Creating a decision support model for wild blueberry production returns and pollination services

By

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Abstract

One agriculture sector that has been greatly affected by a decline in honeybees in the past 2 decades has been the blueberry industry. Blueberries are flowering plants that are dependent on bees for cross pollination. This project was aimed at contributing to the development of a decision support model to aid wild blueberry farmers in Prince Edward Island to quantify their current production costs and increase their understanding of the links between blueberry yield and bee pollination by species. This was done by a) determining the links between blueberry yield and bee pollination, b) calculating the effects of pesticide use on bee abundance c) creating a baseline budget which tallied all of the farmer's costs for a 2 year blueberry production cycle, and incorporated links between yield and bee pollination of their fields, and d) validating the results of this study with blueberry farmers. Methods of data collection and analysis were both quantitative, while qualitative methods were used to validate the results. Results showed the native bees (bumblebees and *Andrena*) were much better pollinators than the managed honeybees and leafcutting bees for wild blueberries. Most pesticides used on these farms were highly toxic to bees. Furthermore, many farmers have limited knowledge of creating baseline budgets and therefore may not even know whether their crops are profitable. I recommended that farmers should put more emphasis on increasing the native bee populations in their fields, switch to using low toxicity pesticides when possible and take the time to learn to use baseline budgets to increase their awareness of the financial status of their fields.

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Chapter 1: Introduction

Background

In the United States, between 2006 and 2009, bee keepers lost roughly a third of their honeybee colonies each year (Mullin et al., 2010). This new phenomena has been coined the Colony Collapse Disorder (CCD) and is defined as the rapid disappearance of all adult bees except for the queen and the brood without any signs of death to adult bees in or around the hive (Naug, 2009; Mullin et al., 2010). The cause of CCD incidences is still unknown (Mullin et al., 2010).

The outbreak of CCD has had serious repercussions on agriculture. North American farmers and bee keepers predominantly use honeybees as the main pollinator species for their crops, as they live in hives that can easily be displaced and they are not particular about which flower species they feed on (Vance, 2011). When CCD heavily struck the honeybee hives, there were fewer honeybees available to pollinate the same amount of crops that were pollinated in previous years (Parsons, 2012). As a result, the cost of renting a single honeybee colony to pollinate their crops has risen to $150/colony, which is three times more expensive than the price in the 1990s (Vance, 2011; Parsons, 2012).

One agriculture sector that has been hit by the decline in honeybees has been the blueberry industry. Blueberries are flowering plants that are dependent on bees for cross pollination. The fruit set of many blueberry plant species mature 4-12 days earlier and grow up to 50% larger when pollinated by bees compared to wind pollination (Rhodes, 2006). Therefore,

the blueberry industry is very dependent on the pollination services of bees if they want to reach the maximum yield and profitability of their crops.

This project was aimed at building a decision support model to aid wild blueberry farmers in Prince Edward Island to quantify their current productions costs and pollination services. This was done by creating a baseline budget which tallied all their costs for a 2 years blueberry production cycle, with an emphasis on pollination services from different bee species.

The importance of pollination to lowbush blueberry yield was addressed by using a mixed methods sequential approach with a pragmatic world view. Mixed methods research is the use of both quantitative and qualitative methods of collecting and analyzing data in the same study (Demscombe, 2008). The reasoning behind such an approach is the belief that neither qualitative nor quantitative approaches alone can provide the breadth of information needed to address certain research questions (Demscombe, 2008). By using mixed methods for this study, the author believes that it will create a robust and accurate decision support model for wild blueberry farmers based on the data collected and on the results that have been derived.

Research Objectives

Purpose: Create a decision support tool for lowbush blueberry farmers that incorporated production costs and a detailed explanation of pollination services on yield.

Objectives:

1. Determined how lowbush blueberry yield was increased by managed and native bee pollination. This was conducted by calculating and comparing the theoretical pollination

rate of each bee species, and thus the theoretical increase in yield due to pollination. I also determined whether fields with more bees had higher blueberry yields.

2. Calculated the theoretical effect of pesticides on honeybees, native bees, and ultimately, blueberry yield. To do so, the toxicity level of each pesticide used by lowbush blueberry farming on bees, and how many bees were killed at each toxicity level were identified.

3. Determined the baseline budget for lowbush blueberry farming, ie. the link between inputs normally used by wild blueberry farmers and their central output (blueberries). These inputs included both man-made inputs (ex. chemicals, labour, and machinery) and natural inputs from objective 1 (interactions between pollination and yield).

4. Presented the study findings to two of the blueberry farmers in this study to validate the results as well as ensure that the results were communicated in a manner that farmers easily understand.

Methods

The data utilized for this study were provided by Steve Javorek, an entomologist and landscape ecologist at Agriculture Canada. The data were collected in the field between 2005 and 2009, and describes the bee species found at various wild blueberry fields owned by 6 different blueberry farmers in Prince Edwards Island. For the first objective, the theoretical pollination rate of each bee species/genera was calculated. Then using GEE, the pollination rates of each bee species/genera were compared to see whether certain species/genera are significantly better lowbush blueberry pollinators than others and thereby, the theoretical increase in blueberry yield due to pollination.

For the second objective, the theoretical effect of pesticides on honeybees and native bees was calculated. To do so, the toxicity level on bees of each pesticide was found for each pesticide common in blueberry farming. Then the decreased theoretical yield that was caused by using each pesticide category was calculated.

For the third objective, data were collected on lowbush blueberry production costs within the past 5 years, which included but was not limited to chemicals, agricultural equipment, field burning, blueberry harvesting, and apiculture. These data were used to generate a baseline budget for lowbush blueberry farming that incorporated the major fixed inputs and variable inputs of lowbush blueberry production.

For the fourth, the baseline budget model was run for two lowbush blueberry farmers in PEI. This allowed the target farmer to visualize his current costs as well as how his farming practices potentially affected the pollination services of the bees in his field. This run through also provided feedback for any possible errors within the model and highlighted potential improvements to the model. Based on his feedback, the necessary adjustments that were identified were made prior to submitting this Thesis.

Justification

With honeybee populations declining rapidly due to Colony Collapse Disorder and large corporate farms increasing their field sizes, there is a greater need for bee pollination than ever before. We must find a way to relieve this increased pollination pressure through means other than honeybee pollination, such as increasing native bee pollination. Furthermore, having the

natural environment providing most of the pollination services that crops need is more sustainable and potentially an economically cheaper means of pollination as there is no need for micromanaging honeybee hives year round or renting them for the blooming season of the farmer's crops.

Chapter 2: Literature Review

Corporate Farming

Monocultures:

Intensification of land use and conversion to large scale monocultures in agriculture is the commonly adopted farming system across most first world countries (Tscharntke et al., 2005; Grant, 2008). Monocultures, the cultivation of a single crop on a large scale farm (Grant, 2008), have become popular as it was seen as a way to decrease the gap between rural and urban incomes due to the elevated output levels that could be obtained (Sylvester, 2009). Also, it was thought that the production of large quantities of 1 or 2 crop types that are in demand would provide farmers with the ability to exploit all aspects of a single market without having to risk planting other crop types that may not be in demand and thus generate less income (Zhu et al., 2003). These farmers would also have the ability to become specialists in producing few crops types, which could result in higher maximum yields and lower costs in having to buy multiple pieces of expensive machinery. The shift towards monocultures has therefore amalgamated and enlarged fields, resulting in homogeneous agricultural landscapes with few little field margins and other non-crop areas (Tscharntke et al, 2005).

In monocultures, plants compete for the same nutrients at the same time and the same soil depth, which depletes the soil of these nutrients very quickly (Grant, 2008). Farmers are therefore forced to artificially supply these nutrients to their crops in order to obtain their maximum crop yields (Grant, 2008). This conversion of complex natural ecosystems to simplified managed ecosystems has led to increased reliance on fertilizers, irrigation,

agrochemicals, and heavy machinery, which greatly increases the farmer's input costs (Tscharntke et al., 2005; Steffan-Dewenter and Westphal, 2008; Sylvester, 2009). In addition, this has led to soil erosion and pollution of groundwater, lakes and rivers (Sylvester, 2009).

Systemic Pesticides and Their Effects on Bees:

The use of pesticides has become increasingly abundant in North America due to the amount of monocultures cultivated and their increased vulnerability to a total crop wipe out from pests (Community Action Publications, 2012). As such, Community Action Publications (2012) conducted a study on estimating the magnitude of the adverse effects of the pesticides used in the United States. They estimated that pesticide application in agricultural fields indirectly cost the United States approximately $8 billion a year (Community Action Publications, 2012). They subdivided the indirect costs of pesticide use into multiple categories such as pesticides poisoning livestock and contaminating food ($30 million), eliminating parasite species that are beneficial to the crop land ($520 million), and harming honeybees and other pollinators ($320 million) (Community Action Publications, 2012).

This has led the pesticide industry to develop systemic pesticides, which are pesticides that either coat the seedling or are sprayed on the soil (Thompson, 2010). These pesticides are designed to reduce the exposure of the pesticide to non-target species compared to conventional pesticides that are sprayed onto the plant once it has started growing (Mullin et al., 2010). The use of this type of pesticide has drastically increased in North America in the past decade as it is intended to concentrate the pesticide in the parts of the plant that need protection (Thompson, 2010). As such, systemic pesticides were marketed as the cure for reducing these indirect effects on the non-targets in the surrounding environment.

Recent studies have revealed that these crops often have residual systemic pesticide in other, unintended parts of the plant tissue (Thompson, 2010). Some examples of unintended contaminated plant tissues are pollen and nectar, which may be quite harmful to bees (Thompson, 2010). Mullin et al. (2010) have analyzed 350 pollen samples from honeybees in the United States and have seen an average of 7 different kinds of pesticides per pollen sample. Many of these pollen samples had levels of pesticides that are considered sub-lethal to honeybees. As a result, when honeybees feed on the pollen and nectar for nutrition, they also ingest the pesticides. This does not directly kill the bees but impairs their behaviour and reduces their immune system (Mullin et al., 2010; Gill et al., 2012). This in turn, makes the honeybees more susceptible to pests and mites, and causes them to exhibit abnormal behaviours. These systemic pesticides are also thought to affect native bees in a similar fashion and are one of the leading theories for the cause of Colony Collapse Disorder (Naug, 2009).

Pesticides Used in Lowbush Blueberry Production:

Lowbush blueberry growers in the northern part of Atlantic North America use a variety of pesticides to manage insect outbreaks. The most common types of pesticides that are used are neonicotinoids, pyrethroids, organophosphates, spinosads and the bacteria *Bacillus thuringiensis* (Bt) where the first three are synthetic pesticides and the last two are biopesticides, which use toxins secreted by bacteria to target pests (IFAS, 2012; D'Apollonio-Cote et al., 2013). These pesticides treat many different kinds of insect outbreaks including the most prominent beetle, fly, worm, moth, and thrip outbreaks (D'Apollonio-Cote et al., 2013) and range in toxicity levels to bees (Devillers et al., 2003; Rabea et al., 2009; IFAS, 2012).

Previous research has concluded that the level of toxicity of a pesticide to bees is based on the degree to which the pesticide increases mortality rates, disrupts foraging, increases the number of bees getting lost, decreases in flower pollination, and decreases in bee reproduction (Devillers et al, 2003; Mayes et al., 2003; Morandin et al., 2005; Johnson et al., 2006; Rabea et al., 2009; Rabea et al., 2010; Gill et al., 2012; Fjordboge et al., 2013). These research studies and others from previous years have also concluded that the majority of the different pesticides they studied affected various bee species to varying degrees (Devillers et al, 2003; Mayes et al., 2003; Morandin et al., 2005; Johnson et al., 2006; Rabea et al., 2009; Rabea et al., 2010; Gill et al., 2012; Fjordboge et al., 2013). As a result, oral and acute toxicity tests on honeybees are now required in Canada and the USA for a pesticide to be registered and commercially used (Morandin et al., 2005).

