950's. After three applications diameter limit cutting registered higher present value of gross harvest revenue. However, all other variables such as ~~sawtimber~~saw timber volume, ~~sawtimber~~saw timber growth, total volume, merchantable volume, regeneration stem density and inventory value were higher in selection stands.

The above findings from literature may seem contradictory, however results are highly dependent on site selection, since every forests' past management history and biological inputs will affect stand production. A commonality emerged across all studies;

Formatted: Right: 0"

diameter limit cuts produce poor quality residual stands when compared to selection cutting systems. Poor residual stands forecast declining future harvest revenues.

D. Timber and Logging Industries

The timber industry itself can be described as “fragmented (and) vertically integrated” (IRS, 2012). At the base of the system are landowners who normally sell their timber directly to loggers, who then sells or transfers the timber to sawmills, who in turn transport the product by train or truck to customers. Hardwood is sold by the board-foot varying from ⅜ inch to 6 inches in thickness and 4 to 16 feet in length. Western Pennsylvania is , asa region in Pennsylvania, the number one hardwood producing state in the U.S., that employs over 80,000 people in forest product industries (IRS, 2012). Cherry, oak , hard maple, and ash species represent the most popular and high quality wood exported from this region to create furniture, cabinets, hardwood flooring, baseball bats, pallets and railroad ties. (McCaskill, 2009). Due to mechanization of shipping in the United States, demand for pallets has especially risen given that 80% of a pallet is usually made of hardwoods like oak (IRS, 2012). Timber industry success is closely linked to outside demand for wood products, like housing materials. Hardwood timber value in Pennsylvania was estimated to be the highest in the United States prior to the 2008 depression. Once the economic downturn hit and housing prices fell, sawmill production levels and overall forestry employment decreased, and prices for finished hardwood products became discounted 30 to 50 percent (McCaskill, 2009).

Major changes have taken hold in the timber industry due to consumer tastes and demand for green products. As the world market globalizes, Pennsylvania mill

Formatted: Right: 0"

products are sent overseas as exports and must compete with other foreign suppliers (PA Hardwood Development Council, 2010). Over the last two decades, consumer demand for oak finished products has fallen after a very long time dominating the market. During the same period of time black cherry has risen in popularity, a boon for Pennsylvania since the state grows very high quality black cherry. In 2016 China imported $700 million ~~dollars~~ worth of wood and wood products, becoming the largest market in the world for U.S hardwoods and softwoods (Guangzhou, 2017). China's domestic supply for wood products cannot support domestic demand which may push the country to import up to 40% of its wood supplies in the future. Chinese f~~F~~urniture manufactures and construction projects are increasingly demanding U.S. specie varietals such as oak, walnut, cherry, ash, maple, cedar, pine, hemlock and spruce as well as premium grades of cherry, black walnut, red oak and white oak lumber.

Even though wood is a renewable resource and sustainably harvested in Pennsylvania, it is still not considered a "green product" by the general public. To capitalize on environmentally aware consumers, the industry must move towards wood product certification and better branding of hardwood for building LEED projects. There are also efforts in Pennsylvania to join the burgeoning renewable energy market by starting to utilize low value wood material for electricity and heat production.

One of the recent issues in the timber industry is the increasing parcelization of forest land. Studies have shown that the last ten years have seen an increasing number of forest owners with an associated decline in average plot size (Rickenbach et al, 2006). Economies of scale for timber harvesting diminish in the form of higher timber production costs when average plot size decreases (Row, 1978). Private nonindustrial

Formatted: Right: 0"

landowners are also less likely to implement and complete forest management with smaller sized tracts (Straka, 1984).

E. Pests and Disease with a Potential to Impact Future Harvests

One of the greatest threats to North American forest health and future forest productivity is the invasion of an exotic pest or pathogen. Chestnut blight has already wiped out adult American Chestnut's from forests. Emerald ash bore, hemlock wooly adelgid and Eeuropean gypsy moth have all either been identified in northwest Pennsylvania forests or are expected to invade in the coming years. Their effects on forest ecosystem processes are just beginning to be understood, but tree death, changes in species composition, and soil organic matter production already are affecting forest quality (Lovett et al, 2006).

Emerald Ash borer (EAB) (*agrilus planipennis fairmaire)* entered the United States in 2002 and has since then killed more than an estimated 53 million white, black, and green ash trees (Kovacs, 2010). Ash trees are popular in urban and residential areas, but have been planted with little genetic diversity, allowing the pest to easily spread and destroy urban forests (Macfarlane et al, 2005). EAB is a phloem-feeding beetle pest native to Asia that disrupts nutrient and water transport throughout a tree, eventually killing the ash in three to four years. Kovacs et al (2010) estimates the predicted cost of treatment, removal, and replacement of EAB from 2009-2019 will amount to $10.7 billion dollars. Kovacs predicted that by 2019 the entirety of Pennsylvania would be infested with EAB. Tactics to slow EAB growth include

Formatted: Right: 0"

preemptive removal of ash trees for timber, systemic insecticides and girdled ash trap trees (Mccullough, 2015).

Hemlock wooly adelgid (HWA), *adelges tsugae,* is a Japanese aphid pest that poses an extreme threat to eastern and Carolina hemlocks (Cowles, 2009). HWA lives and feeds at the base of needles, causing chlorosis of the needle and bud abortion, resulting in tree death. From Maine to Georgia, a large number of hemlock stands have either decreased or died since HWA's introduction in the early 1950's (McAvoy et al, 2017). Biological control efforts have released *Sasajiscymnus tsugae* and *Derodontidae* beetles in multiple eastern U.S states, but there's fear that the spread of HWA may outpace the biological remediation efforts. Chemical control in the form of insecticides imidacloprid and dinotefuran have shown effective treatment of HWA for up to 7 years (Benton et al, 2016). Imidacloprid is applied to the roots and surrounding base of a hemlock tree, later absorbed by fine roots and transported through the tree. Studies such as McAvoy et al (2017) and Brantley (2017) suggest by thinning surrounding trees and exposing HWA to more solar radiation, aestivating sisten populations are decreased. Scientists are also experimenting with controlled release tablets of insecticide to limit chemical movement (Crowles, 2009).

European gypsy moth (Lymantria dispar L.) is considered an outbreak species in the northeastern United States for its widespread destructive defloration (Eisenbies, 2007). Oak stands have been particularly negatively affected. Once the pest deflorates a tree, that tree experiences decreased growth, a decrease in overall quality, physiologically weak and increased rotation time for harvest. Removal of foliage and

Formatted: Right: 0"

canopy gaps from dead trees also allows for shade tolerant and less economically desirable species to grow in place of more desirable species (Fajvan, 1996).

Although not an exotic threat, white-tailed deer are becoming a major pest in Northwestern Pennsylvania. White-tailed deer populations have greatly expanded due to reduced predator populations and human intercession. Deer tend to overgraze on understory trees, affecting regeneration patterns in northern hardwood forests (Horsley et al, 2003). Deer typically graze on seedlings lower than 1.3 meters off the ground, once seedlings become taller they can mature without danger of grazing. Species such as black cherry that deer avoid due to taste, have increased in number as deer density increases. Horsley et al (2003) found that as deer density increases species richness of a forest decreases and the species Aamerican beech, bbirch and rred mmaple all saw negative impacts on height and density. Understory vegetation that's resilient to browsing begins to dominate and alter local habitats for mammals and birds. Deer populations are especially high in western Pennsylvania, making managing said populations especially important for future harvests and wildlife habitat.

F. Conclusion

Diameter limit cutting has generally shown to be an underperforming management strategy when measured against a system of selection cutting. Because the practice of diameter limit cutting is so widespread across the spectrum of landowners, the evaluation of diameter limit cutting effects remains an important topic of study given there are numerous questions about it's ability to sustain long term production levels. Decades long evaluations of the ecological effects and profitability of

diameter limit cutting are still few and far between, representing an industry wide gap in knowledge.

Formatted: Right: 0"

Formatted: Line spacing: Double

Chapter 3: Methods

A. Study Area

Three sites were selected based on geographic location within northwestern Pennsylvania's hardwood stands and excluded any stands that had been high graded within the last 20 years. Two of the stands sampled in this study, Troy Center and Moxie Woods, are managed and owned by The Foundation for Sustainable Forestsry located in Crawford County, Western Pennsylvania. The third sample site, Bousson Environmental Research Reserve, is owned and managed by Allegheny College (Figure 3.1). Allegheny College acquired Bousson in 1935 and has since maintained the tract as a recovering unmanaged forest (French Creek Watershed Research Program, 1996). Local foresters provided an estimation of each forest plots' age. Bousson and Troy Center are considered about 80 years old and Moxie Woods is considered about 60 years old. Forests found on these sites are primarily considered a type of northern Allegheny hardwood, whose territory spans more than 10 million acres in Pennsylvania, southern New York and portions of Maryland and West Virginia (Marquis,1983). Northern hardwood forests dominate the top third of Pennsylvania. Hardwood and conifer species mix in this forest type, with species present such as beech (*Fagus grandifolia*), birch (*Betula*), sugar maple (*Acer saccharum*), red maple (*Acer rubrum*), hemlock (*Tsuga Canadensis*), white pine (*Pinus strobus*) and black cherry (*Prunus serotina*). In the very northwest corner of Pennsylvania exists the beech- sugar maple forests that contain sugar maple and beech but also tulip poplar (*Liriodendron tulipifera*), basswood (*Tilia*), red oak (*Quercus rubra*), cucumber tree (*Magnolia acuminata*), yellow

Formatted: Right: 0"
Formatted: Font: Bold
Formatted: Font: 12 pt, Italic, Font color: Text 1
Formatted: Font: Italic
Formatted: Font: 12 pt, Italic
Formatted: Font: Italic
Formatted: Font: 12 pt, Italic
Formatted: Font: 12 pt, Italic
Formatted: Font: 12 pt
Formatted: Font: 12 pt, Italic
Formatted: Font: 12 pt
Formatted: Font: 12 pt, Italic
Formatted: Font: 12 pt, Italic
Formatted: Font: 12 pt, Italic
Formatted: Font: 12 pt, Italic

buckeye (*Aesculus flava*), ohio buckeye (*Aesculus glabra*), white ash (*Fraxinus Americana*) and black cherry (*Prunus serotina*). For the Bousson and Troy Center plots, the regional average annual precipitation is 44.29 inches and average annual temperature is 47.6°F. For the Moxie Woods plot, the regional average annual precipitation is 39.38 inches and average annual temperature is 48.3°F (U.S Climate Data, n.d).

