An Eastern Hemlock Management Plan for the Impending Infestation of Hemlock Woolly Adelgid in the Erie National Wildlife Refuge

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Table of Contents

Acknowledgements iii

Abstract iv

Introduction 1

Methods 5

Results and Discussion 6

Management Plan 10

Literature Referenced 14

Appendix A 18

Appendix B 19

Appendix C 20

Appendix D 21

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The eastern hemlock is currently facing an invasive species that threatens the total population of the tree species on the east coast. The invasive species is the Hemlock Woolly Adelgid (HWA), and it is spreading at an alarming rate. HWA is decimating the population of an essential species in the Appalachian Mountain Forests. This study focused on the property of the Erie National Wildlife Refuge (ENWR), located in northwestern Pennsylvania. The study looked into the creation of a management plan with multiple treatment methods. The goal was to estimate the cost of the treatment methods for ENWR to use long term. The treatment methods include the application of the pesticides Imidacloprid and Safari, the introduction of beetles, and replacement species for trees that have a low chance of surviving the infestation. Those are all looked at closely. The management plan was determined based upon the diameters, the number of trees, and the basal area. At the end of the study, it was found that the most economically feasible plan that is recommended for the refuge comprises of multiple treatment methods. The management plan is setup for 5 years, and it will cost ENWR $15,510,401.74 for the entire refuge. That comes out to 4,936.47 $/acre. The use of the treatment in this way helped to drive down the initial cost of the treatments, and make the price of the management plan more manageable in the long term.

Introduction

The eastern hemlock is a coniferous tree species located throughout the Appalachian Mountains. The Erie National Wildlife Refuge, located in the northwestern corner of Pennsylvania, is one of the areas in the Appalachian Mountains that has eastern hemlock. Eastern hemlocks are highly important to ENWR. One of the roles that the hemlock plays is temperature regulator (Nelson, G., 2002). The coniferous characteristic of the species is what makes the hemlock so good at this. The year-round canopy prevents sunlight from reaching the forest floor, and it also reduces heat from escaping. In the summers it is cooler in a hemlock stand as compared to a deciduous hardwood stand due to the year-round canopy (Black, & Abrams, 2005). Similarly, in winter, it is warmer in the hemlock stand than the hardwood stand because the heat is trapped underneath the tree. When there are hemlocks near wetlands and streams, they tend to play an important role in cooling the streams to help the aquatic creatures in the water (Adkins, & Rieske, 2013; Churchel, & et. Al., 2011; Snyder, & et. Al., 2002). Many of the fish and aquatic insects only survive in the water if it is at a specific cool temperature. The cooler the temperature of the water, the higher amount of oxygen there will be present (Cessna, & Nielsen, 2012). In addition to aquatic life, there are many different species of wildlife that take advantage of the function that the tree plays. Some of these species that benefit from the hemlock include black bears, squirrels, and white tail deer. The deer not only use the tree as a shelter, but they also use it as a source of food when it gets colder and food becomes scarce (Forestry, 2016). It is important to look at the eastern hemlock as essential to a forest ecosystem with its properties as a temperature regulator and shelter provider for the animals in the forest.



Image 1 Branch of the Eastern Hemlock

Eastern hemlock faces a predator that comes in the form of an insect. This insect is called the Hemlock Woolly Adelgid (HWA) and is a highly devastating invasive insect. HWA is not native to the United States. It first arrived in the state of Virginia in the year 1951 from Japan (Evans, 2016; Thompson, & et. al., 2013). HWA is



Image 2 Hemlock Woolly Adelgid feeding on an eastern hemlock branch

a dark purplish color when it does not have a white fuzzy coat to it (United States Department of Agriculture, 2005; Hemlock Woolly Adelgid (Department of Entomology)). That white fuzzy coating is the result of it feeding on the hemlock's sap (Dhungel, & Et. Al., 2010; Jenkins, & et. Al., 1999). HWA takes up a significant portion of the nutrient-filled sap causing the tree to be slowly starved (Gonda-king, & et. Al., 2014; Small, & et. Al., 2005). The amount of time that it takes HWA to kill infested trees is usually between 4-10 years (Boyd, & et al., 2013; Pennsylvania department of conservation and natural resources, 2013). To make matters worse for the eastern hemlock, HWA reproduces biannually (Ingwell, & et. Al., 2012). HWA does have naturally occurring predators that can help to slow down the spread or even eradicate HWA from the United States.

Predators of HWA are primarily beetles that come from Asia. The beetle called *Laricobius nigrinus* is from the western United States, however, and it has been proposed by forest ecologists as the most effective way to kill the adelgid and stop the spread of the adelgid into new forests. The beetle is known for its success as being a ferocious predator of HWA, since that is its only food source. When all of the HWA population has been eaten by the beetles, the population of beetles decreases until they are all dead from starvation (Lamb, & et. Al., 2006). The trait that the beetles have where they can only eat HWA helps to calm the concerns of the possibility of introducing another predator.

The effectiveness of the beetle can be seen in many studies conducted by forest ecologists. However, beetles are not always going to be the easiest way to treat hemlock for HWA. Beetles are in need of humans to distribute them into the stands and place the appropriate amount on those trees that are affected. It has been found that they can form colonies, but they struggle to spread without human intervention. The colonies that are formed, however, struggle to survive through cold winters on the east coast (Fast, 2002; Mooneyham, & et. Al., 2016). This is the current major worry and drawback to the beetles as it makes beetle treatments very time consuming.



Image 3 Laricobius nigrinus eating hemlock woolly adelgid

Sasajiscymnus tsugae (*S.Tsugae*) which is native to Japan, is commercially available. *S. Tsugae* is a small beetle that looks similar to the *Laricobius nigrinus* with it being completely black in color. However, *S. Tsugae* is more of an oval shape rather than the two sectioned body of the *Laricobius nigrinus. S. Tsugae* mainly feeds on HWA, but they have also been known to feed on other adelgids that threaten the hemlocks in the region. *S. Tsugae* reproduces on its own and does not need any human

interaction to spread to new trees. Once they are put into the ecosystem, they will work to eat all of the HWA and other adelgids out of the ecosystem to ensure that the hemlocks are preserved (Cheah & McClure). Using *S. Tsugae* is the most effective way to solve the infestation issue for the long term at this time.

In some situations, particularly in urban areas, beetles are sometimes not a widely accepted method to treat trees due to the concerns that they would get into houses, colonize, and then proceed to ruin property value. So in urban areas or in areas with hemlocks that have tremendous value, forest ecologists and foresters use chemicals to treat the hemlocks. Imidacloprid is the most commonly used chemical to treat hemlocks for HWA. Imidacloprid is an interesting chemical as it is considered a neonicotinoid and is extremely harmful to all sorts of life (Gibbons, & et. Al., 2015; Knoepp, & et. Al., 2012). Its primary aim is to kill unwanted insects. The insecticide is applied to the tree in a variety of ways. The methods used to apply it are tablets, soil drench, and injection (Doccola, & et. Al., 2005). Treating the hemlocks with chemicals is a very short term solution. With Imidacloprid, the application rate is two years (Benton, & et. Al., 2016). Chemicals become a costly treatment when they have to be retreated so often.