Neonicotinoid pesticides are one of the three extensively used synthetic pesticides used in wild blueberry crops. They can be used as a regular or systemic pesticide and are used to remove a wide range of flies, beetles, worms and thrips (Gill et al., 2012). This group of pesticides works by over-activating acetylcholine (ACh) receptors, which results in involuntary muscle contractions, and paralysis and death at large enough exposures (Gill et al., 2012). Normal neonicotinoid pesticide field levels found in pollen and nectar of flowering crops lead to reduced foraging efficiency of bumblebees (Gill et al., 2012). This results in more worker recruitment for foraging as the impaired workers are unable to keep up with the colony demand for food (Gill et al., 2012). This increase in number of foragers in turn, reduces the number of workers caring for the brood, which decreases the reproductive success of the colony (Gill et al., 2012).

Neonicotinoid pesticides also increase the instances of early queen loss due to getting lost or dying in her nest, which greatly increases the chance of eliminating the colony completely (Gill et al., 2012). Gill et al. (2012) note that neonicotinoid pesticides most likely affect other social bees in a similar manner.

Pyrethroid pesticides are the second group of synthetic pesticides extensively used in agriculture including blueberry crops, and there is a large array of pyrethroids available that range in toxicity levels to different insect species from beetles to flies to thrips (Johnson et al., 2006). This gives the opportunity to choose a pyrethroid pesticide that has the maximum toxicity to the pest in a crop with relatively little damage to the beneficial insects in the fields (Johnson et al., 2006). This type of pesticide disrupts the insects' nervous system by prolonging the time sodium is allowed to enter the neuron, which results in muscle spasms and paralysis, leading to death similar to neonicotinoid pesticides (Johnson et al., 2006; Gill et al., 2012).

Pyrethroid pesticides have very low toxicity levels to mammals such as humans, but range from low toxicity to extremely high toxicity to honeybees as well as other bees (Johnson et al., 2006). The mechanism behind such a large range of toxicity on bees is still unknown, although it is thought that this is likely due to the behavioural response, cuticular penetration, sodium target site sensitivity and/or metabolic detoxification of the various bee species (Johnson et al., 2006).

Organophosphates are the third and final synthetic pesticide and are an older class of pesticides commonly used on blueberry crops. They are regularly used to kill beetle, worm, fly and thrip outbreaks (D'Apollonio-Cote et al., 2013). This class of pesticide uses a toxin that broadly affects multiple species by inhibiting the breakdown of a very abundant and important

neurotransmitter, acetylcholine, which is found in many animal species (Fjordboge et al., 2013). This makes organophosphates highly toxic to mammals, aquatic life and insects, including all bees (Fjordboge et al., 2013). The upside of these pesticides is that they have a short environmental persistency as they quickly biodegrade in soil and through chemical hydrolysis of dissolved compounds (Fjordboge et al., 2013).

Biopesticides, such as spinosad and Bt are considered as the newer generation of pesticides, and are thought to be less harmful to the environment and humans than the other synthetic pesticides such as the neonicotinoids, pyrethroids and organophosphates mentioned above (Morantin et al., 2005). This is due to the fact that biopesticides are often genetically modified to target specific neural pathways of the pest in question and therefore classified as reduced-risk pesticides (Morantin et al., 2005). However, sometimes these safer, environmentally friendly pesticides, such as spinosad, have resulted in significant bee mortality in lab experiments presumably due to the similarities of the neural pathways between the targeted pests and bees (Morantin et al., 2005).

Spinosad has been used to control various worm beetle and fly outbreaks in wild blueberry crops (D'Apollonio-Cote et al., 2013). Spinosads control such outbreaks by using a microbial biopesticide made from the fermentation of the bacteria *Saccharopolyspora spinosa* (Morantin et al., 2005). These pesticides cause acetylcholine receptors to be over-activated, which results in involuntary muscle contractions, tremors and even paralysis after long periods of exposure (Rabea et al., 2010). Scientists are supposedly able to genetically tweak the spinosad so that it only affects the target insect but Mayes et al. (2003) found that spinosad causes significant harm to bees.

Mayes et al. (2003) conducted oral contact and acute toxicity studies of spinosad and concluded that these pesticides are highly toxic to honeybees, bumblebees, and leafcutting bees. However, the dried spinosad residue was relatively harmless to the adult and larvae bees in their lab studies (Mayes et al., 2003). Therefore, Mayes et al. (2003) recommend allowing drying time after the application of spinosad before bees are released.

Bacillus thuringiensis (Bt) is another type of pesticide that is commonly used in wild blueberry farming to kill off certain worm and moth species (D'Apollonio-Cote et al., 2013), although it can be used to control flies, beetles, wasps and even some non-insect species such as nematodes (George and Neil, 2012). Bt can be easily manipulated to target specific pests without affecting non-target species, making this group of pesticides very favourable (George and Neil, 2012). There are many strains of Bt, that express different classes of toxins and, in turn, will target different insects (George and Neil, 2012). Most strains release toxins that disrupt the neurotransmitters such as ACh and sodium channels such as the pesticides above. The majority of these *Bacillus thuringiensis* strains have low toxicity levels to honeybees, bumblebees and leafcutting bees (Devillers et al., 2003), although George and Neil (2012) observed some instances where some Bt strains reduced reproduction of bumblebee workers through contaminated pollen and nectar.

Prince Edward Island Honeybee Initiative:

There have been recent declines in honeybee populations in Prince Edward Island caused by increased exposure to pesticides, disease, and overwintering losses, as well as a low level of local genetic diversity and a shortage of skilled labour (MacKinnon, 2011). This has caused many crop growers to import bees to pollinate their crops each year. For example, the blueberry

industry imports half of their bees from outside of PEI, costing them roughly $700 000/year (MacKinnon, 2011).

As such, the provincial government has invested $100 000 in an initiative to promote the honeybee industry in PEI (MacKinnon, 2011). This Honeybee Development Initiative has 4 different programs which focus on beekeeping job promotion, skilled training, enhancing breeding, and bee hive tracking on the island.

The first program is the honeybee expansion program, with aims to promote beekeeping jobs and ensuring that all PEI bees are used to pollinate the islands crops (MacKinnon, 2011). The second program is the honeybee skilled labour program, which provides courses to beekeepers to improve the effectiveness of their beekeeping skills such as identifying diseases of their colonies (MacKinnon, 2011).

The third program is the honeybee genetic stock program, which encourages beekeepers to propagate their best queen bees (MacKinnon, 2011). Finally, the fourth program is the honeybee colony tracking pilot program, which is the creation of a honeybee tracking system to gather more knowledge about the disease status, hive management, and number of hives present in PEI (MacKinnon, 2011). The creation of this initiative highlights the emerging risks and vulnerability of agriculture to honeybee population declines that is currently being felt in Prince Edward Island. It is however, too early in the program to have any results as to the success rate of this initiative.

Blueberry Farming

Blueberry Industry and Production:

The idea of consuming and producing organically grown and wild blueberries is becoming more popular (Santiago and Smagula, 2012). As a result, wild blueberry, also which incorporates lowbush blueberry, has seen its production rapidly increase since the 1990's (Gervais et al., 2001; Santiago and Smagula, 2012). From the mid 1990's to 2003, the area allotted to blueberry farming in North America has increased by 30% for a total of roughly 97 000 ha of land, with lowbush farming increasing by 33% (Strik and Yarborough, 2006). Maine is the largest producer of wild blueberries in the world (Drummond et al., 2012), producing 15% of the total amount of blueberry production in North America, whereas the eastern Canadian provinces collectively produce 20% of the blueberry production in North America (Drummond et al., 2012).

Lowbush blueberry production initially differed from conventional farming practices as it was used as a complementary crop since farmers did not view blueberry markets as stable enough to rely entirely on that crop type to earn a living (Gervais et al., 2001). However, as blueberry production evolved from local family farming to corporate farming, blueberry production and field size increased, resulting in farmers relying on blueberries as their only source of income (Gervais et al., 2001; Tscharntke et al., 2005). This shift in increased reliance on blueberry crops for income and large corporate farming are part of the reason for this 30% increase in the area allotted to blueberry farming from the mid-1990s to 2005 (Strik and Yarborough, 2006).

Lowbush blueberry (*Vaccinnium angustifolium*) is one of 5 different blueberry species that grow in the wild in Canada (Agriculture, Aquaculture and Fisheries, 2010). *V. angustifolium* is a perennial plant native to northeastern North America (Drummond et al., 2010), and is well suited for acidic, infertile soils that have high organic content (Sanderson et al., 2008). These crops are not planted but instead are naturally occurring as the understory of Boreal and Acadian forests; therefore, the trees are cleared and the blueberry stands are then managed to promote growth and spreading of the plant species (Drummond et al., 2010). These farmed wild blueberries have great genetic variability and a large number of different clones that develop naturally (Sanderson et al., 2008), which greatly reduces the vulnerability of the crop to pests and diseases. However, this also creates significant differences in growth, productivity, flavour and size of fruit within the crop, which may deter certain farmers or corporations from growing wild blueberries (Agriculture, Aquaculture and Fisheries, 2010).

Wild blueberry production follows a 2 year cycle, the crop year and the sprout or pruning year. Pruning is accomplished through the removal of as much above ground vegetation as possible (DeGomez, 1988). In the early spring of crop year, crops are treated with herbicides, pesticides, fungicides, and fertilizers as needed, but after early spring, plants are allowed to grow and very little agrochemicals and fertilizers are added to reduce contamination of the berries (Santiago and Smagula, 2012). After early spring, only spot treatments are used on affected areas (Santiago and Smagula, 2012). Honeybees are often brought in in May and June when the blueberry crops bloom to facilitate pollination and the berries are then harvested in August (Drummond et al., 2010). In the fall or early spring, fields are burned to the ground level or mowed mechanically, which is referred to as pruning (DeGomez, 1988; Santiago and Smagula, 2012). In the spring of the pruning/sprout year, the required fertilizers, pesticides, herbicides,

and fungicides are applied to the field before the plant emerges (Drummond et al., 2010; Santiago and Smagula, 2012) to encourage the regrowth of the blueberry plant during the sprout year. The stronger and larger the blueberry plant is after the regrowth in the sprouting year, the higher the likelihood of having a large fruit set and good quality fruit in the following crop year (DeGomez, 1988; Eaton and Nams, 2006; Agriculture, Aquaculture and Fisheries, 2010).

This biennial pruning forces blueberries into a biennial production cycle, which improves yields of crop years and maintains the blueberry crop as the dominant plant species in the field (Sanderson et al., 2008). It is important to remove as much of the stem on the blueberry plants as possible, as partially pruned plants will have excess branches in the fruit year (DeGomez, 1988). This increased number of blueberry branches increases the difficulty of blueberry cultivation and produces plants with less fruit productivity as a greater amount of plant energy is allocated into vegetative growth (DeGomez, 1988).

There are 2 commonly used methods of pruning among wild blueberry growers; burning and mowing. Farmers traditionally burned their blueberry crops just as the Native Americans practiced before European settlement (DeGomez, 1988). Burning provides many advantages over mowing, as it reduces the amount of insect infestations that are harmful to blueberry plants such as flea and leaf beetles, spanworms, and strawberry rootworms (DeGomez, 1988). Burning may also destroy overwintering fungal organisms such as mummy berry, botrytis blight, and powdery mildew (DeGomez, 1988). Finally, it also maintains the blueberry stands as the dominant plant species as blueberries are an early successional stage species that thrive after fires in the Acadian and Boreal forests (Drummond et al., 2010).