Table 3.1 Study site by soil type (USDA, 2017).

Study Plot	Soil Type
Bousson	CaC (Caimbridge silt loam)
Troy Center	Hz (Hollly silty clay loam)
Moxie Woods	RaC2 (Ravenna silt loam)

Formatted: Right: 0"

Formatted: Font: 12 pt, Not Bold, Italic, Font color: Text 1

Formatted: Font: 12 pt, Italic, Font color: Text 1

Formatted: Font: 12 pt, Italic

Formatted: Font: 12 pt, Not Bold, Italic

Formatted: Font: 12 pt, Not Bold

Formatted: Font: 12 pt, Italic

Formatted: Font: Italic

Formatted: Font: Italic, Font color: Custom Color(RGB(24,24,24))

Formatted: Line spacing: Double

Formatted: Right: 0"

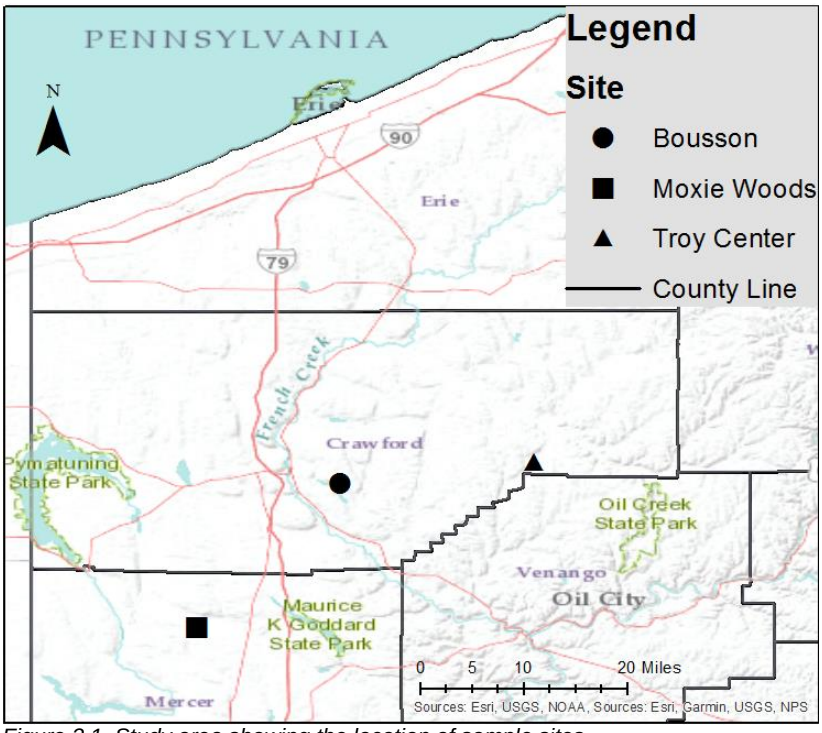


Figure 3.1. Study area showing the location of sample sites.

Formatted: Font: 11 pt

B. Data Collection

Three plots, measuring 50 x 50 meters (.6 acres) were selected from the three sites. I inventoried the diameter at breast height (DBH), species classification and merchantable height f~~F~~or every tree in the plot greater than or equal to 4 DBH ~~I inventoried the diameter at breast height (DBH), species classification and merchantable height~~. Merchantable height of each tree was recorded to the nearest half log. A whole log measures 16 feet.

Formatted: Right: 0"

Formatted: Indent: First line: 0.5", Line spacing: 1.5 lines

For every site, two scenarios of modeling were implemented; a diameter limit cut (DLC) cut scenario and a Worst First cut scenario. Both scenarios wereare modeled over a 40 year period. The DLC scenario models involved removing all trees ≥16 DBH. Guy Dunkle, a local forester employed by Firth Maple Products, provided determinations on which trees from the plot inventory would be cut under "Worst First" management. Worst First cuts were made at 10 year intervals. Diameter limit cuts were made at 20 year intervals. The base year of 2017 represents the present time and ~~or~~ initial harvest. Cuts for worst first occur in 2017, 2027, 2037, 2047 and 2057 whereas DLC only occurs in 2017, 2037 and 2057.

C. Modeling

To account for growth over the 40 year period without having to take cores from merchantable trees, field data was placed into SILVAH 7.0. SILVAH is growth simulation software designed specifically for ~~the~~ mid-Atlantic and Upper Appalachian even-aged hardwood forests~~s~~. SILVAH creates an inventory of a forest that can then be placed into multiple management scenarios and compute standing timber value ~~when prices are held constant~~. I input inventory data from the three stands into SILVAH's "Inventory Entry" and designated parameters specific to each plot such as slope, aspect, stand age, elevation and topographic position (See Appendix I). I held some parameters constant across plots such as designating deer impact as moderate and each site's productivity as medium. Under SILVAH's "Analysis and Prescription" I utilized the "Simulated Growth" tool to grow each plot 40 years in the future. For the 16

Formatted: Right: 0"

DLCBH cut I used the "Future Rx" tool to specify removal of all trees greater than or equal to 16 inches in diameter every cutting cycle. SILVAH calculated growth in DBH for each tree , and increases in saw height and pulp height to calculate a net board feet for each tree. To simplify the assessment, I assumed all trees had a quality rating of acceptable growing stock (ASG) and had no cull unless identified as dead or close to dying from the field inventory. SILVAH only calculates board feet for trees 10.5 inches in diameter and above.

D. Values

I used northwestern Pennsylvania timber prices collected by Pennsylvania State University. Prices dating back from the first quarter of 1992 up to the fourth quarter of 2017 were used to calculate an average annual price increase byfor species. I calculated the average nominal yearly timber price per species by averaging each quarter's average nominal timber price. From each species' average nominal price and yearly average inflation rates, I produced the prices' future value in 2017 terms (Table 3.2). I used the future values to compute annual growth rate and then averaged the growth rates. Average growth rates were used to estimate future prices for species specific timber in 2027, 2037, 2047 and 2057 (Table 3.3).

Table 3.2. A sample from the Black Cherry calculations to find annual growth rate by species.

Formatted: Font: 11 pt

Year	Nominal average price($)	Future value [FV=PV/(1/(1+i)^n)]	Annual Price Growth [(FV$_1$ -FV$_2$)/ FV$_2$]
1992	544.25	949.57	na
1993	748.25	1267.55	0.33487
1994	891.25	1472.1	0.16137
1995	748.75	1202.65	-0.18304
1996	836.25	1304.67	0.08483
1997	968	1476.34	0.13158
1998	1103	1656.44	0.12199
1999	1346.75	1978.78	0.19460
2000	1582.75	2249.91	0.13702

Table 3.3. Price trends modeled by species, 40 years into the future using the average annual growth rates extracted from price information from the northwestern Pennsylvania region during the years 1992-2017.

Species	2017 4th Quarter Average Price($)	Average annual increase(19922007-2017) %	Average annual increase	2027	2037	2047	2057
Northern Rred Ooak	546	0.31%	0.00309	563.12	580.77	598.97	617.75
Wwhite Ooak	415	1.83%	0.01830	497.49	596.39	714.94	857.05
Mmixed Ooak	315	0.93%	0.00927	345.44	378.83	415.44	455.59
Bblack Ccherry	840	0.50%	0.00495	882.55	927.26	974.23	1023.58
Wwhite Aash	274	-0.49	-0.00490	260.87	248.36	236.46	225.12
Hhard Mmaple	390	3.52%	0.03520	551.22	779.09	1101.15	1556.35
soft maple	286	4.27%	0.04269	434.42	659.86	1002.30	1522.45
yellow poplar	148	2.27%	0.02268	185.20	231.76	290.01	362.91
misc. hardwoods	91	2.52%	0.02524	116.76	149.81	192.22	246.63
white pine	59	1.90%	0.01898	71.21	85.94	103.72	125.17

Formatted: Right: 0"

Formatted Table

Formatted: Line spacing: Double

Formatted: Font: 11 pt

Formatted: Right: 0"

Formatted: Indent: First line: 0"

Two revenue calculations will be included in the final results: ~~calculations~~ estimated ~~f~~ed ~~f~~uture prices of timber multiplied by the board ~~foor~~for growth calculations made by SILVAH and the ~~subsequent present values~~net present value (NPV). ~~To calculate the future value of money and discount cash flows for each time period I will use present value:~~

Formatted: Indent: First line: 0"

~~**PV = FV / (1+i)^t**~~

~~**PV= Present Value**~~

~~**FV= Future Value**~~

~~**i= interest rate**~~

~~**t= years of project ifetime**~~

Formatted: Indent: Left: 0", First line: 0"

Because I will have uneven cash inflows from each harvest's revenue, I will specifically use the following formula:

Formatted: Indent: Left: 0", First line: 0"

NPV = (C for Period 1 / (1 + i)^1) + (C for Period 2 / (1 + i)^2) ... (C for Period *x* / (1 + ~~-~~i)^x)

Formatted: Font: 11 pt

Formatted: Left

NPV= Net Present Value

C= Expected Cash Flow

i= Required rate of return

I am not accounting for an initial investment to buy the property or additional costs of inventory and marking. By using the NPV ~~the Present Value~~ equation, I discount future revenues back to the present. After computing present value for each cutting cycle separately, I will sum the results across cutting cycles to get a net present value across the 40 year simulation period.