Besides Imidacloprid, Dinotefuran is a pesticide that is very useful in controlling forest insect predators. The chemical is more widely known as Safari. Safari is extremely effective when it comes to controlling invasive forest insect predators. Safari is administered to trees through a basal spray. This allows the chemical to get into the tree as quickly as possible. Treating with Safari requires the trees to be treated on a yearly basis, as the chemical's effectiveness usually lasts one year (Cortese; Valent).

There are many dangers associated with the use of the pesticides. The pesticides could end up leeching into the wetlands within ENWR, and cause harm to the aquatic life. The Imidacloprid causes even more red flags whenever it is applied anywhere near a water source because of its harmful effects on life. The same harmful effects that are associated with Imidacloprid can be found with Safari. With the Safari, since it is applied through a basal spray, it is important to be careful with it so that none of it washes off of the bark and goes into a stream or water source.

Some forest ecologists and foresters have started to look to the future and begin to incorporate different species into the forest to replace the hemlocks if there is no possible way that they can be preserved. Planting trees is not a treatment method. However, it is important to take into account the use of tree planting to know what trees can be used if HWA decimated the hemlock population. Tree planting can be used as a way to keep HWA from causing a major

problem to an ecosystem. This portion of the story with eastern hemlock and HWA is a part that incorporates landowners. It is important that the landowners are properly educated on the forest issues at hand, how to properly solve those issues, and what is the most sustainable way to manage the forest (Pham, & et. Al., 2004; Wingfield, 2015). This kind of action is needed because if there are educated landowners who want to help find a solution to this issue, it can create an area where the adelgid could be halted.

The United States Fish and Wildlife service created the Erie National Wildlife Refuge in 1959 (About, 2016). ENWR is located in northwestern Pennsylvania outside of the towns of Cambridge springs and Guys Mills. ENWR is split up into two different divisions consisting of approximately 8800 acres in total. The goal of ENWR is to create an area for wildlife to thrive without the impedance of human interaction. It is important to note that ENWR has been placed an importance on creating and managing wetlands. That is their main way to create habitat and is also their main land cover. Since the creation of ENWR, the amount of land that has become wetlands has increased drastically. ENWR manages with a primary focus on migratory birds. In addition to the wetlands, ENWR has over 3000 acres of forested land. The forest is regarded as a Northern Hardwood mix, as the composition includes Black Cherry, Northern Red Oak, and Hard Maple.



Image 4 Sign that is located at the front of the driveway to the main office of ENWR.

It is important to help try and stop the spread of HWA, and to decrease the amount of hemlock trees that are dying. For a place like ENWR, it is important to have a management plan to handle HWA when it arrives onto their property. The goal of this study is to create that management plan. The plan will include recommendations of what treatments should be used as well as information on the pricing of each treatment. The management plan will be focused on being economically affordable for ENWR, while also making sure that HWA is controlled for years to come after the treatments. The best way to create a plan like this is to make it an integrated pest management plan. The adelgid has been found in Crawford County, so the time to create this plan is now.

Methods

Erie National Wildlife Refuge is located in Crawford County in Northwestern Pennsylvania. ENWR itself is located just outside of the villages of Guys Mills and Cambridge Springs, and it is comprised of approximately 8800 acres of land. That land is filled with wetlands, forests, and fields. The land that has Eastern Hemlock within ENWR was analyzed through Geographical Information Systems (GIS). The software that was used was ArcMap 10.4.1. With the use of the software, maps detailing the location of the plots with in the study regions were created. They can be seen in Appendices A and B. Appendices C and D are the select plots that were looked at. All four of the maps were created with a base map provided by the ENWR.

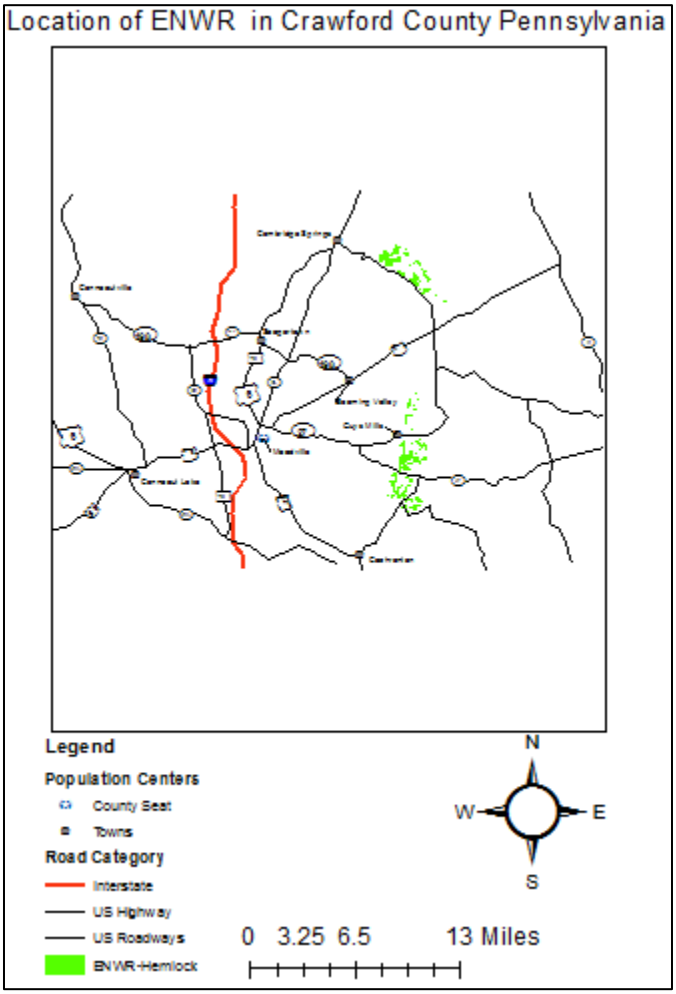


Image 5 shows the location of ENWR relative to highways.

The plots were transferred to an app called Avenza Free PDF Maps. The plots were assessed following the creation of the maps on Avenza. The plots were measured out to be 20x20m with the center of the plot being the value of the longitude and latitude produced by the GIS map. The only tree species that was counted in the plots is the hemlocks. Those were all that was necessary. Using a Biltmore stick, the diameters of the hemlock trees were measured. The diameters and the number of trees in the plots were recorded onto a data sheet. The recorded data were then transferred to an excel sheet. The excel sheet comprised of formulas for the calculation of basal area, averages, and totals for the plots that were measured.

When calculating the costs of the treatments for ENWR, there must be a map of the total forested land with hemlocks. A series of phone calls discussing the appropriate treatment options were then made. Through the phone conversations, the following treatment options

were decided to be addressed: Imidacloprid, Safari, and Beetle. The planting of Norway spruce, Blue Spruce, and Northern White Cedar was also included. The prices were determined by the rates that the companies provided.

Results and Discussion

Through the study, it was found that ENWR had 3142 acres of forests with eastern hemlock. Not all of the land was 100% hemlock, so the basal area was found to determine the amount of hemlocks in the stands. The basal area is also helpful as a way to check the findings of this study with those of other studies. That way the data is as accurate as it possibly can be. The average basal area was 5.88 ft2/20m2. The data were then converted to the value in acres. The average was then 57.59 ft2/acre.