Free-burning, where the blueberry field is simply set on fire, is the most inexpensive method of burning although it is very hard to control and usually does not burn all sections of the field (DeGomez, 1988). To have a more uniform and controlled burn, straw is placed on blueberry fields (roughly 2 tons of straw/acre) as a fuel for the fire and usually results in improved burning patterns (DeGomez, 1988). On the other hand, costs related to labour and straw are relatively higher than other means of pruning (DeGomez, 1988). Fuel oil has also been used as a method of controlling and unifying the burning of the field. Burners spray fuel oil on the ground using efficient burner heads, making fuel oil an effective way of field burning (DeGomez, 1988).

Mowing using flail mowers have become a very effective and inexpensive method of blueberry field pruning. Flail mowers can easily follow the contour of the fields while keeping the organic matter on the field, which may often decrease the cost of fertilizers (DeGomez, 1988). This method of pruning is extremely easy to control, takes much less time, and does not require any permits (such as the burning permit in PEI) (Agriculture, Aquaculture and Fisheries, 2010). On the other hand, flail mowers do not control weed, pests and fungal incidences (DeGomez, 1988) and often will propagate such incidences as the cut plants are scattered on the field during mowing. Most blueberry farmers in PEI prune their fields using flail mowers. The only time they will consider burning their field is when one of their fields has a disease or insect outbreak.

Antioxidants Found in Blueberries:

The relationship between diet and health has become a major focus to the general public in North America in the past couple decades. This has led to consumer's increasing demand for more information and research to be conducted regarding the nutritional value of the food they consume (Paredes-Lopez et al., 2010), especially fruits, vegetables and meat products. Research has recently shown that berries, especially blueberries, are very rich in antioxidants, which increase human health and help prevent chronic diseases (Szajdek and Borowska, 2008; Paredes-Lopez et al., 2010). Antioxidants remove free radicals in the body that can disrupt organ function, cause cancer, and mutate human DNA (Szajdek and Borowska, 2008).

The antioxidant compounds found in berries are vitamin C and polyphenols such as anthocyanins, phenolic acids, flavanols, tannins, and flavonols (Szajdek and Borowska, 2008). Since these natural antioxidants in berries are present in high concentrations and in a natural form, these compounds significantly exceed the health benefits of their corresponding pharmaceutical supplements (Szajdek and Borowska, 2008). Moreover, wild berries, especially blueberries, are found to have much higher levels of antioxidants than domesticated or genetically modified blueberries (Paredes-Lopez et al., 2010). The World Health Organization (WHO) stresses the importance of antioxidants from berries for the prevention of many important health problems such as cardiovascular disease, diabetes, cancer and obesity (World Health Organization, 2002). This has led to a boom in berry production and an increase in the number of companies entering the berry production industry.

Identifying and Assessing Wild Blueberry Land in PEI:

There are a few factors that should be taken into consideration when identifying suitable land for wild blueberry agriculture. The first and foremost is how to determine whether the land will produce wild blueberries (Prouse, 1996). The types of soil that lowbush wild blueberry species prefer are sandy, acidic soils that are cool and humid, such as Culloden, Emyvale, Gowanbrae and Kildare (Agriculture and Agri-Foods Canada, 1988; Agriculture, Aquaculture and Fisheries, 2010). The areas of Prince Edward Island that contain these soil types can be found in the Soils of Prince Edward Island Survey on Agriculture Canada's website.

Also, since wild blueberry plants grow slowly and are not planted, the blueberry plants must already be present on the land before development should be considered (Prouse, 1996). It is recommended that the total land area should consist of at least 30% of blueberry plants, although 60-80% coverage tends to give rise to the most productive fields (Prouse, 1996). Moreover, land that has been cultivated in the past 20 years usually does not have good blueberry potential (Prouse, 1996).

To determine if the selected land is economically viable to develop, 4 main factors should be considered. The cost of purchasing property should be considered as it varies on average between $200-$3000/acre in PEI (Prouse, 1996). The cost of levelling the field should also be considered as lowbush blueberry agricultural lands need to be quite level to facilitate the use of the machinery needed for production. This cost can range between $300-$1500/acre (Prouse, 1996). Another factor is whether the field is accessible or not as it costs approximately $1500/km to build a Class 1 forestry road (Prouse, 1996). Finally, the length of time that a field will become productive after purchase should also be taken into consideration, as wild blueberry

fields in PEI usually take 3-10 years to become operational due to natural blueberry colonization (Prouse, 1996).

Additional factors that should be considered but to a lesser degree are how wet the land is and the amount of windbreakers (trees, tall structures or the distance from the coast) that are present around the field. Pest control products are usually water soluble and therefore do not work effectively if the soils are too wet (Prouse, 1996). Fields with high amounts of windbreakers have less risk of spring frost and fewer high winds that affect the flight of bees (Prouse, 1996).

Jasper Wyman & Son Canada, Inc. Wild Blueberry Company:

Jasper Wyman & Son Canada, Inc. is a family owned company and is the largest United States supplier of wild blueberry products (Wyman's, 2012). Frozen berries represent 99% of their production output are used as food ingredients in processed food whereas the remaining 1% is sold fresh (Drummond et al., 2012). Sustainability is a main focus for this company as they believe that economic profitability, environmental health, and social and economic equity are all important and mutually compatible (Wyman's, 2012). As such, they have become stewards in blueberry production.

Jasper Wyman & Son Canada Inc. is very aware of their dependency on bee pollination and the risk involved with the decline of honeybees due to CCD (Wyman's, 2012). Over recent years, Wyman's has increasingly struggled with the pollination of their crops in Prince Edward Island, partly because all of their wild blueberry crops bloom at the same time, and because the company is continuously increasing the number of fields they utilize to produce blueberries

(Wyman's, 2012). As they own most of the honeybee hives that pollinate their crops, they are also encountering the problem of where to relocate these hundreds of hives after the blueberry bloom is over as these honeybees need to feed themselves for many months of the year.

Biological Aspects of Pollination

Landscape Effects:

A total of 70% of the crop species worldwide are flowering plants that are dependent on the pollination services of animals such as insects (FAO, 2006; Garibaldi et al., 2011). In North America and Europe, the majority of these pollination services come from native bees or domesticated honeybees and bumblebees (FAO, 2006). The decline of native and domesticated bees has major consequences for global agricultural production and ecosystem services (Gill et al., 2012). The spatial and temporal components of animal pollination services and pollinator diversity are imperative for sustaining reliable and predictable crop productivity (Ricketts et al., 2008; Garibaldi et al., 2011). Therefore, understanding plant species reliability and mechanisms of pollination services is crucial to the future of food production (Ricketts et al., 2008).

The need for understanding pollination services in detail has been highlighted in the past several decades in North America and Europe as there has been a shift in agricultural practices from small family farming to large corporate farming (Gervais et al., 2001; Tscharntke et al., 2005). This has resulted in an increase in field size and land conversion to monocultures, which has decreased the ability of agricultural landscapes to support diverse and abundant pollinator communities (Steffan-Dewenter and Westphal, 2008; Garibaldi et al., 2011). This decline is due to the decrease in the amount of available nesting areas and diversity of floral resources, the

increase of pesticide use, the increase in tillage of the land, and the short floral duration of the monoculture crops (Garibaldi et al., 2011). As a result, many native bee species have been forced to nest in natural and semi-natural habitats, which are located in the field margins and shrubby wooded areas surrounding the crop field (Ricketts et al., 2008). Pollinator species richness and floral visits by pollinators in crops declines as the distance from the natural habitat increases (Ricketts et al., 2008). Thus, as crop field size increases, fewer plants in the center of the field are adequately pollinated by native bees.

The mechanism behind this decline in floral visits as distance from the natural habitat increases is based on the optimal foraging theory. This theory suggests that foragers (bees) will try to maximize the long-term net rate of energy gain (expended energy over time: $\frac{gains - costs}{time}$) and therefore have to consider the time and energy expended while collecting food (Westphal et al., 2006). As food resources are widely dispersed in space and time, bees systematically search and exploit the most rewarding resources to optimize their foraging success (Dreisig, 1995). The choices that bees make are based on the spatial distribution and quality of resources in their surrounding environment (Westphal et al., 2006). Furthermore, since native bees prefer nesting in natural habitat around the crop field, they are restricted to foraging in areas within flight range (which is species specific) to their nests (Dukas and Edelstein-Keshnet, 1998).

Honeybee Versus Native Bee Pollination:

Monocultures have become so land intensive and so large that the land can no longer provide the pollination services the crops require. North American farmers must bring in

honeybees and sometimes leafcutting bees or domesticated bumblebees when honeybees are not available to adequately pollinate their crops every year to ensure maximum crop yield (MacKinnon, 2011). Honeybees have become vital to crop growers in North America and any decline in their numbers will have a direct negative impact on farmers' profit margins.

Honeybees are the chosen pollinator in North America as they live in hives that can easily be displaced and they are not particular about what flower species from which they get their resources (Vance, 2011). However, honeybees have little flight activity at temperatures below 16^{o}C and travel very short distances (1-200 m) in wet weather (Rhodes, 2006), which can significantly reduce pollination for crops such as lowbush blueberries that bloom during the cool rainy months of springs (Javorek et al., 2002). Native bees play an important pollination role, even in the presence of honeybees, as native bees are less affected by bad weather conditions (Javorek et al., 2002) and may be attracted to different types of flowers than honeybees.

With regards to the pollination of blueberry plants, native bees are much more effective pollinators than honeybees (Ricketts et al., 2008). Native bees that are pollen harvesters, such as *Bombus* sp. (bumblebees) and *Andrena* sp., pollinate approximately 95% of the blueberry flowers that they visit whereas nectar pollinators, such as honeybees and leafcutting bees, only pollinate 17-25% of the flowers they visit (Javorek et al., 2002). This is partly because native bees such as *Andrena* sp. and *Bombus* sp. have evolved to sonicate blueberry flowers with the speed and rhythm of their wings to dislodge and harvest the pollen within the flower (Javorek et al., 2002; Rhodes, 2006).

Moreover, blueberry flowers are not particularly attractive to honeybees as most blueberry species do not have the flower characteristics that are best suited for nectar harvesters

like the honeybee (Rhodes, 2006). Honeybees prefer flowers with short corollas (petals) or large corolla aperture, and are the best suited for pollinating flowers with short distances between the anther (pollen producer) and the stigma (pollen receptor) (Rhodes, 2006). Many blueberry species have long bell-shaped corollas and large distance between the stigma and the anther, making them less suitable for honeybees (Rhodes, 2006).

For these two reasons, honeybees do not pollinate blueberry flowers as well as native bees. Queen bumblebees pollinate 6.5 flowers and *Andrena* sp. pollinate 3.6 flowers in the same amount of time it takes a honeybee to pollinate a single flower (Javorek et al., 2002). A honeybee would have to visit a flower 4 times to deposit the same amount of pollen that a queen bumblebee or an *Andrena* sp. would in a single visit (Javorek et al., 2002). This reinforces the importance of understanding the mechanisms and effectiveness of the pollination services of bee species with regards to crop yields, whether it is a native or managed bee.