	Moxie Woods	Troy Center	Bousson
# of trees in stand (.6 acre)	89	88	104
Estimated # trees/ acre	148.33	146.66	173.33
# Dead Trees	1	4	4
Average DBH (in)	11.16	11.64	11.31
Min DBH (in)	4.2	4	4
Max DBH (in)	28	28	27
Stems per acre			
Sugar Maple	23.67	123.33	21.67
Red Maple	66.67	6.67	98.33
Black Cherry	6.67	8.33	23.33
Tulip Poplar	21.67	---	5.00
Northern Red Oak	---	---	8.33
White Pine	---	---	---
White Ash	5.00	1.67	---
American Elm	---	---	1.67
Red Oak	---	---	---
Red Pine	---	---	1.67
Norway Spruce	---	---	1.67
American Beech	---	1.67	1.67
Yellow Birch	---	---	3.33
Norway Spruce	---	---	---
Sassafras	6.67	---	---
Black Gum	8.33	---	---
Cucumber Magnolia	1.67	1.67	---
Hophornbeam	3.33	---	---
Black Oak	1.67	---	---
Basswood	---	1.67	---
Hickory	---	1.67	---
Total Basal Area (sqft/acre)	121.86	142.19	146.46
Sugar Maple BA	9.82(8.06%)	114.35(80.42%)	4.96(3.39%)
Red Maple BA	67.71(55.56%)	13.47(9.47%)	92.63(63.45%)
Black Cherry BA	3.44(2.82%)	7.71(5.42%)	26.87(18.35%)
Tulip Poplar BA	49.01(40.22%)	---	8.71(5.95%)
Northern Red Oak BA	---	---	---
White Pine BA	---	---	---
White Ash BA	3.47(2.85%)	1.61(1.13%)	---
American Elm BA	---	---	0.54(0.37%)
Red Oak BA	---	---	9.62(6.57%)
Red Pine BA	---	---	0.88(0.60%)
Norway Spruce BA	---	---	1.14(0.78%)
Beech BA	---	0.16(0.11%)	0.14(0.10%)
Yellow Birch BA	---	---	0.65(0.44%)
Norway Spruce BA	---	---	---
Sassafras BA	4.47(3.67%)	---	---
Black Gum BA	1.52(1.25%)	---	---
Cucumber Magnolia BA	0.22(0.18%)	0.32(0.23%)	---
Hophornbeam BA	0.58(0.48%)	---	---
Black Oak BA	2.55(2.09%)	---	---
Basswood BA	---	0.72(0.51%)	---
Hickory BA	---	2.26(1.59%)	---
Location (Lat, Long)	41.407475, -80.282676	41.645859, -79.810656	41.608000, -80.040168
Total # of trees removed WF	76	58	80
# Trees removed in 2017(WF)	36	3	32
# Trees Removed in 2027(WF)	11	14	10
# Trees Removed in 2037(WF)	16	13	15
# Trees Removed in 2047(WF)	8	17	12
# Trees Removed in 2057(WF)	5	11	11
Total # of trees removed 16 DLC	33	32	32
# Trees removed in 2017(16 DLC)	15	23	19
# Trees Removed in 2027(16 DLC)	0	0	0
# Trees Removed in 2037(16 DLC)	9	3	6
# Trees Removed in 2047(16 DLC)	0	0	0
# Trees Removed in 2057(16 DLC)	9	6	7

Table 4.1 Plot Characteristics for Moxie Woods, Troy Center and Bousson.

Chapter 4: Results

This study compared three modeled diameter limtit cut (DLC) harvests to four modeled Worst First (WF) harvests over a 40 period. I had four objectives; find which

Formatted: Right: 0"

Formatted: Font: Not Italic

Formatted: Line spacing: Double

Formatted: Font: 12 pt

Formatted: Normal, Indent: First line: 0"

Formatted: Indent: First line: 0.5"

harvesting approach resulted in the greatest economic revenue, find which approach resulted in the greatest volume in board feet harvested, which approach resulted in the most consistent harvest revenues and which approach ended with higher residual volume and value. The highest total harvest value by plot is led by WF Bousson with $ 4,695 followed by WF Troy Center ($ 3,378) and in third is DLC Bousson ($3,810). DLC applied to Moxie Woods(6,824 bdft) had the greatest total volume harvested by plot followed by Bousson DLC (6,587 bdft).

When the three plots are combined together, the ~~Worst First(~~WF ~~)~~ aggregate harvest values outperform those of DLC after 40 years even though ~~Worst First~~WF harvested fewer total board feet (Table 4.2). The 2057 WF combined plot residual stands' board feet is 4.45 times greater than the DLC. ~~After adding the WF board feet from 2057 to the total ending harvested board feetWF ends up with a board ft thaexceeds DLC. When the WF 2057 residual stand value is added in a similar manner to the WF total harvestvalue the "Total, with ending residual" value is almost double that of DLC.~~

Table 4.2 Total board feet production, values of harvests and values of residual standing timber in all plots.

ALL PLOTS COMBINED								
	Harvested Volume(Bdft)		Residual Standing Volume(Bdft)		Harvest Value($)		Residual Standing Timber Value($)	
Year	WF	DLC	WF	DLC	WF	DLC	WF	DLC
2017(Pre-Cut)	na	na	18,484	18,484	na	na	6,432	6,432
2017	3674	14,733	14,811	3,752	1,338	3,694	5,094	2,738
2027	2,417	na	14,786	na	882	na	6,893	na
2037	4,448	1,918	12,112	3,503	2,616	1,439	7,608	2,204
2047	3,547	na	11,470	na	2,879	na	8,901	na
2057	2,535	3,391	8,935	2,007	2,560	3,962	11,189	2,582

Formatted: Right: 0"

Formatted: Normal

Formatted: Space Before: 0 pt, After: 0 pt, Line spacing: Double, Widow/Orphan control, Don't keep with next, Don't keep lines together

Formatted: Font: 10 pt

Formatted: Font: (Default) Arial, 11 pt, Italic

~~variabilityindividually~~*Table 4.3 Board feet production, values of harvests and values of residual standing timber in Moxie Woods plot.* [1]

MOXIE WOODS								
	Harvested Volume(Bdft)		Residual Standing Volume(Bdft)		Harvest Value($)	Residual Standing Timber Value($)		
Year	WF	DLC	WF	DLC	WF	DLC	WF	DLC
2017(Pre-Cut)	na	na	5,473	5,473	na	na	1,108	1,108
2017	782	4,207	4,691	1,266	184	713	924	395
2027	1,403	na	4,066	na	350	na	1,066	na
2037	1,754	1,364	2,807	920	524	913	1,126	482
2047	1,068	na	2,060	na	679	na	1,106	na
2057	1,090	1,254	1,175	727	455	1,021	1,308	1,048

Table 4.4 Board feet production, values of harvests and values of residual standing timber in Bousson plot.

BOUSSON								
	Harvested Volume(Bdft)		Residual Standing Volume(Bdft)		Harvest Value($)	Residual Standing Timber Value($)		
Year	WF	DLC	WF	DLC	WF	DLC	WF	DLC
2017(Pre-Cut)	na	na	7,183	7,183	na	na	2,947	2,947
2017	1,752	5,320	5,431	1,863	536	2,269	2,411	678
2027	174	na	5,633	na	66	na	3,121	na
2037	1,581	178	4,813	1,671	1,209	233	3,127	1,038
2047	1,713	na	3,880	na	1,342	na	3,334	na
2057	919	1,088	3,607	818	1,542	1,308	3,436	909

Table 4.5 Board feet production, values of harvests and values of residual standing timber in Troy Center plot.

[1] *Harvest value for all stands is computed by multiplying the species specific board foot yield by species specific timber price.*

Formatted: Right: 0"
Formatted: Line spacing: Double
Formatted: Font: 15 pt, Italic, Font color: Gray-60%
Formatted: Font: 10 pt
Formatted Table
Formatted: Line spacing: Double
Formatted: Font: Italic
Formatted: Line spacing: Double
Formatted: English (United States)

TROY CENTER								
	Harvested Volume(Bdft)		Residual Standing Volume(Bdft)		Harvest Value($)		Residual Standing Timber Value($)	
Year	WF	DLC	WF	DLC	WF	DLC	WF	DLC
2017(Pre-Cut)	na	na	5,829	5,829	na	na	2,377	2,377
2017	1,140	5,206	4,689	623	618	713	1,759	1,664
2027	839	na	5,087	na	465	na	2,705	na
2037	1,113	376	4,493	912	883	293	3,355	683
2047	766	na	4,241	na	858	na	4,461	na
2057	526	1,049	4,153	462	563	1,632	6,445	625

Moxie Woods is the only plot out of the three where WF underperforms when compared to DLC in board feet and value extracted (Table 4.3). It also has the lowest total harvest values overall, under both management approaches, of the three plots. Moxie Woods has just recently come under the management of The Foundation for Sustainable ~~Forestry~~Forest~~sry~~. The cuts made to Moxie under the WF model may be considered more of "recovery cuts" that aren't expected to gain much revenue but rehabilitate the stand after a damaging high grade. After the last cut in 2057, every stand had a different residual standing timber volume. The WF approach resulted in 2057 residual standing volume that numbered in the thousands of board feet compared to the hundreds of board feet for DLC, indicating that WF encourges longevity and quality for a stands' overall heatlh.

Table 4.6 Total harvested volume, residual standing volume, total harvest values and total residual values by individual plot and by all plots summed together.

30

Formatted: Right: 0"

Formatted: Indent: First line: 0"

Formatted: Font: 11 pt, Italic

	Bousson		Moxie Woods		Troy Center		All Plots	
	WF	DLC	WF	DLC	WF	DLC	WF	DLC
Total Harvested Volume(Bdft)	6,138	6,587	6,098	6,824	4,384	6,631	16,621	20,042
Residual Standing Volume 2057(Bdft)	3,607	818	1,175	727	4,153	462	8,935	2,007
Total Harvest + 2057 Residual(Bdft)	9,745	7,405	7,273	7,551	8,537	7,093	25,556	22,049
Total Harvest Value($)	$ 4,695	$ 3,810	$ 2,192	$ 2,647	$ 3,387	$ 2,638	$ 10,275	$ 9,095
Total Residual Standing Timber Value 2057($)	$ 3,436	$ 909	$ 1,308	$ 1,048	$ 6,445	$ 625	$ 11,189	$ 2,582
Total Harvest Value + 2057 Residual Value($)	$ 8,132	$ 4,719	$ 3,500	$ 3,695	$ 9,832	$ 3,263	$ 21,464	$ 11,677

WF showed greater similarity and consistency of harvest yields across time (Table 4.3, 4.4, 4.5). DLC cuts tended to remove a large amount of board feet in the first 2017 cut followed by a very small 2037 cut . In 2017, DLC cuts typically harvested four to five thousand board feet, followed by just a few hundred board feet in 2037 and then approximately 1,000 board feet in 2057. Worst first harvest volume hovered around the mid to low 1,000 board feet every harvest rotation. Bousson saw an ~~anomoly~~anomaly in 2027 when only 174 board feet was harvested for WF (Table 4.4).