The total number of trees and diameters in the plot were an important aspect of the study as they were the variables that determined the amount of the treatments that were going to be necessary. The trees were assessed in the same way as the basal area. The average trees per acre of land was found to be 99 trees per acre. The average total inches per acre according to the plots was 886. The average total sums of the basal area, tree density and total diameter can be seen below.

Table 1

	basal area	Hemlock density	total dbh
	ft2/acre	hemlocks/acre	in/acre
average	56.80	98.98	885.92
standard error	7.28	9.64	100.88
Number of Plots	60	60	60

Table 1 The table represents the average amount for each measurement. The number of plots is in the table to give the sample size, and the standard error is also present to show the range of possible measurements within the different acres.

The chemical treatments, Imidacloprid and Safari, are calculated using the inches from the plots. The Imidacloprid comes in several sized packages, but the one container used to calculate the price for this study is a barrel. When buying the chemicals outright, the cost per barrel of Imidacloprid is $715, and the price for the Safari in the flat of 16 12 oz. bottles is $1,476. The average cost per acre for the Imidacloprid treatment and the Safari treatment can be seen in Table 3. Knowing that ENWR is filled with wetlands, the safer chemical to use would

be the Safari. However, Safari is more expensive, and suggests that another method might be better to use if the cheapest treatment method over the long term is one of the goals.

Table 2			
	basal area	Hemlock density	total dbh
	ft2/refuge	hemlocks/refuge	in/refuge
Hemlock Area	178,469.27	310,995.16	2,783,560.64
standard error	3,810.49	5,045.17	52,818.38

Table 2 This table shows the total amount of measurements throughout the refuge. They are base off of the averages provided in table 1

The beetle treatment was the next treatment that was analyzed. Cost per acre for the beetle treatment can be seen in Table 3 below. Although the price is over $4,000 more expensive than the treatment of Safari, it is the cheaper solution due to the amount of applications that are required. The Safari requires application every year to keep the HWA away from the trees, whereas the beetles would only need to be applied once ("Pricing & Shipping"). Using the beetle treatments would be the cheapest method to combat HWA, however it might not be the cheapest method to deal with HWA.

Table 3	
Treatment options	$/acre
Imidacloprid	149.96
Safari	2,251.71
Beetle	6,609.56
Norway Spruce	45.78
Blue Spruce	45.78
Northern White Cedar	79.18

Table 3 this table shows the price per acre for each of the treatments.

Planting trees is another method that was explored. The trees were selected from an article by Penn State University's Entomology Department. The trees that were determined to be most viable and beneficial to the ecosystem were Norway spruce, Blue Spruce, and Northern White Cedar. Using a chart provided by Penn State extension, the compatibilities between the trees and the ecosystems that the hemlock thrived within were identified, and helped to confirm that those three trees should be used as substitutes for the hemlock ("Forest Landowners Guide to Tree Planting Success (Penn State Extension)"). The price was $.37 per tree for the Norway and Blue spruces, and $.64 per tree for the Northern White Cedar ("Conifer Seedlings & Transplants"). Using these rates, the average cost per acre was calculated. Those values are found in Table 3. These numbers included the addition of 25% more trees than what is actually on ENWR, but that was to take into account for the potential mortality rate that can occur. All of these different methods have their price calculated for just the treatments themselves. They do not include labor as that would vary upon the group that is used to administer the treatments. A table with the price per acre for each of the treatments listed can be found below.

After finding the average cost per acre for each of the treatment methods, it was then time to calculate the total cost for treating ENWR. The average cost per acre for each treatment was then multiplied by the 3142 total acres with hemlock to create the cost for each method. The cost would be equivalent to one year's worth of treatments. The prices of the different methods can be seen in the chart below. These prices are for the total cost of only using one treatment method. As can be seen, the bugs are the most expensive option for treating the first time. The cheapest is planting the Norway spruce or Blue spruce trees.

Table 4						
	Imidacloprid treatment	safari	Beetle	Norway	blue	white cedar
	$/refuge	$/refuge	$/refuge	$/refuge	$/refuge	$/refuge
Hemlock Area	471,175.63	7,074,883.29	20,767,223.56	143,835.26	143,835.26	248,796.13
standard error	8,940.61	134,246.73	336,344.60	2,332.44	2,332.44	4,034.49

Table 4 this table shows the individual prices if the refuge were to treat land with one method for one year.

The idea of using one management method as the best way to handle the threat that the HWA poses to ENWR is difficult to determine. If the study was aimed at trying to find a treatment that is low cost and effective at treating the HWA infested trees without taking into account any environmental factors, then the one treatment method approach is the way to solve the issue. The factors that wouldn't have to be taken into account would be the amount of nearby wetlands, wildlife concentrations, and the application rates. In viewing the data like this, the most expensive treatment would be the beetles, and the least expensive would be the Imidacloprid treatment. Now, when looking at the issue in the long term and no longer ignoring the application rates, the Safari becomes the most expensive while the Imidacloprid stays the same at a low cost.

When adding the seedlings into the mix, it is by far the cheapest option. That would be understandable since ENWR can get seedlings for either $.37 or $.64 apiece. The reason why they were not presented as a relevant option before is because they are more of an adaptation measure for ENWR to take in the event that the infestation is to vast and would require too much money to solve. The planting of the trees is a smart way to approach the problem of introducing a replacement for the loss of the hemlocks in the ecosystem. They wouldn't have been needed if the outside factors could be ignored, but since they are not being ignored, then the seedlings become important.

Having an integrated pest management plan instead of using just one treatment would be more realistic due to the environmental factors that are present on ENWR. It would also

make more sense financially to do an integrated pest management plan. Other management plans that have been suggested by state and federal organizations all agree with the idea of creating an integrated pest management plan. They all call for further research and the use of beetles, chemicals, and other silvicultural management practices (Havill, Vieira, Salom, & McClure, 2016). It might be more expensive if there is a large amount the beetle treatment in the management plan, but the beetles only need to be introduced once while HWA is present on the property. They may need to be reapplied if another wave of HWA were to suddenly infest the refuge. That makes the price for treatment cheaper in the long term. The treatment plan can also take into account the changing nature of the forest ecosystem, and be adjusted to what the forest needs and what the funds allow ENWR to do. In the management plan for ENWR, there will be a very small amount of land that can have the Imidacloprid treatment used on it due to imidacloprid's application method being soil drench and the large amount of wetlands on ENWR. Even the use of the Safari chemical may not be as used heavily as beetles because of the large price tag associated with it, and the large amount of time commitment it requires. This can cause it to be applied in lower amounts. The beetles would be by far the largest treatment used so that ENWR could solve the infestation problem sooner rather than later without having to worry about spending more money on that treatment option every year.

Thinning of the hemlock stands is one silvicultural method that has been suggested as possible treatment to stop HWA. There is no direct evidence proving that the thinning of the stands would be successful, it is more of a way that sounds successful in theory (Havill, Vieira, Salom, & McClure, 2016). The thinning of the stand would open up the canopy and help to decrease the temperature in the forest so that HWA has a higher mortality rate during the winter season. The use of thinning by the refuge should be considered as a viable option as it would create money and help to manage the refuge.