Alfalfa Leafcutting Bees Used for Blueberry Pollination:

Alfalfa leafcutting bees (*Megachile rotundata*) are solitary bees that pollinate alfalfa and some vegetable species while using the leaves of the plants to make cells for their eggs. More recently, scientists have discovered that leafcutting bees are good pollinators of wild blueberry crops, particularly weed-free crops (MacKenzie et al., 1996; Javorek et al., 2002; Stubbs et al., 2007). Alfalfa leafcutting bees are a good candidate as a managed bee for blueberry crop; they can easily be transported from one location to another as these bees usually live in man-made huts containing their leaf cells (Stubbs et al., 2007). Also, these bees that forage for pollen are a more effective wild blueberry pollinator than honeybees as they pollinate 3.4 times more flowers than a honeybee in the same amount of time (Javorek et al., 2002). These bees can be awoken

whenever the farmer requires their services as their hibernation is controlled by the change in ambient temperature and it only takes one month of incubation for the bees to start foraging (Stubbs et al., 2007).

Given this information, there are a few things that a farmer should consider before using leafcutting bees as their managed pollinator. Leafcutting bees prefer other flowering plants over blueberry flowers; therefore their huts should be placed far away from field edges (Stubbs et al., 2007) where other types of flowers may shift their foraging patterns. They also live longer than the blueberry bloom so they need to be relocated to other adequate foraging areas after the blooming period (MacKenzie et al., 1996). Leafcutting bees are also very susceptible to insecticides as many are lethal to these bees (Stubbs et al., 2007). Even residue on the leaves should be avoided as these bees use blueberry leaves to construct their cells (Stubbs et al., 2007). As such, Stubbs et al. (2007) recommends farmers to refrain from spraying any insecticides during the blueberry bloom period. Alfalfa leafcutting bees are bought outright and are not lent out, so this is another fact that farmers need to take into consideration as they need to feed and store the bees after the bloom for subsequent years (Stubbs et al., 2007). On the up side, the only additional expenses for the farmer after the first year would be purchasing of new hibernating bees in the event that not enough cells were laid from the previous year (Stubbs et al., 2007).

Yield Due to Bee Pollination:

For a blueberry to be formed, pollen produced by the anther of a blueberry flower must touch another plant's stigma, which produces a seed and in turn produces the fruit. Lowbush blueberry pollen is sticky and relatively heavy, and, therefore, cannot easily be blown around by wind (Meyer and Cline, 1997). The bell shape and downward sloping of the lowbush blueberry

flower also prevent the pollen produced by the anther to passively touch or fall onto the stigma (Meyer and Cline, 1997). Furthermore, as lowbush blueberry plants are vines that spread across the field, they are many clusters of plants that have the same genetic make-up (ie. clones) (Bobiwash, 2012). As such, even when the pollen of the same plant touches the stigma, pollination may not be successful as these clones are often not self-compatible (Bobiwash, 2012). This resulted in lowbush blueberry plants being poor self-pollinators (autoseminators), which greatly decreases fruit set and thereby yield in the absence of pollinators.

Lowbush blueberry plants, therefore, heavily depend on bee pollination for successful fertilization. As bees enter a blueberry flower to extract nectar and some pollen for their consumption, they brush up against the stigma, which dislodges some of the existing pollen on the bee from another plant onto the stigma on the current plant, thereby pollinating the flower (Meyer and Cline, 1997). Therefore, bee pollination increases the number of fruit set and fruit size of the blueberry plant to approximately 80-90% of the total potential yield whereas in the absence of bee pollination, total fruit set drops to 0-50% of potential yield (USDA, 1991).

Blueberry clones of large sizes may suffer from the lack of self-compatibility even when bees actively pollinate their flowers due to the short flight patterns of smaller bees between flower clusters (Bobiwash, 2012). This is due to the optimal foraging theory of bees that suggests that bees will try to maximize the long-term net energy gain (Westphal et al., 2006), where they will systematically exploit the most rewarding resources in a small area to optimize their foraging success (Dreisig, 1995).

In 2003, Jordan conducted an experiment to quantify how much yield resulted from autosemination in a natural environment. He had 6 plots in 4 different fields in the eastern part of

Prince Edward Island (of which 2 fields were also part of my study) (Jordan, 2003). These 4 by 6 feet plots were divided into 3 treatments: 2 plots had total bee exclusion, 2 plots had managed bees excluded, and 2 plots were the control where they were openly pollinated by all bees (Jordan, 2003). Agribon+^{TM} floating covers were placed over the total exclusion plots prior to blueberry blossom opening, therefore no pollination from any bee was possible (Jordan, 2003). For the plots where the managed bee were excluded, Agribon+^{TM} covers using "U" shaped wires were placed over the plots right before the introduction of managed bees thus allowing the native bees to pollinate the crops (Jordan, 2003). Finally, the control open plots had no covers so managed and native bees were free to pollinate the blueberry flowers (Jordan, 2003).

Agribon+^{TM} produces crop covers for various uses, from minimizing insect and bird predation to over-wintering protection (USGR, 2014). For Jordan's experiment, which occurred in late spring, early fall, AG-15 or AG-19 were the likely models that were used. These models have 80-90% light transmission, do not retain any unnecessary heat, and exclude all insects due to their strong glued seams (USGR, 2014). They also come in various sizes from 83" by 250' to 50' by 1000' (USGR, 2014).

Floating covers were removed shortly after blueberry blossom was over (Jordan, 2003), so any changes in environment that these covers could have had on the blueberry plants on occurred for 4-6 weeks. The managed bees of choice for these fields were either honeybees or leafcutting bees (Jordan, 2003). All plots that were chosen had almost 100% blueberry cover (Jordan, 2003), therefore there was possibly an overestimation of total yield on these plots as blueberry fields range in percent cover of blueberry plants. Plot yield was determined by hand raking prior to commercial harvest on a lbs/acre basis (Jordan, 2003).

Colony Collapse Disorder (CCD):

From 2006 to 2009, bee keepers in the United States have lost on average one third of their honeybee colonies each year to unknown causes (Mullin et al., 2010). This has been named as the Colony Collapse Disorder (CCD), which is defined as the rapid disappearance of all adult bees except for the queen and the brood without any signs of death to adult bees in or around the hive (Naug, 2009; Mullin et al., 2010). The root cause of CCD is still unidentified as most CCD colonies have no significant signs of pests, mites or invasions by other bee species (Mullin et al., 2010). Currently, one leading theory for the cause of CCD is the use of systemic pesticides, which reduce the immune system of the honeybees, making them more susceptible to pests, mites and disease (Mullin et al., 2010; Thompson, 2010).

Cost and Use of Managed Bees in Canada:

There are approximately 600 000 colonies of honeybees in Canada, which contribute approximately $1.3-$1.7 billion annually in increased production to agricultural crops (Canadian Honey Council, 2013). The Canadian Honey Council (2013) recommends 1-2.5 hives of honeybees should be placed on every acre of harvested land for apple, canola and blueberry crops for adequate pollination and 5 hives per acre if these crops have no native pollinators.

The cost of renting honeybee hives are based on the cost of feeding, medicating, transporting, overwintering, labour, loss of honeybees, and loss of queens (Canadan Honey Council, 2013). Current prices of honeybee hive rentals are between $90-$120/hive and may also be higher if honeybee shortages occur (Canadian Honey Council, 2013). This results in a price of $90-$300/acre when native pollinators are present and $450-$600/acre when native pollinators are absent.

As for alfalfa leafcutting bees, Stubbs et al. (2007) recommend placing 2 gallons of bees per acre of blueberry crops for adequate pollination, where each gallon of bees contains approximately 10 000 developing bees. For the past 10 years, one gallon of leafcutting bees costs between $50-$70, the required nesting material costs between $17-$35 /acre and man-made shelters for the leafcutting bees to create their nests in cost between $140-$300 /acre (Stubbs et al., 2007). In total, the cost of using leafcutting bees as a managed pollinator will cost between $207-$405 /acre the first year and a maximum of only $50-$70 /acre the following years as all of the equipment and most, if not all, the required bees will have already been purchased.

Economic Valuation of Pollinator Services

Economic Valuation and Pollination:

An ecosystem service is the ability of the ecosystem to supply goods and services that increase human welfare (De Groot, 1992); of which there are 3 types: production, regulation and cultural services (Millennium Ecosystem Assessment, 2003). A production service is an ecosystem service that fabricates a good or service for human consumption (Millennium Ecosystem Assessment, 2003), such as the production of milk by cattle. A regulation service stabilizes the impacts of the surrounding environment on a good or service (Millennium Ecosystem Assessment, 2003). A good example of this would be the buffering capacity of wetlands to flooding in the spring and drought in the summer. Finally a cultural service is one that has a cultural meaning to the good and service (Millennium Ecosystem Assessment, 2003), such as the sacred grounds of an Aboriginal community.

Pollination services are both ecosystem services and a production practice that have been used by farmers extensively in the world for crop production (Kremen et al., 2001). Pollination

services are a production service as they increase the crop yield through pollination and a regulatory service as they reduce the risk of pollination variability caused by environmental impacts by having many species of pollinators pollinating the crops (FAO, 2006). It is also a production practice; in many of the developed countries bees such as honeybees and bumblebees have been domesticated and placed on farms to ensure adequate pollination of their crops (FAO, 2006; MacKinnon, 2011). Thus, the economic benefits of pollination services from bees are very clear to farmers and have resulted in a well-developed market for bee rentals in North America and Europe (Sumner and Boriss, 2006).

The presence of a well-developed market for bee rentals highlights that there are currently not enough wild pollinators to ensure adequate pollination of all crops throughout the year (Gallai et al., 2009). It also highlights the mindset of farmers seeing pollination services as a production input instead of an ecosystem service. This is partly because the abundance and diversity of native bees and honeybees are declining and some species are at risk (Gallai et al., 2009). This decline in bee abundance and diversity shows a market failure where pollination services are being undervalued and therefore over exploited, which has resulted in the demise of their species.

Chapter 3: Methods

Mixed Methods Approach

The research paradigm applied in this Master's Thesis is a mixed methods approach with an emphasis given to quantitative data collection procedures. Mixed methods research is the use of both quantitative and qualitative methods of collecting and analyzing data in the same study (Demscombe, 2008). The reasoning behind such an approach is the belief that neither qualitative nor quantitative approaches alone can provide the breadth of information needed to address certain research questions (Demscombe, 2008). Instead, qualitative and quantitative research are viewed as complementary approaches, which used together can deal with the complexity of the real problems facing society (Fielding, 2010). This belief comes from a pragmatic worldview where the tools and approaches taken to address a problem should be chosen based on the practical bearings of the given situation (Johnson and Onwuegbuzie, 2004). In other words, all problems are unique, complex and spread over multiple disciplines and therefore the solutions to these problems should also be unique, complex and multidisciplinary.

Conducting a mixed methods study may be more challenging than a mono-method study (quantitative or qualitative) as the study requires more time, resources, effort, and the researcher must have a broader spectrum of skills to be able to collect and analyze the data adequately (Molina-Azorin, 2011). As the mixed method is an emerging research paradigm used by multiple disciplines, there is little consensus in the literature on the methods that should be used when conducting such a study (Johnson and Onwuegbuzie, 2004).

There are three forms of strategy of inquiry for mixed methods: concurrent, transformative and sequential (Creswell, 2003). Under the concurrent strategy of inquiry, the qualitative and quantitative data is collected and analyzed independently, yet the results of both are merged together to produce the final analysis (Leech and Onwuegbuzie, 2009). The transformative strategy of inquiry is the use of qualitative and quantitative from an advocacy or transformative worldview that addresses social injustice issues (Creswell, 2003 chapter 8). The qualitative approach collects the perspective of the people involved and the quantitative approach is applied to give credibility to the claims made from the perspectives generated from these people (Mertens, 2007). A sequential strategy of inquiry conducts either qualitative or quantitative methods first and then the other method is conducted thereafter (Ivankova et al., 2006).