After adding the WF standing board feet from 2057 to the total ending harvested board feet, WF ends up with a total combined plot board foot value that exceeds DLC (Table 4.6). When the WF 2057 residual standing timber value is added in a similar manner to the WF total harvest value the “Total, with ending residual” value is almost double that of DLC. Combining all of the plots doesn’t demonstrate the wide variability that the three plots experienced individually in their response to each management approach.

Formatted: Right: 0"

Formatted: Font: 12 pt

Formatted: Indent: First line: 0.5", Line spacing: Double

Formatted: Font: Italic

Formatted: Right: 0"

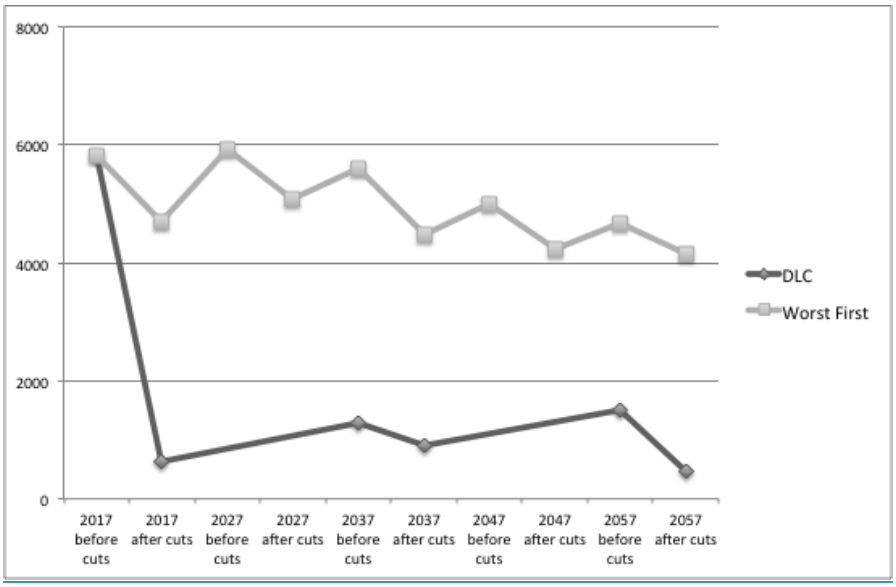


Figure 4.1 Worst First and DLC standing volume of timber in Troy Center.

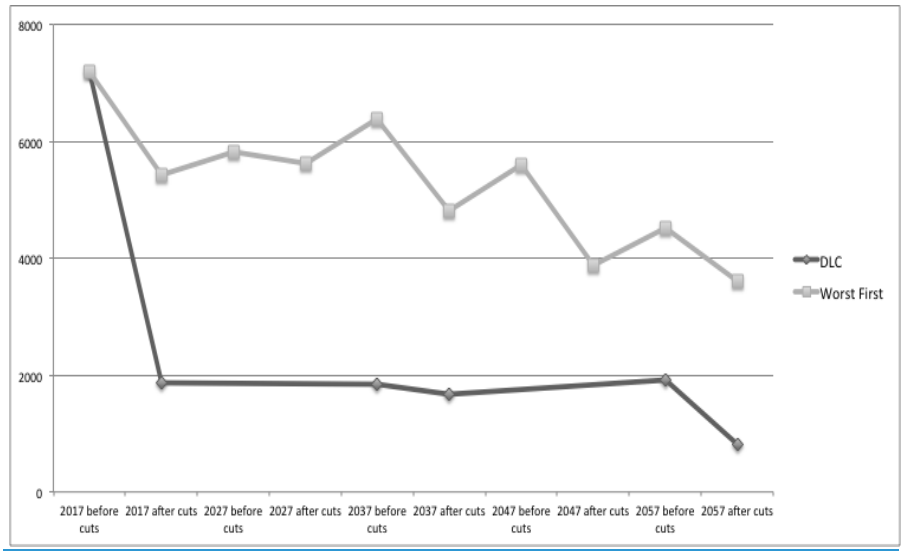


Figure 4.2 Worst First and DLC of standing volume of timber in Bousson.

Formatted: Right: 0"

Formatted: Font: Italic

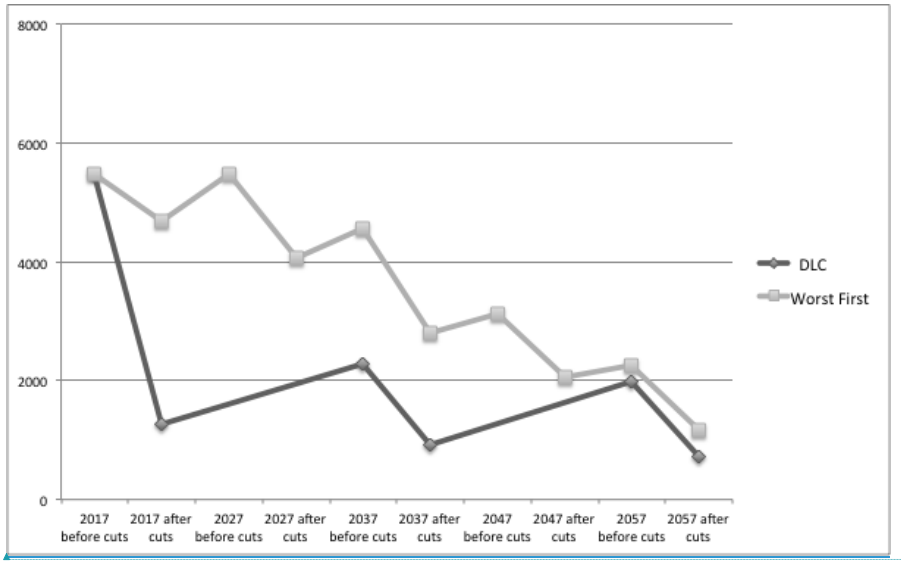


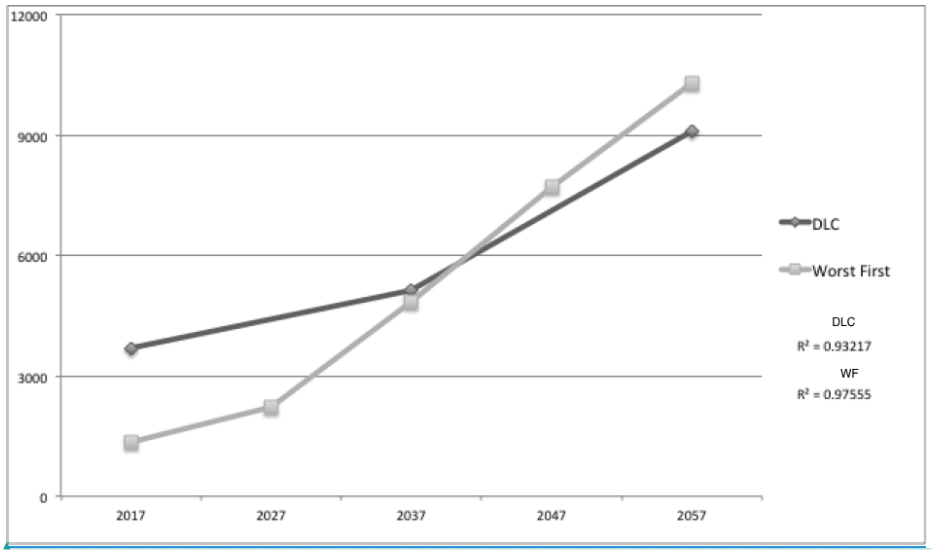
Figure 4.3 Worst First and DLC of standing volume of timber in Moxie Woods.

Formatted: Indent: First line: 0"

Because of the cyclical process of harvesting and then allowing trees to grow we see a seesaw pattern of the standing volume of timber in each plot (Figure 4.5, 4.6, 4.7). Worst First timber harvests sustain higher levels of long term production capabilities across time in Bousson and Troy Center compared to DLC (Figure 4.5, Figure 4.6). Nevertheless, Bousson and Troy Center still experience an overall downward trend in standing volume over the 40 year period. Troy Center has the least Moxie Woods more closely follows the severe downward trend of DLC (Figure 4.4). For all three plots the DLC scenario takes a sharp drop in standing volume right after the 2017 harvest and then stays under approximately 2000 board feet for the rest of the model. The modeled DLC forest seems to never be able to regenerate to it's original standing volume throughout the 40 years.

Formatted: Right: 0"

The Bousson and Troy Center plots register higher WF total revenue from total harvested board feet even though, like the aggregated plot data, WF removed lower amounts of board feet (Table 4.4, Table 4.5). When the 2057 residual board feet are added to the total harvested board feet WF scenarios increase by an average of $3,730 and 2,978 board feet. Comparatively, DLC only increases by an average of $861 and 669 board feet.



Formatted: Font: Italic, Font color: Black

Formatted: Heading 5, Indent: First line: 0"

Figure 4.4 Total Non-Discounted Revenues of all plots combined comparing Worst First to DLC 2017-2057.

Formatted: Font: 11 pt, Italic, Highlight

A landowner will want to know when they will receive pay-back after investing in a management approach. DLC is~~has been know~~known to give~~s~~ high initial payouts and WF is~~has been know~~known for economic benefit over the long term. The point in the future at which those benefits are ~~accured~~accrued is important to an individual

landowners' time horizon. I took the equation of a line for both total non-discounted revenues, after calculating the intercept and slope for each, to find at what period in time the two approaches overlap (Figure 4.7). In the year 2040, Worst First revenues will equal DLC revenues and Worst first will then overtake DLC in profitability. After approximately 23 years Worst First forestry will be a better investment than a DLC cut.

35

Formatted: Right: 0"

Formatted: Font: 10 pt

MOXIE WOODS								
	Harvested Volume(Bdft)		Residual Standing Volume(Bdft)		Harvest Value($)		Residual Standing Timber Value($)	
Year	WF	DLC	WF	DLC	WF	DLC	WF	DLC
2017(Pre-Cut)	na	na	5,473	5,473	na	na	1,108	1,108
2017	782	4,207	4,691	1,266	184	713	924	395
2027	1,403	na	4,066	na	350	na	1,066	na
2037	1,754	1,364	2,807	920	524	913	1,126	482
2047	1,068	na	2,060	na	679	na	1,106	na
2057	1,090	1,254	1,175	727	455	1,021	1,308	1,048

Figure 4. of standing volume of timber in Moxie Woods.