The prices that were found for each of the treatments help to determine the feasibility of implementing a management plan to ENWR. With the high cost for treatments and the current number of employees at ENWR, it is realistic that a management plan of any kind for HWA treatment would be unlikely to be implemented. All of the treatments require manpower that the refuge cannot afford. The cost for treatments could have help with the use of funding from grants. The following management plan has been created for just in case ENWR was able to afford treating their hemlocks for HWA.

Management Plan

The management plan that has been created for the Erie National Wildlife Refuge is an integrated pest management approach. Based upon all of the data collected and the process of completing the project, the following tables have been created to address the presence of HWA within the property of Erie National Wildlife Refuge. The plan is meant to be implemented 4 years after the first known presence of HWA on the property. The plan focuses on reducing both the price and necessary treatments for ENWR.

In the first year of the management plan, all of the refuge will be receiving treatment. The plan focuses on treating 60% of the refuge with the beetles, 30% of tree planting trees, and 10% pesticide treatments. The exact totals can be seen in the management plan table. The 30% of land being planted by trees is designated to be the area that HWA first infested.

Since the basal area that has been treated by the beetles and tree planting is a one application treatment, there is no need to take that into account for the second year. The second year only takes into account the land that was treated with Safari the year prior. The land that was treated with Imidacloprid is in need of treatment every 2 years, so the basal area that was treated with it does not need a treatment administered.

The third year's goal is to try to eliminate the need to use pesticides by reducing the usage of them by 50% with the use of beetles. This allows only 5% of the original basal area left to be treated after the third year.

The fourth year is aimed at replacing the Safari treatment with beetles. This is to help with the goal to create a long term solution for ENWR. After year four of treatment the refuge should be left with 2.5% of the total basal area within ENWR. That 2.5% was treated the year prior with Imidacloprid.

The fifth and final year of the management plan comprises of treating the rest of ENWR with beetles. It is within this year that ENWR will have to begin their assessments of the refuge to determine the effectiveness of the plan. The assessments will also check for the presence of HWA. In association to the management plan, it is recommended that the forests be assessed every two years after the management plan is completed. If HWA is found on a low population of trees, then it is suggested that ENWR use Safari to keep the infestation from growing more. If there is a large population, then the use of beetles is recommended. The chart labeled treatment totals has the final costs for each treatment in ENWR for the 5 year plan. It also includes the total amount that will be spent and the average cost of treatment per acre.

An option to cut down on the cost of the management plan is to incorporate thinning the stands into the plan. This would reduce the amount of trees that will need treated and it would also open up the canopy and possibly influence the way that HWA infests the land. Thinning would be best done in the winter time when the ground is hard so that there is no disturbances in the soil.

The other treatments have certain times of years when they should be used. It is suggested that the use of Imidacloprid begin during early spring time when the trees begin to leaf. The Safari can be used during the same time period, but can be applied throughout the entire spring season. It is also suggested that the chemicals be used during the fall, due to the fact that it is during that time that HWA tends to begin hibernation. Beetle treatments are to be done during the early spring as well. This is so they can be on the same life cycle schedule as HWA. The replanting aspect of the management plan is suggested to be done during the spring or summer.

Treatment Totals		
Treatment	Basal Area of Hemlock Stands	Price
	ft2/refuge	$/refuge
Imidacloprid	13,385.19	35,338.17
Safari	22,308.65	884,360.41
Beetle	124,928.48	14,537,056.49
Norway	12,492.85	14,383.53
Blue	12,492.85	14,383.53
Cedar	12,492.85	24,879.61
Total	**198,100.87**	**15,510,401.74**
Average per acre	**63.05**	**4,936.47**

5 Year Management Plan								
1st year		Imidaclopr id	Safari	Bug	Norway	Blue	Cedar	Total Treatment
% of treatme nt		5%	5%	60%	10%	10%	10%	100%
Basal area	ft2/refu ge	8,923.46	8,923.4 6	107,081. 56	17,846.9 3	17,846.9 3	17,846.9 3	178,469.27
Price	$/refuge	23559	353744	1246033 4	14384	14384	24880	12,891,283. 74
2nd year		Imidaclopr id	Safari	Bug	Norway	Blue	Cedar	Total Treatment
% of treatme nt		0%	100%	0%	0%	0%	0%	100%
Basal area	ft2/refu ge	-	8923	-	-	-	-	8,923.46
Price	$/refuge	0	353744	0	0	0	0	353,744.16
3rd year		Imidaclopr id	Safari	Bug	Norway	Blue	Cedar	Total Treatment
% of treatme nt		25%	25%	50%	0%	0%	0%	100%
Basal area	ft2/refu ge	4,462	4,462	8,923	-	-	-	17,847
Price	$/refuge	11,779	176,87 2	1,038,36 1	-	-	-	1,227,013
4th year		Imidaclopr id	Safari	Bug	Norway	Blue	Cedar	Total Treatment
% of treatme nt		0%	0%	100%	0%	0%	0%	100%
Basal area	ft2/refu ge	-	-	4,461.73	-	-	-	4,461.73
Price	$/refuge	0	0	519181	0	0	0	519,180.59
5th year		Imidaclopr id	Safari	Bug	Norway	Blue	Cedar	Total Treatment
% of treatme nt		0%	0%	100%	0%	0%	0%	100%
Basal area	ft2/refu ge	-	-	4,461.73	-	-	-	4,461.73
Price		0	0	519181	0	0	0	519,180.59