This study uses a sequential strategy of inquiry as it has two key components, where one is better suited for a quantitative analysis while the other is more suited for a qualitative analysis. The first component was to collect and analyze data on bee abundance and habitat on 9 wild blueberry fields over 3 crop years (2005, 2007, 2009), as well as evaluating wild blueberry production costs in order to maximize native bee pollination without increasing the costs of production. Then the study determined how the ratios of each bee species influenced blueberry yield and how the use of a pesticide affected yield through bee mortality. The second component was to discuss the findings of this study with one of the target farmers to solicit feedback as to whether the findings were logical and ideally helped the farmer get a better understanding of the interactions occurring on his field. Therefore, this research project began with quantitative methods, and then transitioned into qualitative methods in order to meet the project's goals.

Thus, priority was given to the quantitative approach as the majority of the data was ecological and economic in nature.

Study Area

Agriculture provides an important source of income in Prince Edward Island (PEI), due to its rich red soils and suitable temperatures (Encyclopedia of Canadian Provinces, 2007). Of the total land mass of the island, 45% or 250 000 ha, is currently devoted to agriculture (PEI: Department of Agriculture, 2011). Lowbush wild blueberry farming comprises approximately 2230 ha of that agricultural land and this number is growing rapidly (Strik and Yaraborough, 2006). One of the main reasons for the prominence and growth of lowbush wild blueberry farming in PEI is due to the favourable soil conditions and the presence of the very large blueberry company, Jasper Wyman & Son Canada, Inc.

Most of the fields in this study are located on the east end of Prince Edward Island, except for 2 fields located in the north western end of Nova Scotia close to the New Brunswick border. Bee abundance, diversity and habitat were collected from 7 selected fields owned by 6 different farmers. These fields were selected based on owner's agreement to participate and incorporated a wide range of landscapes and field sizes.

The fields selected were sampled for 3 years (2005, 2007, 2009). Each of these fields goes through a 2-year crop cycle whereby one year the blueberry field is pruned (sprout year) and the alternate year the blueberry field is allowed to grow (crop year). Data were collected only during crop years. As these fields consist of wild plants and therefore were not planted, the

range of percent cover of the lowbush blueberry plants was quite variable. Nonetheless, all fields sampled had between 30% to 90% wild blueberry cover.

Data Collection and Analysis

Data Collection and Analysis of Bee Abundance, Diversity, and Habitat Requirements:

The bee data incorporated in this study were collected by Steve Javorek, an entomologist and landscape ecologist at Agriculture Canada in New Minas, Nova Scotia, and Matthew Grant and assistants, between 2005 and 2009. The data were collected from 16 fields in Prince Edward Island and Northern Nova Scotia. Bees were collected between late May and late June at early, mid, and late blueberry bloom and were sampled at 3 different locations of the field in each time period. This resulted in 9 data points per field per year and described bee species found at various wild blueberry fields. Seven out of the 16 fields were selected for this thesis as these farmers agreed to provide the additional information needed to complete the analyses of this Thesis. The data collected by Steve Javorek included bee species, abundance of each species, field size, and field location. A summary table of the data collected can be found in Appendix I.

First Objective:

The first objective was to find links between lowbush blueberry yield and bee abundances. To accomplish this, I first estimated theoretical effects of pollination on yield, and then measured empirical effects of bee abundance on yield.

Theoretical Effects on Yield:

To calculate the theoretical effects that each bee species/genera had on yield, the pollination rates of each species or genera of bees were determined (Equation 1). The theoretical

number of flowers that a single bee in each species/genera could pollinate in a season was calculated by multiplying the calculated pollination rate by the average number of hours the temperature was above the threshold of temperature needed to fly by each species over the 3 crop years of the study. This provided the farmers with a rough estimate of how much any given species/genera contributed to their blueberry yield in 2005, 2007, and 2009.

This was accomplished by multiplying estimates for number of flowers visited per minute (# flwrs visited) by the likelihood of pollinating a flower when visited (% poll success) (Javorek et al., 2002). This was then multiplied by the number of hours that the temperature was above the flight temperature threshold of each bee species/genera (hrs above thres) (Javorek et al., 2002; University of Maine, 2010) for blueberry bloom in 2005, 2007, 2009 (Government of Canada, 2013). These three factors were multiplied by the number of caught bees per species/genera found on all of the 7 fields sampled from 2005, 2007, and 2009 ((S. Javorek, May 2012, Agriculture Canada, Pers. Comm.). This equation allowed me to predict the theoretical increase in blueberry yield of each species/genera on a per acre basis for each field (Equation 1).

Equation 1. $$yield\ due\ to\ a\ bee\ species = (\#flwrs\ visited * \%\ poll\ success) * (hrs\ above\ thres) * (\#caught\ bees)$$

Empirical Effects on Yield:

I also determined whether there was a relationship between bee abundance and actual blueberry yield. I compared total bee abundance/acre, field size, and year to the yield/acre from the blueberry fields in this study using Generalized Estimating Equations (GEE). The GEE models were chosen because the standard error can be structured to compensate for correlations among repeated measures within sites (Koper and Manseau, 2010). The empirical or sandwich

variance estimator was used in the GEE analyses, as it is robust even when the working correlation structure does not correctly describe the correlation in the data (Koper and Manseau, 2009).

I attempted to conduct a second analysis, replacing total bee abundance per acre with bee abundance per species per acre. There was high colinearity among the species/genera abundances per acre. The data were centered in an effort to remove colinearity (Quinn and Keough, 2002). Unfortunately, this solution did not remove the colinearity between honeybee, *Andrena*, and bumblebee species. Therefore it was impossible to determine if there was a relationship between specific bee species/genera per acre and yield per acre.

I determined whether the abundance of one bee species was positively correlated with the abundance of another species and whether field size was negatively correlated with bee species abundance. I used GEEs to model the abundance of each bee species/genera relative to the logged field size (as trend was non-linear) and honeybee abundance, separately for each species. Honeybees were used as the standard bee species for comparison as it was the managed bee species present in the majority of the fields in different crop years. Finally, I determined whether the total number of rented bee hives per field was positively correlated with yield, as this is the main reason that farmers rent such hives each year. I used a polynomial model to evaluate the effect of the total number of hives on blueberry yield, meaning I added an interaction term of total number of rented hives times itself to allow the trend to be nonlinear, if necessary.

For all of the results, an alpha of 0.1 was used instead of 0.05 for significance to reduce the likelihood of making a Type II error, which is a common concern in many branches of biology, including conservation biology (Taylor and Gerrodette, 1993).

Second Objective:

The second objective was to calculate the theoretical effect of pesticides on honeybees and native bees. To do so, I used the toxicity level of each pesticide on bees for all of the commonly used pesticides in lowbush blueberry farming, as estimated by the Institute of Food and Agriculture at the University of Florida (IFAS). In their database, they list pesticide toxicity on bees by severity of LD_{50}. LD_{50}, also known as the medial lethal dose, is a statistically derived dose of a chemical that causes death to at least 50% of bees 24-48 hours after chemical exposure to the bee (OECD, 1998). The IFAS (2013) regards the effects of a pesticide on a bee as being relatively the same irregardless of the bee species. The IFAS database divides pesticide toxicity on bees into 3 categories: low, moderate and high LD_{50}. Based on the definition given to each category of pesticide toxicity by the IFAS, I estimated how many bees are likely to be killed in each category:

High Toxicity: I assumed 50%-100% mortality of all bees. This was assumed irregardless of whether the bees were in direct contact with the pesticide or only in contact with the residuals of the pesticide as both direct contact and residual contact kills at least 50% of all bees.

Moderate Toxicity: Between 0%-50% bee mortality was assumed when pesticides were applied at a time when bees would not be in direct contact with pesticides (dusk and dawn), as bee mortality due to residual pesticide effects does not reach the LD_{50} threshold; mortality rates of 50%-100% were assumed when pesticides were applied at a time when bees would be in direct contact with pesticides (during the day). At dusk and dawn, the chances of bees coming into contact with the pesticide were greatly reduced as the bees have returned to their nests for

the night and therefore not flying among the blueberry flowers. However, when pesticides were sprayed during the day when bees are more active and would greatly increase the chances to be in direct contact with the pesticide, it was assumed that the pesticide behaved like the pesticides in the high toxicity category.

Low Toxicity: 0%-50% mortality was assumed as LD_{50} threshold was not reached for either direct or residual contact of bees with the pesticides. The decreased theoretical bee yield and percent decrease in total yield that was caused by using each of these pesticide categories was calculated using the above thresholds:

Equation 5. $$Yield\ Loss = \left(\frac{Px}{Hour} * \frac{Hours\ above\ Tresh}{Season} * Bee\ Yield * \frac{Bee\ Abund}{acre}\right) * \left(Bw * \frac{\#\ Berries}{Plant} * \frac{Ave\ \#\ Plants}{Acre}\right) * (Bragg's\ Harv.Eff.) * (Bee\ Mort.)$$

Where yield loss was the estimated loss in yield due to declines in pollinator abundance, Px/hour is the amount of flowers each bees species can successfully pollinate in an hour, hours above threshold per season was the amount of hours in each day of blueberry bloom that is warm enough for an individual bee species to forage (Government of Canada, 2013), and the bee abundance per acre was the abundance of bees caught per acre on a given field (Equation 5). The Bw was the weight of one blueberry, # berries/plant was average number of berries on a single plant, the ave. number plants per acre was the average number of plants on any given acre of a wild lowbush blueberry field (Equation 5) (Wild Blueberry New Brunswick Factsheet, 2010; University of Maine, 2013; Find the best, 2013). The Bragg's Harvester efficiency was the estimated percentage of berries that were collected off the plants when using a Bragg's Harvester (Farmer 7, pers. comm., 2014). The bee yield was the estimated increase in blueberry yield due to pollination, which had 2 different estimates (Equation 5). As such, Equation 5 was calculated

twice using each estimate of bee contribution to identify the range of the contribution of bee pollination on yield.

The costs related to using each of the different pesticides used in lowbush blueberry farming in Prince Edward Island were calculated, using the average cost of each pesticide per acre for 2012 and 2013 (Mr. MacKenzie, Cavendish Agriculture, pers. comm., 2013), the costs related to decreases in yield based on their level of toxicity to bees, calculated above, and an estimate of average yield of 6000 lbs/acre of blueberries at wholesale price which is 40% of retail price of $1.65/lbs (Wild Blueberry New Brunswick Factsheet, 2010; University of Maine, 2013; Find the best, 2013).

Third Objective:

The third objective was to determine the baseline budget for lowbush blueberry farming, ie. the link between inputs normally used by wild blueberry farmers and their central output (blueberries). This budget included major fixed inputs (machinery, insurance, marketing) that vary little from one year to the next, as well as variable inputs (pollination, managed bees, pesticides, pesticide effect on pollination), which were the focus of this study. This budget was conducted on an average two years cycle, including the sprout year and the following crop year.

The average cost of agricultural equipment, apiculture, insurance, and land improvements were extrapolated from Mussell et al.'s (2013) study on benchmarking Atlantic blueberry farming production costs and yields. However, the cost of chemicals, harvesting, and mowing included the cost of labour, equipment and fuel as most family farmers pay outsides, such as Wyman's, to spray, mow and harvest their crops (Farmer 3, pers. comm.; Farmer 7, pers.

comm.). To compliment these data, each of the farmers in the study were asked to provide their yield/acre, the number of hives of each bee species they rented and the cost of each hive for crop years 2005, 2007, and 2009. With this complimentary data, each baseline budget was tailored to the inputs and outputs of the 7 fields for each of the 3 sprout/crop years.