Formatted: Right: 0"

Formatted: Font: 10 pt

Formatted: Font: Italic

Formatted: Right: 0"

~~*Figure 4. and standing volume of timber in Troy Center.*~~

~~*igure 4. and of standing volume of timber in Bousson.*~~

Formatted: Line spacing: Double

~~*Figure 4. Total Non-Discounted Revenues of all plots combined comparing Worst First to DLC 2017-2057.*~~

Table 4.7. Net present value per acre for Worst First and 16 DLC through a 40 year period based on growth simulations of real mixed hardwood stands. Revenues without the 2057 residual stand value are shown as "2017-2057 harvest NPV". Revenues with the 2057 NPV harvest values summed with the value of 2057 residual stands values are shown as "w/ 2057 residual harvest value".

Formatted Table

~~**Combined Plots**~~

~~DLC~~

~~WF~~

~~**Troy Center**~~

~~DLC~~

~~WF~~

~~**Moxie Woods**~~

~~DLC~~

~~WF~~

~~**Bousson**~~

~~DLC~~

~~WF~~

Net Present Value						
	2%		4%		6%	
	2017-2057 harvest NPV($)	w/ 2057 residual harvest value($)	2017-2057 harvest NPV($)	w/ 2057 residual harvest value($)	2017-2057 harvest NPV($)	w/ 2057 residual harvest value($)
Moxie Woods						
WF	1,405	1,997	964	1,236	705	832
DLC	1,709	2,264	1,342	1,561	1,097	1,199
Bousson						
WF	2,843	4,399	1,867	2,583	1,333	1,667
DLC	3,018	3,430	2,648	2,837	2,469	2,557
Troy Center						
WF	2,322	5,332	1,717	3,101	1,357	2,003
DLC	1,649	1,932	1,187	1,317	963	1,024
All Plots						
WF	6,571	11,638	4,549	6,879	3,396	4,484
DLC	6,457	7,626	5,176	5,714	4,528	4,779

I used Cost-Benefit Analysis (CBA) to compare returns on investments by measuring Net Present Value (NPV). Both management approaches had a positive net present values at 2, 4 and 6% interest rates (Table 4.7). No initial investment in the land was included in the calculations. When WF is used on the Troy Center plot the resulting NPV was greater than using DLC at a 2, 4 and ~~2% and~~ 6% ~~-~~ interest rates with and without the 2057 residual stand values ~~was greater than using DLCt 4%~~. There's a large difference, in NPV values, numbering thousands of dollars, that places WF above DLC

Formatted: Right: 0"

Formatted: Font: 12 pt, Highlight

Formatted: Indent: First line: 0", Line spacing: single

Formatted: Not Highlight

Formatted: Not Highlight

Formatted: Not Highlight

for the Troy Center with 2057 residuals added. ~~-~~After combining all plots into a final NPV, WF resulted in a higher NPV than DLC at the 2% interest rate with and without the 2057 residual stand values ~~e~~and then at 4% only when the 2057 residual stand values were added. DLC outperformed WF for all interest rates in the ~~Bousson and~~ Moxie Woods plots and WF only had a higher NPV at 2% in Bousson when the 2057 residual stand values were added.

~~. DLC returns greater NPV than in the majority of plots when the original 2017 harvest revenue is added to the total. For every plot, including combined, the NPV is higher for in the "w/o 2017 Revenue Cut" category.~~ DLC harvests typically generate more upfront revenues from initial harvests that then decline in subsequent entries to the stand. ~~Where as~~Whereas most of the WF harvest revenues occurred steadily over time or towards the end of the 40 year model, the bulk of DLC harvest revenues occurred immediately in 2017 or in 2057 (Figures 4.2, 4.3, 4.4). Any revenues registered towards the end of the 40 year period will be lower in present value terms, since higher discount rates discount revenues more when received later in time (Jacobson, 2001). For example, Bousson had relatively high revenues in 2037 ($1,209), 2047 ($1,342) and 2057 ($1,542) under WF. I expect those revenues to have lower present value's than revenues ~~registared~~registered in previous years, even if 2057 was the highest revenue year WF had in Bousson. Higher NPV values from future cuts may indicate the ability for WF to "catch up" to DLC or recuperate revenue in the future.

The interest rates 2%, 4% and 6% represent what a landowner could expect to earn from the best alternative investment like a savings account or a mutual fund. Considering that the average annualized return on the S&P 500 index over the past 90

Formatted: Right: 0"

Formatted: Not Highlight

Formatted: Indent: First line: 0.5", Line spacing: Double

years is 9.8%, a landowner may consider doing a DLC cut thereby extracting a large amount of upfront cash to then invest long term in the stock market (Santoli, 2017). If timber prices increase at a faster rate than the growth rate of an alternative investment then WF becomes more economically attractive in the long run.

Formatted: Right: 0"

Formatted: Font: 12 pt, Not Italic

Formatted: Line spacing: Double

Table 4.8. Total number of ≥16 DBH trees harvested and minimum and maximum DBH, average DBH, and remaining trees ≥ 16 DBH in 2057 residual stands .

Total trees >=16 DBH harvested	WF	DLC
Bousson	11	32
Troy Center	13	32
Moxie Woods	10	33
Average DBH in 2057 Residual Stand		
Bousson	13.55	9.53
Troy Center	13.43	8.583
Moxie Woods	13.261	9.55
Min, Max DBH in 2057 Residual Stand		
Bousson	4.69, 41.31	4.9, 15
Troy Center	4.52, 32.84	5.08, 15.43
Moxie Woods	5.62, 23.96	5.07,15.7
Remaing Trees >= 16 DBH in 2057 Residual Stand		
Bousson	8	0
Troy Center	10	0
Moxie Woods	5	0

Worst first leaves behind trees in larger diameter classes. Guy Dunkle evaluated each plot, and left trees standing that he thought were of the highest quality, purposefully leaving trees which were ≥16 DBH. Any tree 16 inches in diameter or above could be considered high quality Grade 1 or even veneer logs, both of which will sell for higher prices than average. My NPV analysis does not treat trees above or below 16 DBH ~~seperately~~separately with different prices. Over the period of 40 years

Formatted: Right: 0"

DLC cut roughly 30 trees ≥16 DBH from each plot, while WF cut roughly a third of trees that size (Table 4.8). This could increase profits for DLC cuts over what it currently made. 2057 residual stands cut with DLC ended poorly stocked because of they lacked high value trees. In 2057, DLC had no remaining trees ≥16 DBH and only had a maximum DBH of approximately 15 DBH. Worst first had a number of ≥16 DBH trees left in 2057 and had maximum DBH's ranging from 23 to 41 DBH. The plots managed under WF are growing more complex age class structures and have retained quality trees. From the perspective of future economic sustainably, WF may be better preparing the plots for future harvests.

Formatted: Right: 0"

Chapter 5: Discussion

This study aimed to expand the extremely sparse academic literature on Worst First forestry. Results provide foresters and ladnowners with data to compare two treatments with overlapping cuting cycles but very different removal criteria. Although single tree selection criteria will differ stand to stand, Worst First essentially prescribes a treatment where "unmerchantable and poor vigor trees are removed to create a high quality, vigerous stand with a wide distribution of ages and sizes" (Kenefic, 2005). Diameter limit cutting treatments remove any tree at or above a certain DBH, without taking into account the residual stand condition. No single management appraoch can be prescribed to maximize returns from diameter limit cuts compared to worst first. The optimal harvest depends on the stand and the landowners' financial parameters.

Total harvest volume did not differ greatly between the two appraoches, although DLC did remove slightly more. Simulation data for the three stands indicate that using Worst First forestry in even and uneven aged hardwood stands ensures more consistent and similar levels of of harvest volumes from one cutting cycle to the next. Following the 2017 and 2027 harvest in Bousson, Worst First was consistently returning revenues between $1,200 and $1,500 dollars. In all five harvests Troy Center's revenues hovered between $500 and $800 per acre. Past studies (Kenefic et al. 2003, Reed et al. 1986, Miller and Smith 1991, Nyland 2005) support my findings that landowners using DLC will realize less long-term yields. Kenefic et al (2002) explained that through "taking the best and leaving the rest" the greater size, quality and volume of trees removed by the intitial DLC entries will always outpace other management approaches, at least in the short run. Stands that underwent a DLC in this study had

poor residual value and quality, which eliminates a great deal flexibilty in the future management of a stand. Society will suffer a loss 100 years in the future if the value of trees as a continuing economic resource has fallen below current value. Landowners commited to more sustainble production will find themselves better served by worst first.

Revenues from harvests were highly dependant on the stand. When WF was applied to Troy Center, WF outpreformed the other two stands DLC net present values at 2 and 6%. Past comparisons of diameter limit cutting with selection system showed selection systems outpreforming 14 and 16 inch diamater limit cuts at 2, 4 and 6% interest rates (Nyland, 2005).

Approxiamtely 20 years after the beginning f te simulation Worst First foestry will overtakeDLC in profitabiltiy.

The three plots chosen for this project have distinctive management histories that may impact the results shown. Before Moxie Woods was acquired by The Foundation for Sustainable Forests, it underwent severe high grading. Considering a forest needs time to recover stand health and vigor after undergoing such management, this may explain why Moxie Woods registered lower revenues and board feet volumes than the other two plots. No harvesting has occured at Bousson since Allegheny College acquired the property in 1935. or the past 80 years Bousson has been allowed to grow completely naturally without improvement thinnings to increase species diversity or create openings for sunlight. Previous owners employed the land as agricultural fields and that land use is seen in the flat appearance of Boussons' plot. The Foundation for Sustainable Forests has managed Troy Center since 1997. Guy Dunkle, their lead forester, has already taken out the dead and worst trees at Troy Center long before this study's'

Formatted: Right: 0"

Formatted: Indent: First line: 0"

Formatted: Not Highlight

Formatted: Not Highlight

inventory in 2017 took place. As opposed to Moxie Woods or Bousson, Troy Center is expected to have a mix of trees 30 to 40 years deemed “long term” previously promoted as the healthy and vigorous stems instand. Troy Centers’ beginning volume of board feet in the plot was between Moxie’s lowest volume and Boussons’ highest volume in 2017. The consistent regeneration of Troy Center’s board feet decade after decade may be a testament to historic and modeled cutting choices made by Guy Dunkle in the field.