	$/refuge							

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Appendix A

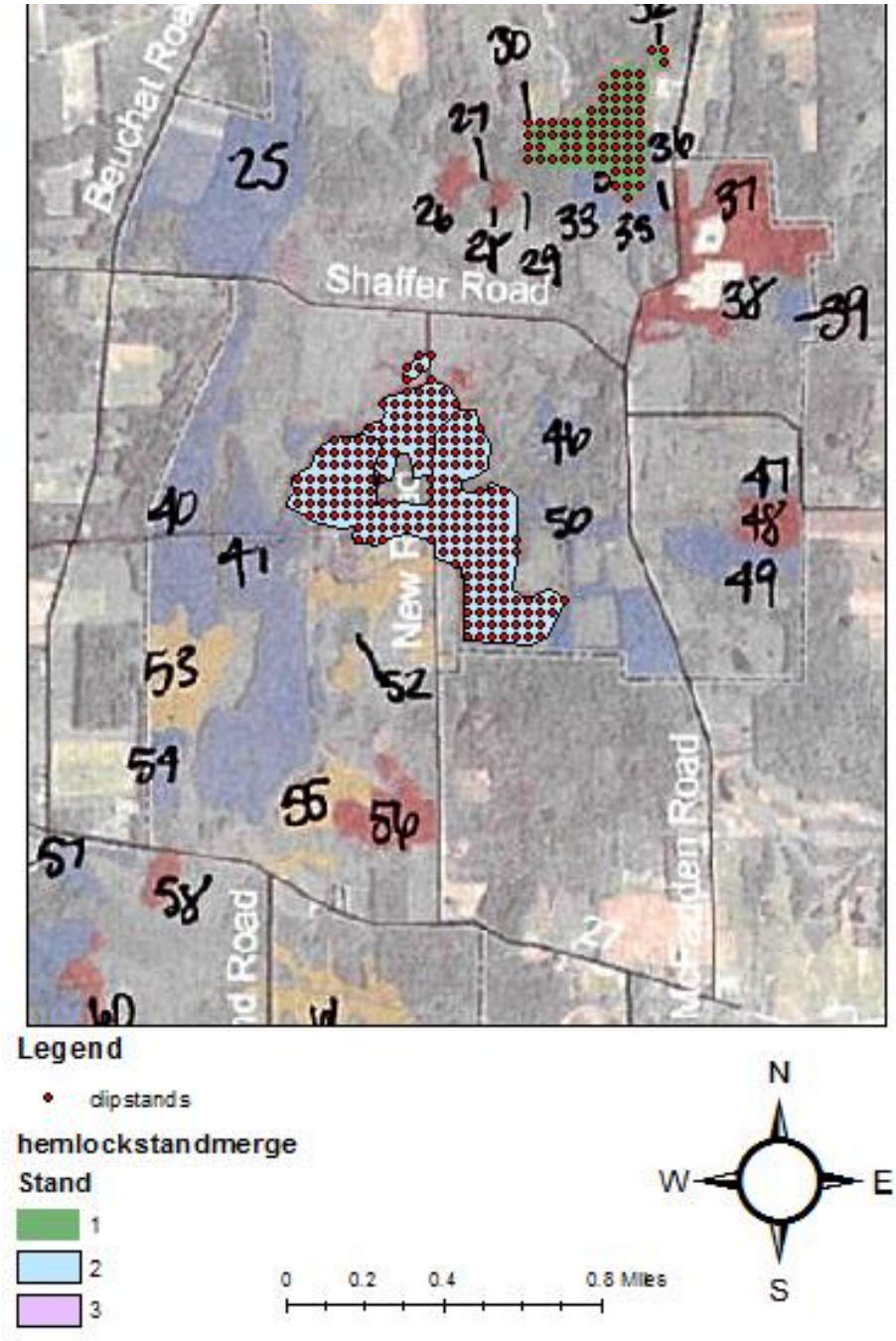


Image 6 Base map data from (Muller, 2016). Map shows the location of the stands in the Sugar Lake division.

Appendix B

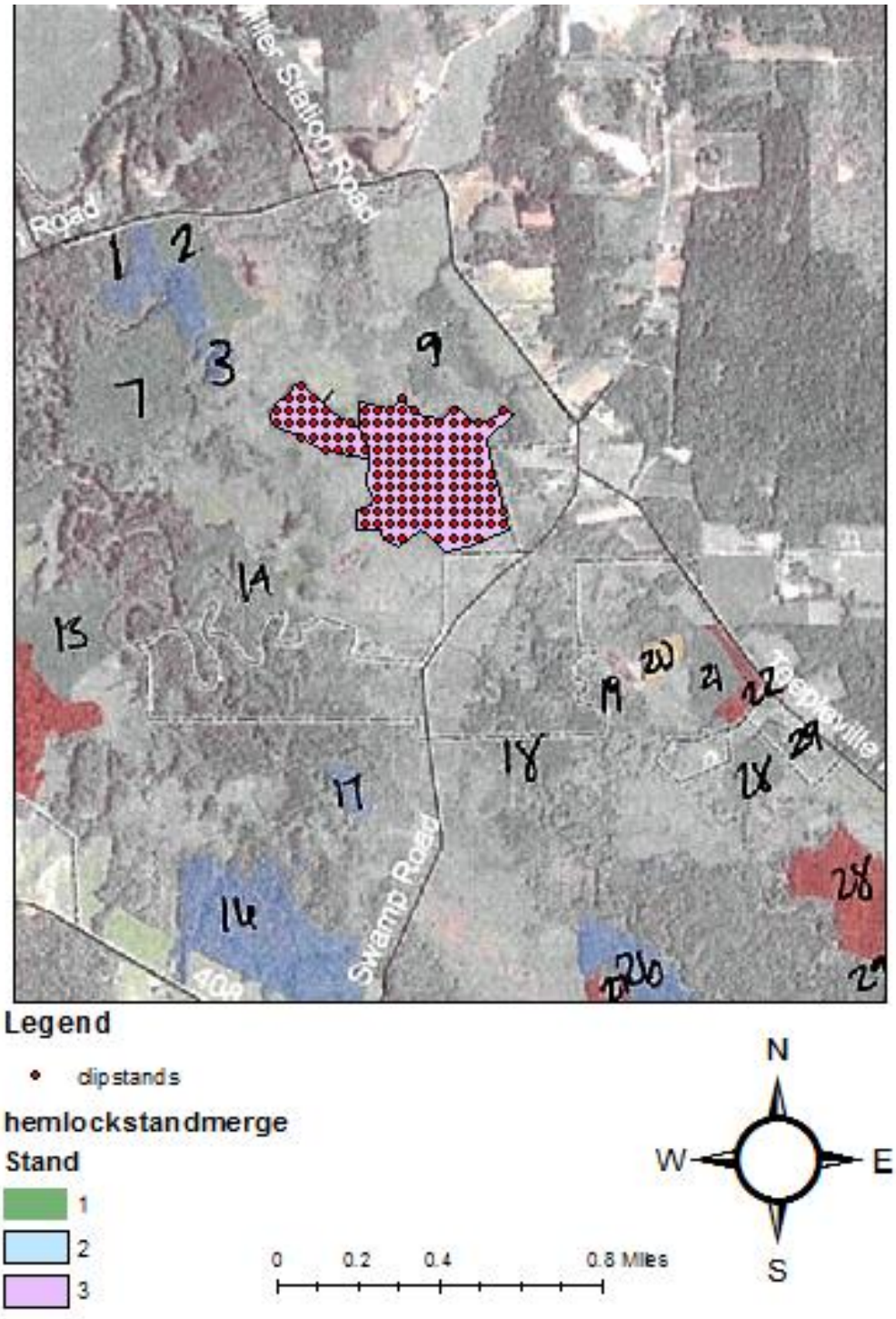


Image 7 Base map data from (Muller, 2016). Map shows the location of the stands in the Seneca Division.