The focus of this study was the variable inputs that directly influenced the farmer's yield and profit margins. As such, a theoretical breakdown of how much each bee species contributed to yield was calculated to evaluate how important bee populations were to overall yield. I used the theoretical pollination rate estimated for each bee species/genera to illustrate how much each bee species theoretically contributed to the farmer's overall yield. This was calculated by multiplying the number of caught bees of one species (# caught bees) by the pollination rate of each species (pollination rate) and by the number of hours above the temperature threshold for that species (hrs above temp threshold) for 2005, 2007, and 2009 respectively (Equation 6).

Equation 6. $$Species\ poll.index = \#caught\ bees * pollination\ rate * hrs\ above\ temp\ threshold$$

There are many factors that affect blueberry yield; however, the only factor I examined was bee pollination on yield. The species yield index for the 4 species were divided by sum of all of the species to get the relative pollination contribution of each species to overall pollination (species ratio). Finally, the amount of the total yield due to the pollination efforts of each bee species/genera (yield due to species) was calculated by multiplying the species ratio by the total yield produced in each of the fields in the study in one year (total yield) and by a ratio of bee yield ("2/3") as unfertilized blueberry plants produce roughly 1/3 of the total blueberry yield through autosemination (Jordan, 2003) (Equation 7).

Equation 7. $$Yield\ due\ to\ species = species\ ratio * total\ yield * \frac{2}{3}$$

I also tested Chris Jordan's autosemination estimate that bee pollination was responsible for 2/3rds of the yield. As such, I regressed yield per acre on the sum of all the species pollination indices per field (Total Species Index). I then determined the actual percentage of yield due to bee pollination at the average estimate of yield due to bee pollination (A) and at the upper limit estimate of yield due to bee pollination (5^{th} percentile) (UL) based on my data in two steps. First, I multiplied the estimate (A or UL) by the average total species index and adding the intercept value (B) to determine the total average and upper limit yields (Equation 8a and b).

Equation 8a. $$Total\ Average\ Yield = A * Average\ Total\ Species\ Index + B$$

Equation 8b. $$Total\ Upper\ Limit\ Yield = UL * Average\ Total\ Species\ Index + B$$

Then I multiplied the estimates (A and UL) by the average total species index and divided these two numbers by their respective total yield for average and upper limit to determine the actual percentage of yield due to bee pollination (% Yield) (Equation 9a and b).

Equation 9a. $$\%\ Average\ Yield = \frac{A * Average\ Total\ Species\ Index}{Total\ Average\ Yield}$$

Equation 9b. $$\%\ Upper\ Limit\ Yield = \frac{UL * Average\ Total\ Species\ Index}{Total\ Upper\ Limit\ Yield}$$

The impact of pesticide use depending on the toxicity of the pesticides a farmer used was also incorporated into the budget. This was accomplished by asking the farmers which pesticides they used in 2005, 2007, and 2009. The level of toxicity to bees and the respective decrease in yield associated with that level of toxicity were determined for each pesticide using the results

from objective 2. To remain conservative, the lower limits of pesticide toxicity to bees were used for this calculation. Then the potential theoretical yield if the pesticide(s) were not used was calculated by multiplying the actual yield of the farmer's field for a given year by the percent loss in yield due to the use of pesticide 1 ($1\text{-}P_1$), the percent yield loss of pesticide 2 ($1\text{-}P_2$), and the yield loss in the use of any other pesticide ($1\text{-}P_n$) (Equation 10). This calculation was done using the both 26% (Table 3) and 66% (Jordan, 2003) estimates for the contribution of bee pollination on yield to give the range of possible effects of pesticides on total yield. However, this calculation does not take into consideration the losses in yield due to the presence of the pest in which the pesticide is being sprayed for. Also, these estimates were probably overestimated as the bee recolonization of the field after pesticide use was not estimated in this calculation. As such, this calculation was merely demonstrating the implications of using pesticides on bee populations in a manner that might be more tangible to a farmer.

Equation 10. $$Yield_{pot} = \frac{Yield_{Actual}}{(1-P_1)(1-P_2)\ldots(1-P_n)}$$

Fourth Objective:

The fourth objective was to trouble-shoot the baseline budget model with two lowbush blueberry farmers in PEI. This allowed the target farmer to visualize his current costs as well as how his farming practices potentially affected the pollination services of the bees in his field, and facilitated potential improvements to the model.

The choice of which farmer to run this model by was based on the following criteria (as per human ethics requirements): he had to be one of the farmers that has accepted to provide data for this study as well as having access to the native bee data for his field. He had to be willing to

take the time to implement the model and discuss its implications. Finally, there was no financial compensation, and a time commitment would be required on the farmer's behalf. In exchange, he has received all information from the findings of this study that was beneficial to him. Also, by discussing the findings with him, he may find new ideas on how to improve his blueberry production on his fields.

Each farmer was interviewed using the semi-structured type of interview. I presented all of the major findings of this study that pertained to yield and pollination (Figure 1-3, Table 1), pesticide toxicity to bees (Table 5), and a baseline budget for each farmer for 2005, 2007, and 2009 (Table 2, Table 9). Each figure and table was thoroughly explained then allowed time for the farmer to ask any questions or make any comments after each figure/table. These comments were written down and all questions were answered to the best of my ability.

For certain figures and tables, I asked the farmers a few questions (Appendix II) to generate a discussion about certain points of my Thesis that I thought was either lacking or potentially contrary to popular belief in the agricultural industry. Finally, a baseline budget was conducted for each farmer using their actual yields and chemicals used for 2005, 2007, and 2009. A few questions were also asked about the baseline budgets with regards to the validity of my baseline budget and potential improvements that could be made (Appendix II).

Chapter 4: Results

First Objective

There were two components to finding how lowbush blueberry yield was increased by managed and native bee pollination. I estimated a theoretical pollinators' effect on yield for each bee species/genera, and also empirically measured effects of bee abundance on yield.

Theoretical Effect on Yield:

One bumblebee is estimated to pollinate an average of 5214 flowers, an *Andrena* bee would pollinate 1770 flowers, a leafcutting bee would pollinate 127 flowers, and a honeybee would pollinate 72 flowers in an average season (Table 1). Therefore, on average, bumblebees pollinated 71.58 times more than a honeybee, 41.01 times more than a leafcutting bee (LCB), and 2.94 times more than an *Andrena* bee (Table 1) in a season.

Table 1. Average numbers of flowers each bee species (bumblebee, *Andrena*, honeybee, leafcutting bee (LCB)) is estimated to pollinate based on the theoretical pollination rates of each bees species, the abundance of bees caught in each field (S. Javorek, May 2012, Agriculture Canada, Pers. Comm.), and the number of hours the temperature was above the species temperature threshold (Equation 1) in Prince Edwards Island, in spring of 2005, 2007, and 2009. Columns (denominator) can be compared against rows (numerator) to demonstrate how many times one bee species pollinates more flowers in a given season than another.

	Flowers Poll/ Season	**Bumblebee**	***Andrena***	**LCB**	**Honeybee**
Bumblebee	5214	X	2.94	41.01	71.58
Andrena	1770	0.34	X	13.93	24.31
LCB	127	0.02	0.07	X	1.75
Honeybee	72	0.01	0.04	0.57	X

Empirical Effects on Yield:

There was a significant positive relationship between total bee abundance and yield (*p*-value 0.0651; SE = 17.91; β = 45.09) but there was no significant effect of field size on yield (lbs/acre) (*p*-value 0.1497; SE = 31.29; β = 45.09). There were high correlations in abundance of many individual species of bees (honeybee:*Andrena* *r*=0.9837; honeybee:bumblebee *r*=0.933; *Andrena*:bumblebee *r*=0.9074), suggesting that fields that provided suitable habitat for one species also provided suitable habitat for other species.

There was a significant negative relationship between honeybee abundance and logged field size (*p*-value <0.0001; SE =5.3410; β =-49.6563) as well as a significant negative correlation between total bee abundance and logged field size (*p*-value <0.0001; SE =29.0462; β = -215.3666). There was a significant positive relationship between *Andrena* species and honeybees (*p*-value <0.0001; SE = 0.0174; β = 0.4627) and a significantly negative relationship between *Andrena* and logged field size (*p*-value <0.0001; SE = 4.3546; β = -29.2755) (Figure 1b). Similarly, there was a significant positive correlation between bumblebee and honeybee abundances (*p*-value <0.0001; SE =0.0111; β = 0.2055) but a significant negative correlation between bumblebees and logged field size (*p*-value <0.0001; SE = 1.9697; β =-49.7405) (Figure 1b). Furthermore, there were positive significant relationships between LCB and honeybee abundances (*p*-value <0.0001; SE = 0.0592; β = 0.3280), and with LCB and logged field size (*p*-value >0.1; SE = 0.2061).

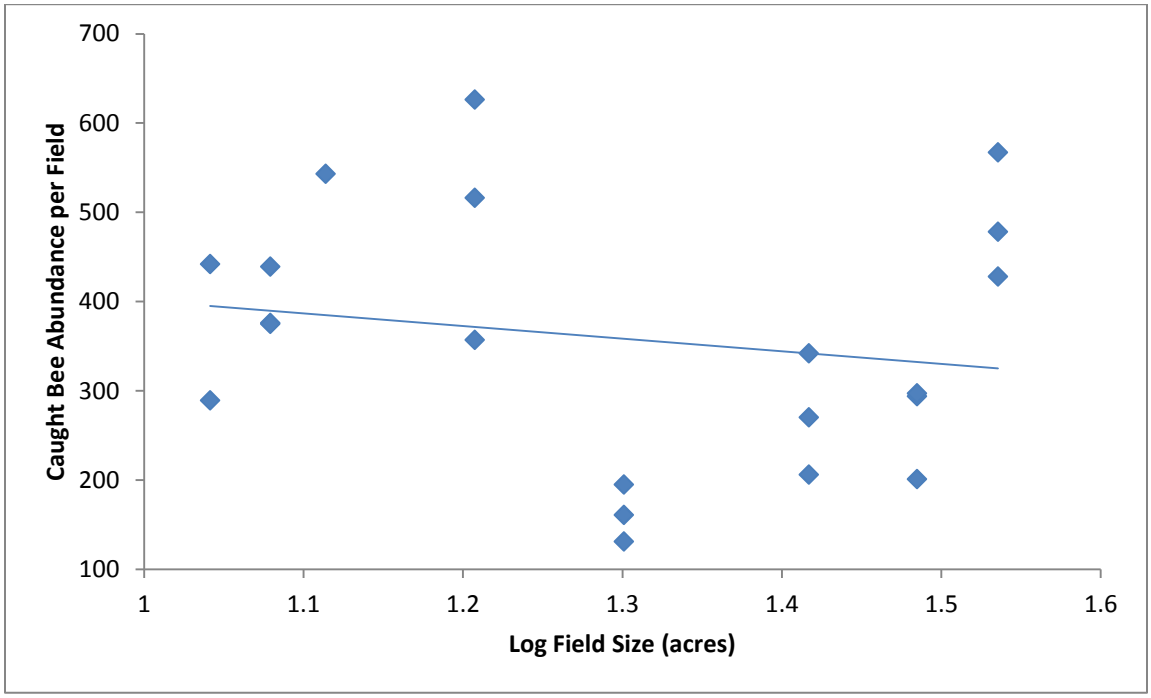


Figure 1a. Total caught bee abundance on total field size in acres (S. Javorek, May 2012, Agriculture Canada, Pers. Comm.)for all of the 7 fields and each crop year (2005, 2007, 2009) in this study situated in PEI.