The modeling this study with SILVAH only utilized the growth simulation function and did not follow stands into the future to observe regeneration patterns.Stands that continued under DLC treatment were shown by Hart (1964) to accumulate cull timber that came from trees either defective or of poor vigor. My model used generally optimistic assumptions about the volume quantity and value of trees. Accordingly, these results could be influenced by any number of factors that occur in the future. For one, Troy Center already has Beech Bark disease on the property. The Troy Center beech trees currently app the disease but FSF will keep a close watch on when they may have to remove the species. Particularly violent weather patterns, like high winds, prematurely fell trees and cause damage to stands.There are specific aspects of The Foundation for Sutainble Forestry and their use of Worst First that might attract clients. First, for those landowners who value the natural aestheic of a forest, worst first will retain more board feet within a stand over time. The forest will not appear to be clearcut or have large swaths removed. Worst First forestry harvests timber with manual horse logging. Horsescompact forest soil less than their mechanical counterparts (Deal, 2002). For landowners in Pennsylvania whose tracts of forest are becomign increasingly

Formatted: Right: 0"

Formatted: Not Highlight

Formatted: Not Highlight

Formatted: Right: 0"

~~fragmented, high capitalization costs or costs to hire mechincal crews are disproportionateSecondly, landowners don't like to be taken advantage of. Regionally, there's a practice of timber manageers revceiving a 10 %to 15% sale comission once harvested timber is sent to the highest bidding mill. Managers have an incentive to high grade, or remove the most valuable trees possible. Foresters from FFS operate on a different budget scale from using horse logging, enter stands more frequently but cut smaller amounts each time and tend to develop more personal relationships with clients.~~

Formatted: Indent: First line: 0"

~~*A. Conclusion & Management Implications*~~

This study aimed to expand the extremely sparse academic literature on Worst First forestry. Results provide foresters and landowners with data to compare two treatments with overlapping cutting cycles but very different removal criteria. Although single tree selection criteria will differ stand to stand, Worst First essentially prescribes a treatment where "unmerchantable and poor vigor trees are removed to create a high quality, vigorous stand with a wide distribution of ages and sizes" (Kenefic, 2005, p.). Diameter limit cutting treatments remove any tree at or above a certain DBH, without taking into account the residual stand condition. No single management approach can be prescribed to maximize returns because the optimal harvest depends on the stand characteristics and the landowners' financial parameters.

Total harvest volume did not differ greatly between the two approaches, although DLC did remove slightly more. Simulation data for the three stands indicate that using Worst First forestry in even and uneven aged hardwood stands ensures more

Formatted: Right: 0"

consistent and similar levels of harvest volumes from one cutting cycle to the next. Following the 2017 and 2027 harvest in Bousson, Worst First was consistently returning revenues between $1,200 and $1,500 dollars. In all five harvests Troy Center's revenues hovered between $500 and $800 per acre and the revenues in Moxie Woods followed the same pattern but in the low hundreds of dollars. Past studies (Kenefic et al. 2003, Reed et al. 1986, Miller and Smith 1991, Nyland 2005) support my findings that a 16-inch DLC has high initial returns however, stands will realize less regular and frequent yields of volume and value. Kenefic et al (2002) explained that through "taking the best and leaving the rest" the greater size, quality and volume of trees removed by the initial DLC entries will always outpace other management approaches, at least in the short run. Stands that underwent a DLC in this study had poor residual value and quality, which eliminates a great deal flexibility in the future management of a stand. Society will suffer a loss 100 years in the future if the value of trees as a continuing economic resource has fallen below its current value. Landowners committed to more sustainable production will find themselves better served by Worst First.

Revenues from harvests were highly dependent on the stand. When WF was applied to Troy Center, WF very obviously outperformed DLC at all interest rates. Past comparisons of diameter limit cutting with selection system showed selection systems outperforming 14 and 16-inch diameter limit cuts at 2, 4 and 6% interest rates (Nyland, 2005).

Approximately 20 years after the beginning of the simulation, Worst First forestry will overtake DLC in profitability (Figure 4.3). Although, this finding only holds when the return on investment of the next best alternative is zero. Cutting a forest with DLC

Formatted: Right: 0"

and reinvesting the money attains the utility maximizing goals for landowners concerned with economic profit. Anecdotally, landowners in Western Pennsylvania are deciding to cut their forest to cover everyday costs such as fixing a roof or paying off medical bills. This indicates that landowners don't even reach the investment stage when money from harvest could grow in an alternate with a higher interest rate. Further study should be directed toward whether owners actually feel comfortable investing harvest revenue in financial instruments and their knowledge of investing. Forest owners have a complex set of management intentions, only one of which is economic. The forest may used for outdoors activities (hunting, hiking etc.) and owners may want to pass down the property to future generations. Prioritizing maximum economic revenue in a forest can dramatically impact the way a forest owner can utilize their forest for other activities. Under improper management, which can happen under DLC, the appearance and makeup of a forest changes and often times changes negatively.

The three plots chosen for this project have distinctive management histories that may impact the results shown. Before The Foundation for Sustainable Forests acquired Moxie Woods, it underwent severe high grading. Considering a forest needs time to recover stand health and vigor after undergoing such management, this may explain why Moxie Woods registered lower revenues and board feet volumes than the other two plots. No harvesting has occurred at Bousson since Allegheny College acquired the property in 1935. For the past 80 years Bousson has been allowed to grow completely naturally without improvement thinning's to increase species diversity or create openings for sunlight. Previous owners employed the land as agricultural fields and that land use is seen in the flat appearance of Boussons' plot. The Foundation for

Formatted: Right: 0"

Sustainable Forests has managed Troy Center since 1997. Guy Dunkle, their lead forester, has already taken out the dead and worst trees at Troy Center long before this study's' inventory in 2017 took place. As opposed to Moxie Woods or Bousson, Troy Center is expected to have a mix of trees, 30 to 40 years old, that were deemed "long term" after previously being promoted as the healthy and vigorous stems in the stand. Troy Centers' beginning volume of board feet in the plot was between Moxie's lowest volume and Boussons' highest volume in 2017. The consistent regeneration of Troy Center's board feet decade after decade may be a testament to historic and modeled cutting choices made by Guy Dunkle in the field.

Formatted: Indent: First line: 0.5"

The modeling this study applied with SILVAH only utilized the growth simulation function and did not follow stands into the future to observe regeneration patterns. Only existing trees in each stand were followed for growth and revenue production. Future studies should examine the long-term regeneration potential of stands when using WF and DLC. Stands that continued under DLC treatment were shown by Hart (1964) to accumulate cull timber that came from trees either defective or of poor vigor. Even when regeneration does occur in DLC stands, the next generations of trees are of lower grade timber that won't fetch a high price on the market.

My model used generally optimistic assumptions about the volume quantity and value of trees. Accordingly, these results could be influenced by any number of factors that occur in the future. For one, Troy Center already has Beech Bark disease on the property. The Troy Center beech trees currently appear not infected by the disease but FSF will keep a close watch on when they may have to remove the species. Particularly violent weather patterns, like high winds, prematurely fell trees and cause damage to

Formatted: Right: 0"

stands. If within the next 40 years another recession like the 2008 economic downturn occurs prices for timber will fall sharply again as consumer demand decreases. This study used prices from 1992- 2017 to take into account not only downturns in the economy but high upswings, as we saw in the late 1990's and early 2000's. I increased timber prices by their species specific yearly averages based on 20 price trends. Certain species becoming more valuable based on taste preference for wood appearance will certainly impact future price trends and revenues. As stated in my methods, I did not take any costs into account like the price of land, logging, inventory, marking or sales preparation costs. To apply the Worst First approach conceivably might add a small amount of additional cost to a landowner given the steps needed to prepare a pre-harvest inventory report, prepare a marketing guide and mark trees to cut. A landowner examining this study's' results should factor in loss tolerance for unexpected events that would negatively impact revenues.

There are specific aspects of The Foundation for Sustainable Forests and their use of Worst First that might attract clients. First, for those landowners who value the natural aesthetic of a forest, worst first will retain more board feet within a stand over time. The forest will not appear to be clear-cut or have large swaths removed. Worst First forestry harvests timber with manual horse logging. Horses encourage healthy forest growth by compacting forest soil far less than their mechanical counterparts (Deal, 2002). Manual logging also does not inflict damage to standing timber during the process of extraction. For landowners in Pennsylvania whose tracts of forest are becoming increasingly fragmented, high capitalization costs or costs to hire mechanical crews are disproportionate. Loggers are pushed to cut as many trees as possible to

make the operation cost effective for the owner and themselves. Secondly, landowners don't like to be taken advantage of. Regionally, there's a practice of timber managers receiving a 10 %to 15% sale commission once harvested timber is sent to the highest bidding mill. Managers have an incentive to high grade, or remove the most valuable trees possible. Foresters from FFS operate on a different budget scale from using horse logging, enter stands more frequently but cut smaller amounts each time and tend to develop more personal relationships with clients.

A. Conclusion & Management Implications

These simulations show important differences in long-term volume and value yields between WF management and DLC. Data obtained from the models of this experiment establish the consequences of both approaches and prepare expectations for future studies that could follow the outcomes of actual cutting regimes. Findings should encourage Pennsylvania mixed-hardwood forest landowners to challenge the regional practice of extracting the largest, most valuable saw timber trees from stands. This study serves as a confirmation of The Foundation for Sustainable Forests intuition that using Worst First to encourage overall healthy forests indeed results in more consistent volume recovery and revenue streams.

~~These simulations show important differences in long term volume and value yields betweenmanagement and. Findings should encourage Pennsylvania mixed-hardwood forest landowners to challenge the regional practice of extracting the largest,~~

50

Formatted: Right: 0"

Formatted: Line spacing: Double

Formatted: Not Highlight

~~most valuable sawtimber trees from stands.his study serves as a confirmation of The Foundation for Sustainable Forestries' intuition that using Worst First to encourage~~

Formatted: Right: 0"

Formatted: Normal1

Formatted: Font: 11 pt, Italic

Formatted: Normal1

Formatted: No underline

Formatted: No underline

Appendix I. SILVAH 10.7 stand criteria.