Appendix C

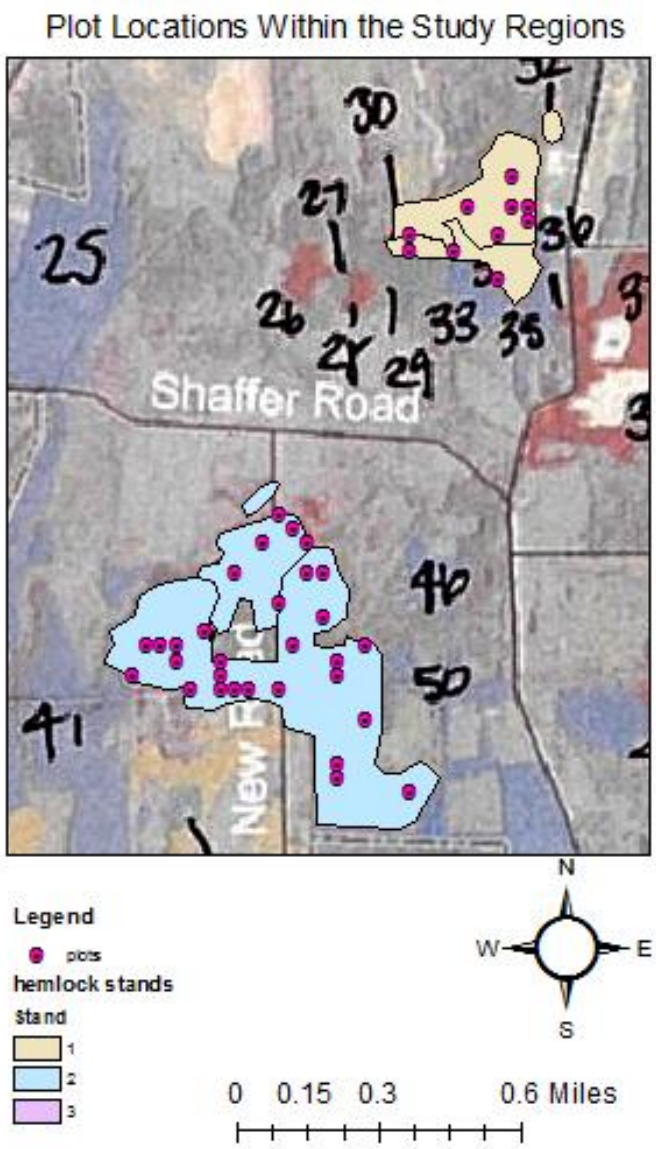


Image 8 Base map data from (Muller, 2016). The map shows the plots that were assessed in Stands 1 and 2.

Appendix D

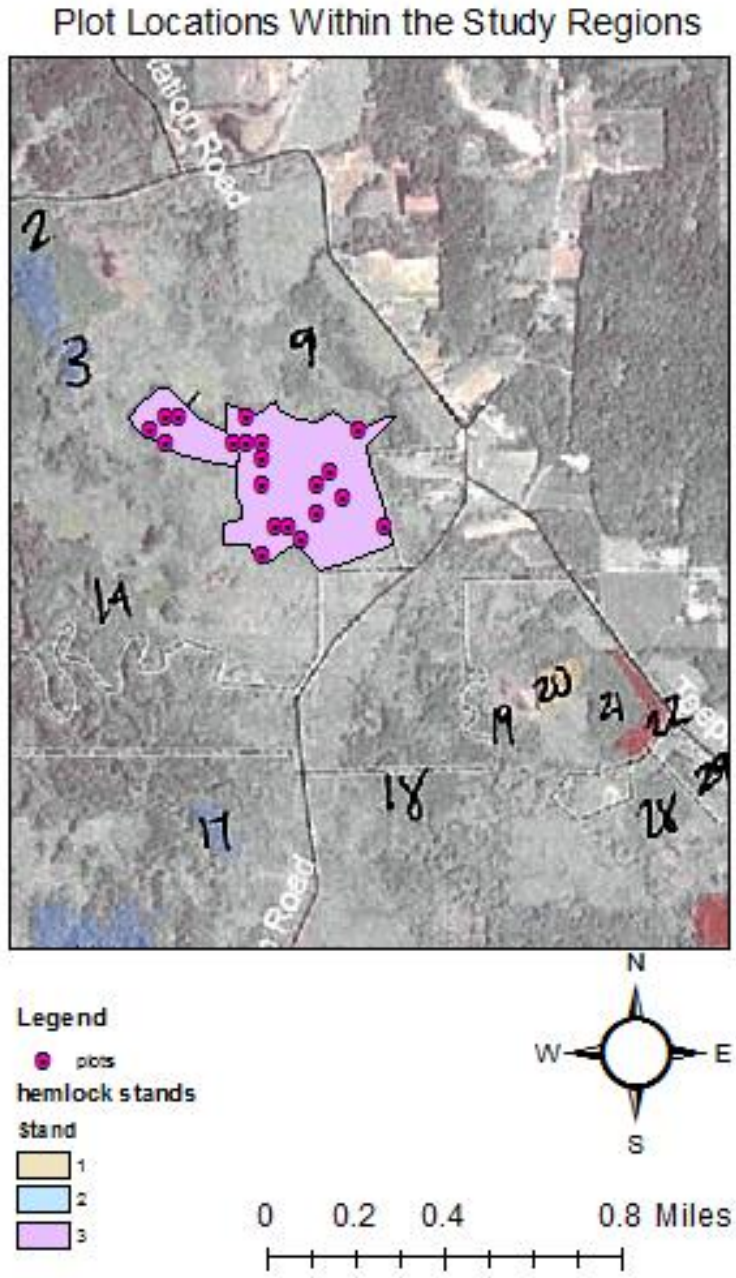


Image 9 Base map data from (Muller, 2016). Map displays Plots in the 3rd stand that were assessed.

Appendix E

Byron Thesis condensed data

Stand #	Plot #	Basal Area Per Plot	Basal Area per Acre	Trees in plot
2	178	15.7243	154.0984	25
	179	8.4539	82.8486	28
	200	0.0000	0.0000	0
	198	2.7707	27.1530	6
	194	6.1196	59.9717	8
	191	15.7680	154.5260	21
	153	20.1204	197.1797	22
	143	20.0277	196.2710	28
	117	20.9167	204.9835	24
	69	15.2225	149.1809	23
	67	2.5362	24.8546	11
	66	1.0581	10.3694	4
	65	2.3889	23.4114	7
	82	13.5318	132.6112	14
	100	2.6780	26.2443	9
	128	8.0612	79.0001	15
	112	3.6870	36.1327	5
	76	3.6979	36.2396	5
	111	0.5454	5.3451	1
	113	4.6742	45.8073	14
	97	4.8760	47.7849	21
	63	2.7871	27.3133	7
	90	2.6562	26.0305	8
	106	11.1865	109.6274	16
	121	0.0000	0.0000	0
	50	8.0721	79.1070	8
	33	0.0000	0.0000	0
	24	1.3963	13.6834	1
	21	7.3522	72.0516	10
	173	9.7684	95.7302	19
3	317	19.4495	190.6052	37
	305	15.7243	154.0984	19
	281	2.2580	22.1286	5
	292	0.8508	8.3383	9
	291	0.8236	8.0711	5
	270	0.4636	4.5433	2

	321	0.3982	3.9019	6
	344	2.9562	28.9703	6
	359	1.3145	12.8816	5
	358	2.1108	20.6854	6
	357	11.1101	108.8791	15
	352	0.0055	0.0539	1
	368	4.7397	46.4487	8
	387	5.0669	49.6557	8
	388	3.1689	31.0549	4
	391	0.7690	7.5365	4
	325	8.9230	87.4454	13
	336	10.3683	101.6098	14
	299	0.4200	4.1157	3
	383	0.9436	9.2470	4
1	258	1.0690	10.4763	1
	249	1.5544	15.2335	3
	250	2.4489	23.9994	7
	246	4.5924	45.0055	14
	240	5.6778	55.6422	7
	228	8.5685	83.9711	17
	223	1.1454	11.2246	15
	213	5.4651	53.5567	8
	216	1.5163	14.8593	3
	206	12.6536	124.0056	12