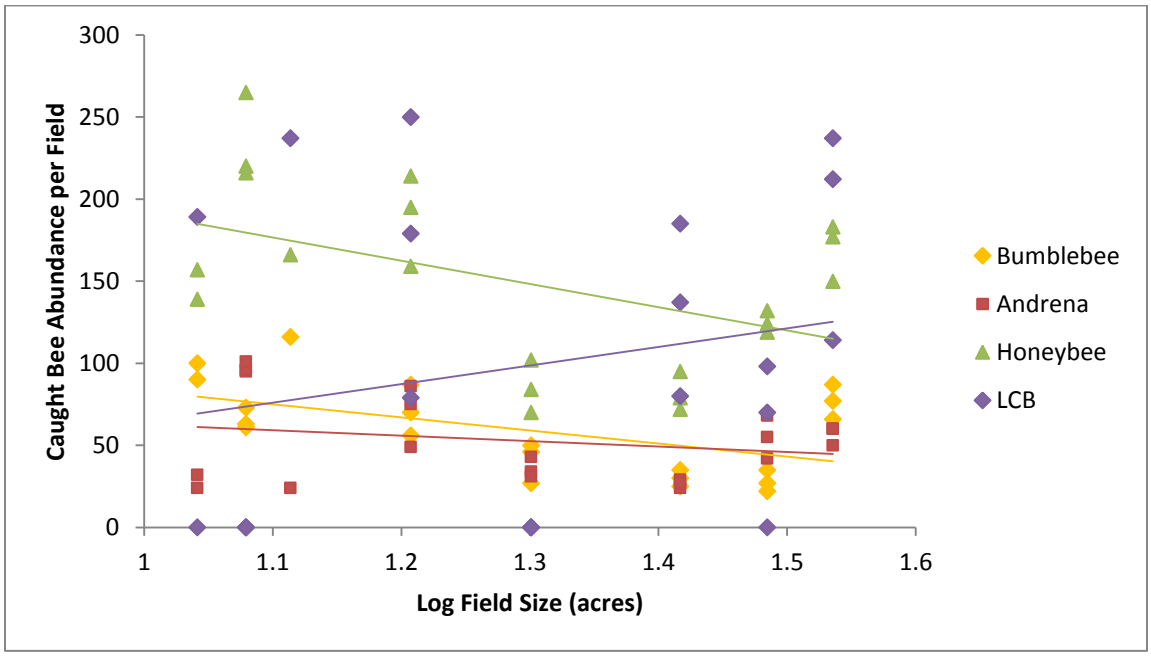


Figure 1b. Caught bee abundance per species/genera (bumblebee, *Andrena*, honeybee, leafcutting bee (LCB)) on total field size in acres (S. Javorek, May 2012, Agriculture Canada, Pers. Comm.) for all of the 7 fields and each crop year (2005, 2007, 2009) in this study situated in PEI.

There was a significant positive relationship between the number of rented hives used and blueberry yield (*p*-value <0.0001; SE = 363.4077; β = 2200.845) (Figure 2). There was also a significant correlation between field size on total number of rented hives (*p*-value 0.0229; SE = 510.5283; β = 1161.707). Finally, the total rented hive and year interaction term was positively significant with blueberry yield (*p*-value <0.0001; SE = 4.8199; β = 28.5093) meaning that some years renting hives had a stronger effect on blueberry yield than others. The trendlines in Figure 2 for 2005 and 2007 suggested that total yield increased as more rented hives were purchased, whereas this correlation was not as strong in 2009. Unfortunately, the sample sizes for each year was not large enough to test for significance separately by year.

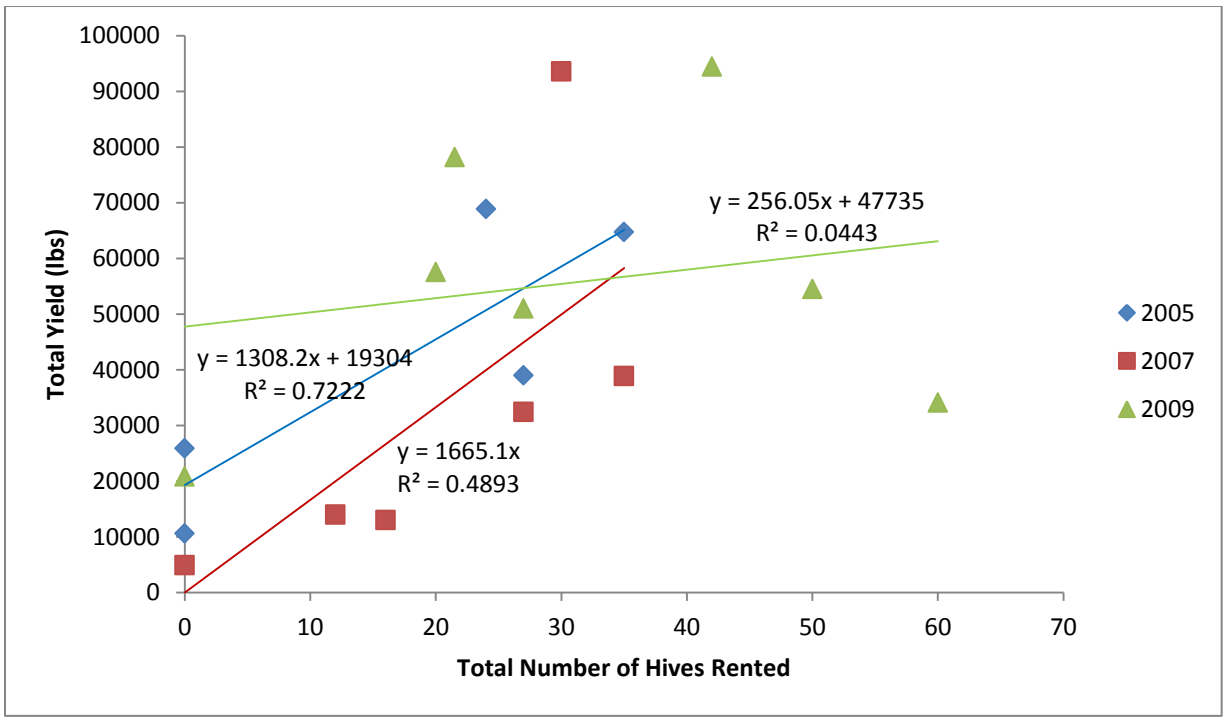


Figure 2. Total yield in pounds per field over 3 crop years (2005, 2007, 2009) relative to total number of honeybee and leafcutter bee hives rented for the 7 fields in this study in PEI (S. Javorek, May 2012, Agriculture Canada, Pers. Comm.).

To determine whether this positive relationship between total rented hives and yield was mostly due to one managed species, I repeated the analysis with abundance of leaf-cutter bee and honeybee hives as separate variables. I could not evaluate bumblebee hives on yields due to small sample sizes. When yield was regressed on rented honeybee hives, there was a significant positive relationship (*p*-value 0.05177; SE = 1031.818; β = 2141.386) despite the numerous zeros in the data (Figure 3). In contrast, there was no significant correlation between the number of leafcutting bee hives and yield (*p*-value 0.3698; SE = 635.519; β = 603.901).

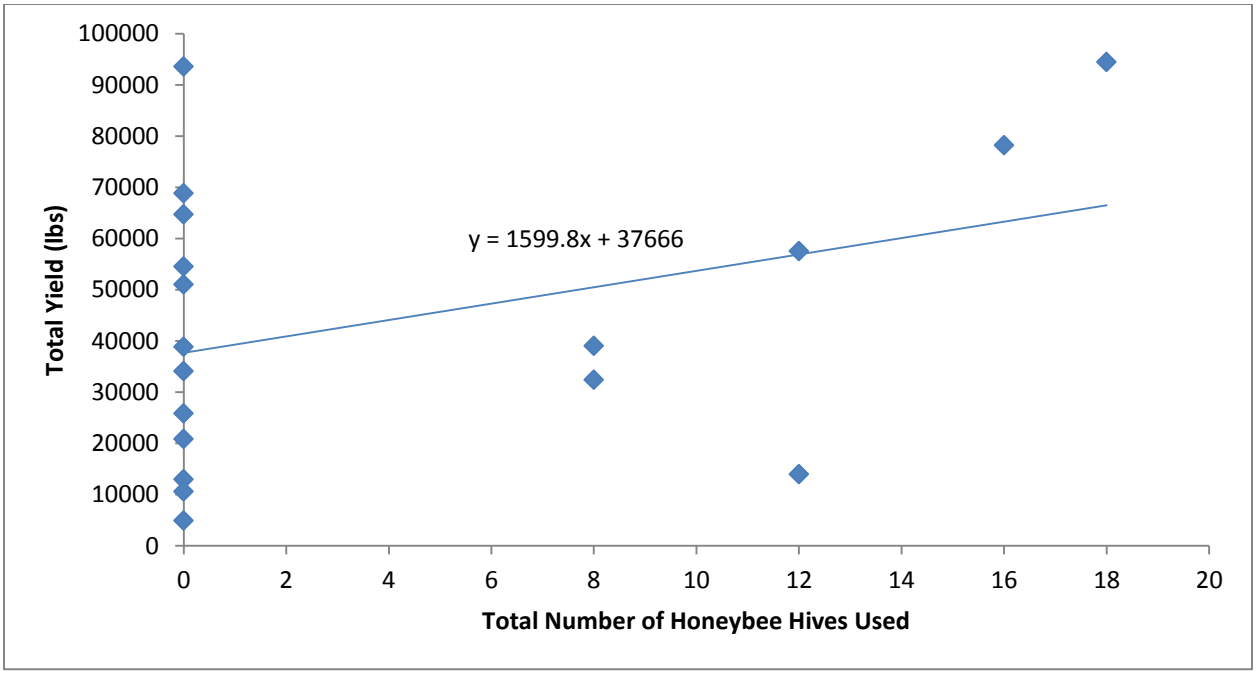


Figure 3. Total yield in pounds per field over 3 crop years (2005, 2007, 2009) on total number of honeybee hives rented for the 7 fields in this study in PEI (S. Javorek, May 2012, Agriculture Canada, Pers. Comm.).

Second Objective

The second objective was to calculate the theoretical effect of pesticides on honeybees and native bees. This was accomplished in two parts; determining the percent mortality of bees due to pesticide toxicity levels, and the resulting decrease in yield, as well as determining the economic costs related to pesticide use including loss of yield.

The pollination rates and the hours above temperature threshold that each species can forage were the main factors that contributed to yield as the average caught abundances were relatively similar to one another and all other factors were the same for each species (Table 2). For an average blueberry crop yield of 6000 lbs/acre (University of Maine, 2013), roughly 4261.77 lbs/acre was estimated to result from bee pollination whereas only 1738.23 lbs/acre was due to the capacity of blueberry plants to autoseminate (Table 2). If that assumption is correct (Jordan, 2003), bumblebees contributed the most to blueberry yield (3119 lbs/acre) with *Andrena* species contributing the second most (849.74 lbs/acre) despite the smaller abundance of bumblebees compared to the managed bees abundances in each field (Table 2) as they were able to pollinate for more hours in the season due to their capacity to forage in colder temperatures. The total blueberry yield resulting from the pollination of each species (Table 2) was used in Table 5 to represent the potential effects of pesticide use on loss of yield due to bee mortality.

Table 2.The theoretical average annual blueberry (BB) yield estimated to be generated from the average abundance of bee species (bumblebee, *Andrena*, honeybee, leafcutting bee (LCB)) present (Equation 1) in the 7 fields of my study for the 3 crop years (2005, 2007, 2009) in PEI.