Management Parameters	**Bousson**	**Moxie Woods**	**Troy Center**
Prescription charts	northern/ allegheny hardwood	northern/ allegheny hardwood	northern/ allegheny hardwood
Silv System Restrictions	No clearcutting	No clearcutting	No clearcutting
Start Regeneration Now	Yes, regardless of conditions	Yes, regardless of conditions	Yes, regardless of conditions
Management Value	Not Observed	Not Observed	Not Observed
Favor Oak	No	No	No
Deer Impact	Moderate	Moderate	Moderate
Residuals Desired	No	No	No

Stand Parameters	**Bousson**	**Moxie Woods**	**Troy Center**
Stand Area (acres)	.6	.6	.6
Stand Age	80	60	80

Formatted: Right: 0"

Site Class	Medium Productivity	Medium Productivity	Medium Productivity
Even or Uneven Age	Uneven Age	Even Age	Even Age
Aspect	250	10	250
Slope	10	10	10
Elevation	1099	360	483
Topographic Position	Bottom	Bottom	Lower Slope
Operability	No limitations	No limitations	No limitations
Accessibility	Road within mile	Road within mile	Road within mile

Inventory Settings	**Bousson**	**Moxie Woods**	**Troy Center**
Type of plot	Fixed Area	Fixed Area	Fixed Area
Overstory Plot size (acres)	.6	.6	.6
DBH classes	1 inch	1 inch	1 inch
Tally Month/ Year	December 2017	December 2017	December 2017

Literature Cited

Formatted: Font: Bold, No underline

Atmadja S.S., Sills E.O. (2013) Forest Management and Landowners' Discount Rates in the Southern United States. In: Kant S. (eds) Post-Faustmann Forest Resource Economics. Sustainability, Economics, and Natural Resources, vol 4. Springer, Dordrecht

Beach, R., Pattanayak, S., Yang, J., Murray, B., & Abt, R. (2005). Econometric studies of non-industrial private forest management a review and synthesis. *Forest Policy and Economics, 7*(3), 261-281. doi:10.1016/S1389-9341(04)00065-0

Brubaker, R. D., Finley, J. C., & McDill, M. E. (2006). The effect of timber value information on pennsylvania's private forest landowner: A case study. *Northern Journal of Applied Forestry, 23*(4), 234-240. Retrieved from https://search.proquest.com/docview/198184580?accountid=8268

Formatted: Font color: Text 1

Formatted: Font: 11 pt, No underline, Font color: Text 1

Formatted: Font color: Text 1

Butler, J., Hewes, J., Dickinson, B.., Andrejczyk., Butler, S., Markowski-Linsday, M. (2013) Family Forest Ownerships of the United States. Findings from the USDA Forest Service's National Woodland Owner Survey. Journal of Forestry, 2016;114(6):638-647

Coufal, J. E. 1998. Teaching core values: some questions. In: Heister, C. G. Heister (Comp.), Proc. Second Bien. Conf. Univ. Educ. Nat. Res., March 7-10, 1998, Utah State University, Logan, UT, pp. 37-42.

Costanza, R., D'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Van, D. B. (1997). The value of the world's ecosystem services and natural capital.*Nature, 387*(6630), 253-260. doi:http://dx.doi.org.ezproxy1.allegheny.edu:2048/10.1038/387253a0

Davis(1996)Towards More Accurate Growth Simulations and NPV Appraisals: Using INFORM to Project Tree Grade and Market Value Increases. The Compiler .Vol. 14, No. 1. Retreived from http://www.daviesand.com/Papers/Economics/NPV_Appraisals/index.html

Deal, J. (2002). Site Disturbance and Social Impacts of Animal Logging and Conventional Logging in Appalachia. Department of Forestry. Retreived from http://www.healingharvestforestfoundation.org/uploads/1/7/0/8/17089550/joshua_deal_abstract.pdf

Duncker, P. S., K. Raulund-Rasmussen, P. Gundersen, K. Katzensteiner, J. De Jong, H. P. Ravn, M. Smith, O. Eckmüllner, and H. Spiecker. 2012. How forest management affects ecosystem services, including timber production and economic return: synergies and trade-offs. *Ecology and Society* **17**(4): 50.

Davis, L., Johnson, K. N., Bettinger, P. S., & Howard, T. E. (2005). Chapter 7: Financial Analysis in Forestry. In Forest Management (4th ed.) (pp.317-394). Long Grove, IL: Waveland Press Inc.

Eyre, F., Zulgitt, W.(1953) Partial Cutting in Northern Hardwoods of the Lake State: Twenty Year Experimental Results. United States Department of Agriculture. Retreived from: http://ageconsearch.umn.edu/bitstream/156549/2/tb1076.pdf

Foundation for Sustainable Forest~~s~~ry. About Us. Retrieved from http://foundationforsustainableforests.org/about. 2017.

Formatted: Right: 0"

Formatted: Font: (Default) Arial, Font color: Text 1

Formatted: Normal, Space Before: Auto, After: Auto

Formatted: Font: 10 pt, Font color: Text 1, English (United States)

Formatted: Font color: Text 1

Formatted: Font: 11 pt, No underline, Font color: Text 1

Formatted: Font color: Text 1

Formatted: Font: 11 pt, No underline, Font color: Text 1

Formatted: No underline, Font color: Text 1

Formatted: Font color: Text 1

French Creek Watershed Research Program (1996, December). A Characterization of Bousson Forest. Retrieved March 07, 2018, from http://watershed.allegheny.edu/data/es-440

Guangzhou, A. (2017, February 9). South China Expands As a Huge Market for U.S. Wood and Wood Products. USDA Foreign Agriculture Service. Retrieved March 11, 2018, from https://gain.fas.usda.gov/Recent%20GAIN%20Publications/South%20China%20A%20Huge%20Market%20for%20U.S.%20Wood%20and%20Wood%20Products_Guangzhou_China%20-%20Peoples%20Republic%20of_2-9-2017.pdf

Hart, A.C. 1964. The Penobscot management-intensity demonstration plots. USDA For. Serv. Res. Pap. NE-25. 24 p.

Hetzler, Paul. “Practicing silviculture, not “silver-culture””. North Country Public Radio. 2015.

Helms, J.A. 1998. The dictionary of forestry. Bethesda, MD: Society of American Foresters. 2 0 p.

Heiligmann, R. B., Bratkovich, S. M. (2016). Measuring Standing Trees: *Determining Diameter, Merchantable Height, and Volume. Ohio State Department of Natural Resources Division of Forestry. Retrieved from https://ohioline.osu.edu/factsheet/F-35-02*

Hoogsta, M.A., Schanz, H. (2008) ‘How (Un)Certain Is the Future in Forestry? A Comparative Assessment of Uncertainty in the Forest and Agricultural Sector’, Forest Science, volume 54, number 3, pp.316-327

Holopainen, A. Mäkinen, Rasinmäki, K. Hyytiäinen, Bayazidi, I. Pietilä. (2010). Comparison of various sources of uncertainty in stand-level net present value estimates. Forest Policy Econ., 12; 377-386.

Jacobson, M.(2017).Timber Prices: 10 Year Trends for Northwest Pennsylvania. Penn State Extension. Retrieved from https://extension.psu.edu/timber-prices-10-year-trends-for-northwest-pennsylvania

Jacobson, M.(2017). Forest Economic Data: Crawford County. Penn State Extension. Retrieved from https://extension.psu.edu/forest-economic-data-crawford-county

Jacobson, M.(2017). Timber Prices: 10-year Summary of Price Trend Percentages.Penn State Extension. Retrieved from https://extension.psu.edu/summary-of-price-trend-percentages

Formatted: Right: 0"

Formatted: Font: 11 pt, Font color: Text 1

Formatted: Font: 11 pt, No underline, Font color: Text 1

Formatted: Font color: Text 1

Jacobson, M.(2017). Timber Market Report Methods. Retrieved from https://extension.psu.edu/timber-market-report-methods

Jacobson, M. (2017). Forest Finance 1: Sustainable Forest Harvesting: An Economic Perspective. Penn State Extension. Retrieved from https://extension.psu.edu/forest-finance-1-sustainable-forest-harvesting-an-economic-perspective

Kant, S. (2003) 'Extending the boundaries of forest economics', Forest Policy and Economics, number 5, pp. 39-56.

Klase, W., Steele, T.W. (2011) Logging Methods for Wisconsin Woodlands. UW Extension. Retreived from http://dnr.wi.gov/topic/forestmanagement/documents/pub/fr-778.pdf

Kenefic, L., Nyland, R. (2005) Diameter Limt Cutting and Siliviculture in Northeastern Forests: aprimer for Landowners, Practitioners and Policymakers. USDA Forest Service. Retreived from: http://masswoods.org/sites/masswoods.net/files/pdf-doc-ppt/DiameterLimitCutting.pdf

Kenefic, L. S., Sendak, P. E., & Brissette, J. C. (20066). Comparison of fixed diameter-limit and selection cutting in northern conifers. *Northern Journal of Applied Forestry, 22*(2), 77-84. Retrieved from https://search.proquest.com/docview/198199864?accountid=8268

Kenefic, Laura S.; Nyland, Ralph D., eds. 2006. Proceedings of the conference on diameter-limit cutting in northeastern forests. Gen. Tech. Rep. NE-342. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 51 p.

Keefer, M. J., Finley, J. C., Luloff, A. E., & McDill, M. E. (2002). Characterizing loggers' forest management decisions. *Journal of Forestry, 100*(6), 8-15. Retrieved from https://search.proquest.com/docview/220790603?accountid=8268

Klase, W., Steele, T.W. (2011) Logging Methods for Wisconsin Woodlands. UW Extension. Retreived from http://dnr.wi.gov/topic/forestmanagement/documents/pub/fr-778.pdf

Klemperer, W.D. (1996), Forest Resource Economics and Finance, McGraw-Hill, New York.

Leopold, A. (1934) Conservation Economics. Journal of Forestry. 32.5;537-544.