Appendix F

inches per acre	Imidacloprid Ounces needed	imidacloprid packets	Imidacloprid price	safari	safari price
2528.40	84.28	52.68	427.98	70.23	6426.35
1548.40	51.61	32.26	262.10	43.01	3935.52
0.00	0.00	0.00	0.00	0.00	0.00
431.20	14.37	8.98	72.99	11.98	1095.97
617.40	20.58	12.86	104.51	17.15	1569.23
2067.80	68.93	43.08	350.02	57.44	5255.66
2714.60	90.49	56.55	459.50	75.41	6899.61
2959.60	98.65	61.66	500.97	82.21	7522.32
2695.00	89.83	56.15	456.18	74.86	6849.79
2381.40	79.38	49.61	403.10	66.15	6052.73
617.40	20.58	12.86	104.51	17.15	1569.23
235.20	7.84	4.90	39.81	6.53	597.80
490.00	16.33	10.21	82.94	13.61	1245.42
1538.60	51.29	32.05	260.44	42.74	3910.61
578.20	19.27	12.05	97.87	16.06	1469.59
1293.60	43.12	26.95	218.97	35.93	3287.90
509.60	16.99	10.62	86.26	14.16	1295.23
509.60	16.99	10.62	86.26	14.16	1295.23
98.00	3.27	2.04	16.59	2.72	249.08
1009.40	33.65	21.03	170.86	28.04	2565.56
1215.20	40.51	25.32	205.70	33.76	3088.63
441.00	14.70	9.19	74.65	12.25	1120.88
558.60	18.62	11.64	94.55	15.52	1419.78
1421.00	47.37	29.60	240.53	39.47	3611.71
0.00	0.00	0.00	0.00	0.00	0.00
921.20	30.71	19.19	155.93	25.59	2341.38
0.00	0.00	0.00	0.00	0.00	0.00
156.80	5.23	3.27	26.54	4.36	398.53
1058.40	35.28	22.05	179.16	29.40	2690.10
1597.40	53.25	33.28	270.39	44.37	4060.06
2244.20	74.81	46.75	379.88	62.34	5704.01
2058.00	68.60	42.88	348.36	57.17	5230.75
431.20	14.37	8.98	72.99	11.98	1095.97
352.80	11.76	7.35	59.72	9.80	896.70
264.60	8.82	5.51	44.79	7.35	672.53
127.40	4.25	2.65	21.57	3.54	323.81
186.20	6.21	3.88	31.52	5.17	473.26
529.20	17.64	11.03	89.58	14.70	1345.05
323.40	10.78	6.74	54.74	8.98	821.98
460.60	15.35	9.60	77.97	12.79	1170.69
1617.00	53.90	33.69	273.71	44.92	4109.88
9.80	0.33	0.20	1.66	0.27	24.91
774.20	25.81	16.13	131.05	21.51	1967.76
715.40	23.85	14.90	121.10	19.87	1818.31
441.00	14.70	9.19	74.65	12.25	1120.88
225.40	7.51	4.70	38.15	6.26	572.89
1274.00	42.47	26.54	215.65	35.39	3238.08
1440.60	48.02	30.01	243.85	40.02	3661.53
127.40	4.25	2.65	21.57	3.54	323.81
205.80	6.86	4.29	34.84	5.72	523.08
137.20	4.57	2.86	23.22	3.81	348.72
284.20	9.47	5.92	48.11	7.89	722.34
499.80	16.66	10.41	84.60	13.88	1270.33
940.80	31.36	19.60	159.25	26.13	2391.20
813.40	27.11	16.95	137.68	22.59	2067.39
1499.40	49.98	31.24	253.80	41.65	3810.98
490.00	16.33	10.21	82.94	13.61	1245.42
764.40	25.48	15.93	129.39	21.23	1942.85
235.20	7.84	4.90	39.81	6.53	597.80
1489.60	49.65	31.03	252.15	41.38	3786.07

Appendix G

Byron Thesis Bug data								
Stand #	**Plot #**	**Basal Area Per Plot**	**Basal Area per Acre**	**Trees in plot**	**trees per acre**	**Colonies per acre**	**beetles per acre**	**price per acre**
2	178	15.7	154.1	25.0	245.0	81.7	8166.7	16333.3
	179	8.5	82.8	28.0	274.4	91.5	9146.7	18293.3
	200	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	198	2.8	27.2	6.0	58.8	19.6	1960.0	3920.0
	194	6.1	60.0	8.0	78.4	26.1	2613.3	5226.7
	191	15.8	154.5	21.0	205.8	68.6	6860.0	13720.0
	153	20.1	197.2	22.0	215.6	71.9	7186.7	14373.3
	143	20.0	196.3	28.0	274.4	91.5	9146.7	18293.3
	117	20.9	205.0	24.0	235.2	78.4	7840.0	15680.0
	69	15.2	149.2	23.0	225.4	75.1	7513.3	15026.7
	67	2.5	24.9	11.0	107.8	35.9	3593.3	7186.7
	66	1.1	10.4	4.0	39.2	13.1	1306.7	2613.3
	65	2.4	23.4	7.0	68.6	22.9	2286.7	4573.3
	82	13.5	132.6	14.0	137.2	45.7	4573.3	9146.7
	100	2.7	26.2	9.0	88.2	29.4	2940.0	5880.0
	128	8.1	79.0	15.0	147.0	49.0	4900.0	9800.0
	112	3.7	36.1	5.0	49.0	16.3	1633.3	3266.7
	76	3.7	36.2	5.0	49.0	16.3	1633.3	3266.7
	111	0.5	5.3	1.0	9.8	3.3	326.7	653.3
	113	4.7	45.8	14.0	137.2	45.7	4573.3	9146.7
	97	4.9	47.8	21.0	205.8	68.6	6860.0	13720.0
	63	2.8	27.3	7.0	68.6	22.9	2286.7	4573.3
	90	2.7	26.0	8.0	78.4	26.1	2613.3	5226.7
	106	11.2	109.6	16.0	156.8	52.3	5226.7	10453.3
	121	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	50	8.1	79.1	8.0	78.4	26.1	2613.3	5226.7
	33	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	24	1.4	13.7	1.0	9.8	3.3	326.7	653.3
	21	7.4	72.1	10.0	98.0	32.7	3266.7	6533.3
	173	9.8	95.7	19.0	186.2	62.1	6206.7	12413.3
3	317	14.6	142.9	23.0	225.4	75.1	7513.3	15026.7
	305	15.7	154.1	19.0	186.2	62.1	6206.7	12413.3
	281	2.3	22.1	5.0	49.0	16.3	1633.3	3266.7
	292	0.9	8.3	9.0	88.2	29.4	2940.0	5880.0
	291	0.8	8.1	5.0	49.0	16.3	1633.3	3266.7
	270	0.5	4.5	2.0	19.6	6.5	653.3	1306.7
	321	0.4	3.9	6.0	58.8	19.6	1960.0	3920.0
	344	3.0	29.0	6.0	58.8	19.6	1960.0	3920.0
	359	1.3	12.9	5.0	49.0	16.3	1633.3	3266.7
	358	2.1	20.7	6.0	58.8	19.6	1960.0	3920.0
	357	11.1	108.9	15.0	147.0	49.0	4900.0	9800.0
	352	0.0	0.1	1.0	9.8	3.3	326.7	653.3
	368	4.7	46.4	8.0	78.4	26.1	2613.3	5226.7
	387	5.1	49.7	8.0	78.4	26.1	2613.3	5226.7
	388	3.2	31.1	4.0	39.2	13.1	1306.7	2613.3
	391	0.8	7.5	4.0	39.2	13.1	1306.7	2613.3
	325	8.9	87.4	13.0	127.4	42.5	4246.7	8493.3
	336	10.4	101.6	14.0	137.2	45.7	4573.3	9146.7
	299	0.4	4.1	3.0	29.4	9.8	980.0	1960.0
	383	0.9	9.2	4.0	39.2	13.1	1306.7	2613.3
1	258	1.1	10.5	1.0	9.8	3.3	326.7	653.3
	249	1.6	15.2	3.0	29.4	9.8	980.0	1960.0
	250	2.4	24.0	7.0	68.6	22.9	2286.7	4573.3
	246	4.6	45.0	14.0	137.2	45.7	4573.3	9146.7
	240	5.7	55.6	7.0	68.6	22.9	2286.7	4573.3
	228	8.6	84.0	17.0	166.6	55.5	5553.3	11106.7
	223	1.1	11.2	15.0	147.0	49.0	4900.0	9800.0
	213	5.5	53.6	8.0	78.4	26.1	2613.3	5226.7
	216	1.5	14.9	3.0	29.4	9.8	980.0	1960.0
	206	12.7	124.0	12.0	117.6	39.2	3920.0	7840.0
totals					5948.6	1982.9	198286.7	396573.3