Formatted: Right: 0"

Formatted: Font: 11 pt, No underline, Font color: Text 1

Formatted: Font color: Text 1

Formatted: Font: 11 pt

Formatted: Normal, Space Before: Auto, After: Auto

Formatted: Font color: Text 1

Formatted: Font color: Text 1

Formatted: Font color: Text 1

Formatted: Font: 11 pt, No underline, Font color: Text 1

Formatted: Font color: Text 1

Formatted: Font: 11 pt, No underline, Font color: Text 1

Formatted: Font color: Text 1

Formatted: Right: 0"

Lockhart, Brian Roy and Nyland, Ralph D. (2004) "Teaching professional codes of ethics to forestry and wildlife students: A case study using diameter-limit harvesting in a bottomland hardwood stand," Natural Resources and Environmental Issues: Vol. 12, Article 27.

Lovett, G. M., Weiss, M., Liebhold, A. M., Holmes, T. P., Leung, B., Lambert, K. F.,

Orwig, D. A., Campbell, F. T., Rosenthal, J., McCullough, D. G., Wildova, R., Ayres, M. P., Canham, C. D., Foster, D. R., LaDeau, S. L. and Weldy, T. (2016), Nonnative forest insects and pathogens in the United States: Impacts and policy options. Ecol Appl, 26: 1437–1455. doi:10.1890/15-1176

Lu, H. and Buongiorno, J. (1993), 'Long- and short-term effects of alternative cutting regimes on economic returns and ecological diversity in mixed-species forests', Forest Ecology and Management, 58(3-4): 173-192.

Pennsylvania Hardwood Development Council.(2010). Sustaining Pennsylvania's Hardwoods Industry: An Action Plan. Pennsylvania Department of Agriculture. Retrieved from: http://www.docs.dcnr.pa.gov/cs/groups/public/documents/document/dcnr_20031337.pdf

Pell, J.A. 1998. Variables characterizing timber resource sustainability of recently harvested tracts across Pennsylvania. M.Sc. thesis, Penn. State Univ., University Park, PA. 139 p.

Peng, C. (2000). Growth and yield models for uneven-aged stands: Past, present and future.*Forest Ecology and Management, 132*(2), 259-279. doi:10.1016/S0378-1127(99)00229-7

Pubanz, Dan. (2016) Why the Forestry Profession Should Harshly Criticize High Grading. National Woodlands Magazine. National Woodlands Owners. Volume 39, No.1.

Płotkowski, L., Zając, S., Wysocka-Fijorek, E., et al. (2016). Economic optimization of the rotation age of stands. *Folia Forestalia Polonica*, 58(4), pp. 188-197. Retrieved 27 Sep. 2017, from doi:10.1515/ffp-2016-0022

Marquis, D. (1983). Ecological and historical background: northern hardwoods. 1983 Penn State Forestry Issues COnference: Proceeding of Regenerating Hardwoods Stands. School of Forestry Resources and Cooperative Extension Service of Pennsylvania State University, State College, PA. 9-29

Maynard, C.A., Overton, R.P. and Johnson, L.C. (1987), 'The silviculturist's role in tree improvement in northern hardwoods', in R. D. Nyland, (ed.) Managing Northern Hardwoods, State University of New York, College of Environmental Science and

Formatted: Right: 0"

Forestry Faculty of Forestry, Miscellaneous Publication No. 13 (ESF 87-002), Syracuse.
Matthews, E., Payne, R., Rohwee, M., & Siobahn, M. (2000). *Pilot analysis of global ecosystems: forest ecosystems* (p. 86). Washington, DC: World Resources Institute.

McCaskill, George L., McWilliams,William H., Alerich, Carol A., Butler, Brett J., Crocker, Susan J., Domke, Grant M., Grif th, Doug, Kurtz, Cassandra M., Lehman, Shawn., Lister, Tonya W., Morin, Randall S., Moser, W. Keith., Roth, Paul, Riemann, Rachel., Westfall, James A. (2013). Pennsylvania's Forests, 2009. Resour. Bull. NRS-82. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 52 p.

McKetta, C.(1992). Forest Valuation Theories and Applications Lecture Notes Study Objectives and Exercises. Pakistan Forest Institute. Retrieved from: http://pdf.usaid.gov/pdf_docs/PNABW307.pdf

Miller, G., Smith,W.(1991). Comparing partial cutting practices in central appalachian hardwoods. 8t Central Hardwoods Forest Conference. P. 105-119.

Nowak, C.A. and Marquis, D.A. (1997), Distribution-of-Cut Guides for Thinning in Allegheny Hardwoods: A Review, USDA Forest Service Research Note NE-362, Radnor.

Niese, J.N. and Strong, T.F. (1992), 'Economic and tree diversity trade-offs in managed northern hardwoods', Canadian Journal of Forest Research, 22(11): 1807-1813.

Nyland, R.D. 2003. Rehabilitating stands after diameter-limit cutting. In: Beland, M., ed. Proceedings of the tolerant hardwoods management conference; 2003 8 May; Edmundston, NB: Universite de Moncton-Campus d'Edmundston. [CD rom].

Nyland, R. D. (2005). Diameter-limit cutting and silviculture: A comparison of long-term yields and values for uneven-aged sugar maple stands. *Northern Journal of Applied Forestry, 22*(2), 111-116. Retrieved from https://search.proquest.com/docview/198266313?accountid=8268

Nyland, R. D. 1992. Exploitation and greed in eastern hardwood forests. Will foresters get another chance? J. For., 90, pp. 33-37.

Oliveira A., (2002) 'A discussion of rational and psychological decision-making theories and models: the search for a cultural-ethical decision-making model', Electronic journal of business ethics and organization studies, volume 12, number 2, pp. 12-17.

Raunikar, R., & Buongiorno, J. (2006). Willingness to pay for forest amenities: The case of non-industrial owners in the south central united states. *Ecological Economics, 56*(1), 132-143. doi:10.1016/j.ecolecon.2005.01.013l

Reed, D.D., Holmes, M.J. and Johnson, J.A. (1986), 'A 22-year study of stand development and financial returns in northern hardwoods', Northern Journal of Applied Forestry, 3(1): 35-38.

Rhoads,A., Block, T.(2005) Trees of Pennsylvania: a complete reference guide. The University of Pennsylvania Press. Retrieved from: http://envirothonpa.org/documents/2-1_ForestTypesPA_001.pdf

Rideout, D. and Hesseln, H. (2001), Principles of Forest & Environmental Economics, Resource and Environmental Management, LLC, Ft Collins.
SFRC.(2006) The Financial Analysis. Florida Forest Stewardship. Retreived from http://www.sfrc.ufl.edu/extension/florida_forestry_information/planning_and_assistance/financial_analysis.html

Rutledge, Jason. (2013) "Restorative Forestry and Modern Horselogging." *Healing Harvest Forest Foundation*, www.healingharvestforestfoundation.org/restorative-forestry-and-modern-horselogging.html.

Santoli, M. (2017, June 18) The S&P has already met its average return for a full year, but don't expect it to stay here. CNBC. Reteived from : https://www.cnbc.com/2017/06/18/the-sp-500-has-already-met-its-average-return-for-a-full-year.html

Schlüter, A. (2007) 'Institutional change in forestry sector – The explanatory potential of New institutional Economics', Forest Policy and Economics, number 9, pp. 1090-1099.

Smith, H.C. and Miller, G.W. (1987), 'Managing Appalachian hardwood stands using four regeneration practices: 34-year results', Northern Journal of Applied Forestry, 4(4): 180- 185.

Timber Tax. (2012). Chapter 2 Timber Investment Considerations. Retreived from https://timbertax.org/publications/fs/aghandbook/ch2.pdf.

USDA. (2017). Web Soil Survey. The Department of Agriculture, Natural Resource Conservation Service. Retreived from: https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

Formatted: Right: 0"

Formatted: Font: 11 pt, No underline, Font color: Text 1, Not Highlight

Formatted: Font color: Text 1

Formatted: Font: 11 pt, No underline, Font color: Text 1

Formatted: Font color: Text 1

Formatted: Font: 11 pt, No underline, Font color: Text 1

Formatted: Font color: Text 1

U.S Climate Data (n.d.). Temperature - Precipitation - Sunshine - Snowfall. Retrieved April 01, 2018, from https://www.usclimatedata.com/climate/greenville/pennsylvania/united-states/uspa0658

Wagner, J., Nowak, C., Casalmir, L. (2003). Small-scale Forestry. Financial analysis of diameter-limit cut stands in northern hardwoods. 2; 357-376. DO - 10.1007/s11842-003-0025-3

Wang, S., & Fu, B. (2013). Trade-offs between forest ecosystem services. *Forest Policy and Economics, 26*, 145-146. doi:10.1016/j.forpol.2012.07.014

Wittwer, R.F., Marcouiller, D.W., Anderson, S. (1990) Even and Uneven-aged Forest

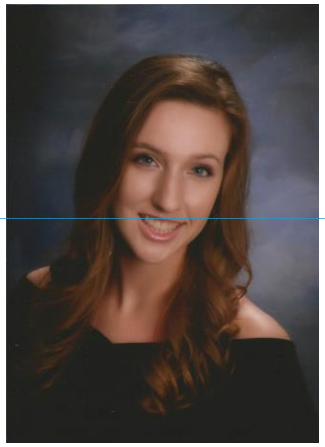
Management. OSU Extension Facts No. 5028, Oklahoma Cooperative Extension Service, Stillwater, OK. p.6.

Wilusz, W. and Giertych, M. (1974), 'Effects of classical silviculture on the genetic quality of the progeny', Silvae Genetica, 23(4): 127-130.

Formatted: Right: 0"

60

Formatted: Right: 0"



Formatted: Left

About the Author

Formatted: Font: 12 pt

Formatted: Font: 11 pt, No underline

Valerie Lynn Zablotny Hurst is an Economics and Environmental Studies double major at Allegheny College. Her freshman and sophmore year were spent serving in the Meadville community as a Bonner Leader. During her time on campus she worked as a residence advisor in Brooks Hall. She's been heavily involved in student government, serving as a senator, class president and then Vice-President of Allegheny Student Government. Valerie anticipates graduting *cum laude.* She has conducted research at Allegheny on the opioid crisis in Crawford County and continues her work currently employed by Crawford County Human Services as Project Manager /GIS technician of an intitiative to map health indicators in the county. Post-graduation she plans on entering into the field of environmental eocnomics.