Appendix H

byron thesis tree data									
Stand #	**Plot #**	**Basal Area Per Plot**	**Basal Area per Acre**	**Trees in plot**	**Total Number of Trees**	**Norway Spruce**	**White Cedar**	**Blue Spruce**	**dead tress**
		ft2/20m2	**ft2/acre**	**trees/20m2**	**trees/acre**	**$/acre**	**$/acre**	**$/acre**	**trees/acre**
2	178	15.72	154.10	25.00	245.00	113.31	196.00	113.31	61.25
	179	8.45	82.85	28.00	274.40	126.91	219.52	126.91	68.60
	200	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	198	2.77	27.15	6.00	58.80	27.20	47.04	27.20	14.70
	194	6.12	59.97	8.00	78.40	36.26	62.72	36.26	19.60
	191	15.77	154.53	21.00	205.80	95.18	164.64	95.18	51.45
	153	20.12	197.18	22.00	215.60	99.72	172.48	99.72	53.90
	143	20.03	196.27	28.00	274.40	126.91	219.52	126.91	68.60
	117	20.92	204.98	24.00	235.20	108.78	188.16	108.78	58.80
	69	15.22	149.18	23.00	225.40	104.25	180.32	104.25	56.35
	67	2.54	24.85	11.00	107.80	49.86	86.24	49.86	26.95
	66	1.06	10.37	4.00	39.20	18.13	31.36	18.13	9.80
	65	2.39	23.41	7.00	68.60	31.73	54.88	31.73	17.15
	82	13.53	132.61	14.00	137.20	63.46	109.76	63.46	34.30
	100	2.68	26.24	9.00	88.20	40.79	70.56	40.79	22.05
	128	8.06	79.00	15.00	147.00	67.99	117.60	67.99	36.75
	112	3.69	36.13	5.00	49.00	22.66	39.20	22.66	12.25
	76	3.70	36.24	5.00	49.00	22.66	39.20	22.66	12.25
	111	0.55	5.35	1.00	9.80	4.53	7.84	4.53	2.45
	113	4.67	45.81	14.00	137.20	63.46	109.76	63.46	34.30
	97	4.88	47.78	21.00	205.80	95.18	164.64	95.18	51.45
	63	2.79	27.31	7.00	68.60	31.73	54.88	31.73	17.15
	90	2.66	26.03	8.00	78.40	36.26	62.72	36.26	19.60
	106	11.19	109.63	16.00	156.80	72.52	125.44	72.52	39.20
	121	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	50	8.07	79.11	8.00	78.40	36.26	62.72	36.26	19.60
	33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	24	1.40	13.68	1.00	9.80	4.53	7.84	4.53	2.45
	21	7.35	72.05	10.00	98.00	45.33	78.40	45.33	24.50
	173	9.77	95.73	19.00	186.20	86.12	148.96	86.12	46.55
3	317	14.58	142.87	23.00	225.40	104.25	180.32	104.25	56.35
	305	15.72	154.10	19.00	186.20	86.12	148.96	86.12	46.55
	281	2.26	22.13	5.00	49.00	22.66	39.20	22.66	12.25
	292	0.85	8.34	9.00	88.20	40.79	70.56	40.79	22.05
	291	0.82	8.07	5.00	49.00	22.66	39.20	22.66	12.25
	270	0.46	4.54	2.00	19.60	9.07	15.68	9.07	4.90
	321	0.40	3.90	6.00	58.80	27.20	47.04	27.20	14.70
	344	2.96	28.97	6.00	58.80	27.20	47.04	27.20	14.70
	359	1.31	12.88	5.00	49.00	22.66	39.20	22.66	12.25
	358	2.11	20.69	6.00	58.80	27.20	47.04	27.20	14.70
	357	11.11	108.88	15.00	147.00	67.99	117.60	67.99	36.75
	352	0.01	0.05	1.00	9.80	4.53	7.84	4.53	2.45
	368	4.74	46.45	8.00	78.40	36.26	62.72	36.26	19.60
	387	5.07	49.66	8.00	78.40	36.26	62.72	36.26	19.60
	388	3.17	31.05	4.00	39.20	18.13	31.36	18.13	9.80
	391	0.77	7.54	4.00	39.20	18.13	31.36	18.13	9.80
	325	8.92	87.45	13.00	127.40	58.92	101.92	58.92	31.85
	336	10.37	101.61	14.00	137.20	63.46	109.76	63.46	34.30
	299	0.42	4.12	3.00	29.40	13.60	23.52	13.60	7.35
	383	0.94	9.25	4.00	39.20	18.13	31.36	18.13	9.80
1	258	1.07	10.48	1.00	9.80	4.53	7.84	4.53	2.45
	249	1.55	15.23	3.00	29.40	13.60	23.52	13.60	7.35
	250	2.45	24.00	7.00	68.60	31.73	54.88	31.73	17.15
	246	4.59	45.01	14.00	137.20	63.46	109.76	63.46	34.30
	240	5.68	55.64	7.00	68.60	31.73	54.88	31.73	17.15
	228	8.57	83.97	17.00	166.60	77.05	133.28	77.05	41.65
	223	1.15	11.22	15.00	147.00	67.99	117.60	67.99	36.75
	213	5.47	53.56	8.00	78.40	36.26	62.72	36.26	19.60
	216	1.52	14.86	3.00	29.40	13.60	23.52	13.60	7.35
	206	12.65	124.01	11.00	107.80	49.86	86.24	49.86	26.95
Totals			3408.07		5938.80	2746.70	4751.04	2746.70	1484.70