Bee Species	**Pollination Rate (Hours)[a]**	**Yield Increase Due to Bee Pollination[b]**	**Annual Hours Above Threshold[c]**	**Ave. Caught Abundance[d]**	**lbs/Berry[e]**	**# Berries/ Plant[f]**	**# Plants/ Acre[f]**	**Bragg Harvester Efficiency[g]**	**Total BB Yield From Bee Pollination (lbs/Acre)**
Bumblebee	370.50	3.00	850	3.57	$6.614x10^{-7}$	30	70	66.67%	**3119.00**
Andrena	205.20	3.00	496	3.01	$6.614x10^{-7}$	30	70	66.67%	**849.74**
LCB	60.54	3.00	289	4.96	$6.614x10^{-7}$	30	70	66.67%	**241.20**
Honeybee	15.00	3.00	143	8.70	$6.614x10^{-7}$	30	70	66.67%	**51.83**
								Total:	**4261.77**

a, Numbers calculated from Equation 1. b, Jordan, 2003; University of Maine, 2013. c, Government of Canada, 2013. d, S. Javorek, May 2012, Agriculture Canada, Pers. Comm. e, Wild Blueberry New Brunswick Factsheet, 2010. f, Find the best, 2013. g, Farmer 7, pers. comm. 2014.

The yield due to bee pollination estimated from my empirical data was different from the theoretical rate calculated elsewhere (Jordan, 2003). Jordan calculated the yield due to pollination explained 66% of the total blueberry yield, whereas Table 3 suggested that bees have much less influence on total yield. It was only at the upper limit that bees had close to the same yield influence as Jordan's (2003) 66% with a yield due to bees of 51% (Table 3). However, there was a 95 percent chance that the actual yield due to pollination services was less that 51% (Table 3). The average estimate for the percent blueberry yield due to bee pollination was much lower at 26%. As such, when a quarter instead of two thirds was used to calculate the average annual blueberry yield estimated (Table 4), the total yield due to pollination was estimated to be 1894.12 lbs/acre.

Table 3. The calculated actual yield due to bee pollination through a regression of total species indices and yield per acre (Equations 5 a and b, 6 a and b) in the 7 fields of my study for the 3 crop years (2005, 2007, 2009) in PEI.

	Equation	**Calculated Yield**
Average Total Index	217.668	
Average Estimate	y = 2.131x + 1324.279	1788.217
Upper Limit	y = 6.365x + 1324.279	2709.781
Yield From Poll Services (Ave)	% = 2.131(217.668)/1788.217	25.94%
Yield From Poll Services (Upper)	% = 6.365(217.668)/2709.781	51.13%

Table 4.The actual average annual blueberry (BB) yield estimated to be generated from the average abundance of bee species (bumblebee, *Andrena*, honeybee, leafcutting bee (LCB)) present (Equation 1) in the 7 fields of my study for the 3 crop years (2005, 2007, 2009) in PEI.

Bee Species	**Pollination Rate (Hours)[a]**	**Yield Increase Due to Bee Pollination[b]**	**Annual Hours Above Threshold[c]**	**Ave. Caught Abundance[d]**	**lbs/Berry[e]**	**# Berries/ Plant[f]**	**# Plants/ Acre[f]**	**Bragg Harvester Efficiency[g]**	**Total BB Yield From Bee Pollination (lbs/Acre)**
Bumblebee	370.50	4/3	850	3.57	$6.614x10^{-7}$	30	70	66.67%	**1386.22**
Andrena	205.20	4/3	496	3.01	$6.614x10^{-7}$	30	70	66.67%	**377.66**
LCB	60.54	4/3	289	4.96	$6.614x10^{-7}$	30	70	66.67%	**107.20**
Honeybee	15.00	4/3	143	8.70	$6.614x10^{-7}$	30	70	66.67%	**23.04**
								Total:	**1894.12**

a, Numbers calculated from Equation 1. b, Number calculated for average estimate in Equation 6a; University of Maine, 2013. c, Government of Canada, 2013. d, S. Javorek, May 2012, Agriculture Canada, Pers. Comm. e, Wild Blueberry New Brunswick Factsheet, 2010. f, Find the best, 2013. g, Farmer 7, pers. comm. 2014.

There were 13 pesticides commonly used in lowbush blueberry production. Out of these pesticides, 9 were considered highly toxic to bees, 2 were considered moderately toxic, while 2 pesticides had low toxicity to bees (Table 5).

Table 5. Percent mortality of bee species (bumblebee, *Andrena*, honeybee, leafcutting bee (LCB)) and decreases in yield due to pesticide toxicity levels (high, moderate, and low) for all 16 pesticides commonly used in lowbush blueberry production in PEI. This was based on an average yield of 6000 lbs/acre (University of Maine, 2013). Estimates used for the proportion of yield due to pollination were a factor of 3 (Jordan, 2003) in the top half table and a factor of 4/3 based on calculations from Table 3 in the bottom half of the table. High toxicity was assumed to have between 50%-100% bee mortality (11 chemicals), moderate toxicity to have between 0%-100% depending on the time of day that the pesticide is sprayed (3 chemicals), and low toxicity is assumed to have 0%-50% toxicity on bees (2 chemicals).

				Low and Moderate (Dusk/Dawn application) Toxicity				**Low, Moderate, and High Toxicity**		**Moderate (Daytime application) and High Toxicity**			
				0% Mortality		**25% Mortality**		**50% Mortality**		**75% Mortality**		**100% Mortality**	
Yield[a] Increases Pollination by 3 (Jordan, 2003)	**Yield From Bee Pollination (lbs/acre)**	**Yield Without Pollination (lbs/acre)**	**Total Theoretical Yield (lbs/acre)**	**Decrease in Yield (lbs/acre)**	**% Loss in Total Yield**	**Decrease in Yield (lbs/acre)**	**% Loss in Total Yield**	**Decrease in Yield (lbs/acre)**	**% Loss in Total Yield**	**Decrease in Yield (lbs/acre)**	**% Loss in Total Yield**	**Decrease in Yield (lbs/acre)**	**% Loss in Total Yield**
Bumblebee	3119	1738.23	6000	0	0%	779.75	13.00%	1559.5	25.99%	2339.25	38.99%	3119	51.98%
Andrena	849.74	1738.23	6000	0	0%	212.43	3.54%	424.87	7.08%	637.3	10.62%	849.74	14.16%
Honeybee	241.2	1738.23	6000	0	0%	60.3	1.00%	120.6	2.01%	180.9	3.01%	241.2	4.02%
LCB	51.83	1738.23	6000	0	0%	12.96	0.22%	25.92	0.43%	38.88	0.65%	51.83	0.86%
Total	**4261.77**			**0**	**0%**	**1065.44**	**17.76%**	**2130.88**	**35.51%**	**3196.33**	**53.27%**	**4261.77**	**71.03%**
Yield Increases Pollination by 4/3 (Table 4)													
Bumblebee	1386.22	4105.88	6000	0	0%	346.555	5.78%	693.11	11.55%	1039.665	17.33%	1386.22	23.10%
Andrena	377.66	4105.88	6000	0	0%	94.415	1.57%	188.83	3.15%	283.245	4.72%	377.66	6.29%
Honeybee	107.2	4105.88	6000	0	0%	26.8	0.45%	53.6	0.89%	80.4	1.34%	107.2	1.02%
LCB	23.04	4105.88	6000	0	0%	5.76	0.10%	11.52	0.19%	17.28	0.29%	0.38	0.86%
Total	**1894.12**			**0**	**0%**	**473.53**	**7.89%**	**947.06**	**15.78%**	**1420.59**	**23.68%**	**1894.12**	**31.27%**

a, Numbers from calculations in Table 2

Note: Pesticides would most likely not completely eliminate pollinators if fields are only sprayed a few times per year due to the recolonization of bees on the field. As such, these decreases in yield are probably overestimating the actual decline in yield.

Pesticides that were categorized as having high toxicity to bees resulted in a decrease in total yield of 2131 lbs/acre to 4262 lbs/acre in blueberry yield losses per season if bees contributed to 66% of total yield (Jordan, 2003) (Table 5). The decrease in yield of highly toxic pesticides when using an estimate of 26% of yield due to bee pollination was 947 lbs/acre to 1894 lbs/acre (Table 5). These amounts were calculated using a $0.66/lbs wholesale price,40% of the retail price of $1.65/lbs (Wild Blueberry New Brunswick Factsheet, 2010; Farmer 7, interviews this thesis) (Table 5). For moderate toxicity, there was also a 2131 lbs/acre to 4262 lbs/acre (66% bee contribution) or 947 lbs/acre to 1894 lbs/acre (26% bee contribution) decrease in yield when the pesticide was sprayed during the day, as bees are strongly affected by these pesticides when they are in direct contact with them.

However, there was a much lower effect when the moderate toxicity pesticide was sprayed at dusk and dawn, namely a 0 lbs/acre to 2131 lbs/acre (66% bee contribution) and 0 lbs/acre to 947 lbs/acre (26% bee contribution) decrease in yield, as bees are not foraging at such hours and therefore have less risk of direct contact with the pesticide. Finally, pesticides that were categorized by the IFAS as having low toxicity to bees were estimated to result in a 0 lbs/acre to 2131 lbs/acre (66% bee contribution) and 0 lbs/acre to 947 lbs/acre (26% bee contribution) decrease in yield.

The range of pesticide use on costs due to loss of yield and pesticide price per acre was quite large due to the range of pesticide effect on bees as well as whether bee pollination contributed to 66% of yield (Jordan, 2003) or 26% of yield due to calculations using my data (Table 3). As such, the lower limit of the ranges in Table 6 were calculated using 50% bee mortality for high toxicity, and moderately toxic pesticides used during the day, or a 0% bee

mortality for low toxicity, and moderately toxic pesticides used at dusk an dawn, as well as the 26% bee contribution estimate. The upper limits in Table 6 were calculated using 100% bee mortality for highly toxic, and moderately toxic pesticides used during the day, or a 50% bee mortality for low toxicity, and moderately toxic pesticides used at dusk and dawn, as well as the 66% bee contribution estimate (Jordan, 2003).

Pesticides with high toxicity to bees are estimated to result in a $625.06 to a $2812.72 yield loss per acre (Table 6). This, however, does not account for any losses that would have resulted from the spread of disease if the pesticide had not been applied nor recolonization of bees once existing populations were wiped out. A pesticide with low toxicity had a bee mortality range of 0% to 50%, which resulted in a $0 to $1406.20 decrease in blueberry yield per acre plus the added price of the pesticide per acre (Table 6). The range of costs of pesticides were relatively similar and negligible compared to the costs they inflict blueberry yield losses. However, the upper limits of the estimates used in this study were most likely overestimating the true effects of bee pollination on yield as other environmental factors affecting yield were not examined.

Of all the chemicals commonly used in lowbush blueberry farming in the Maritimes, there were a total of 14 herbicides commonly used, where 5 of these were also used as spot treatments (Agriculture, Aquaculture, and Fisheries, 2012; Burgess and Wood, 2012). These herbicides ranged from $3.62/acre to $172.50/acre (Mr. MacKenzie, Cavendish Agriculture, 2013, pers. comm.). There were 13 pesticides commonly used, where 3 were also used as spot treatments (Delbridge and Rogers, 2012) and costing between $4.88/acre and $64.16/acre (Mr. MacKenzie, Cavendish Agriculture, 2013, pers. comm.), which had a much smaller range of

prices and were generally less expensive than herbicides. Finally, there were a total of 15 fungicides used (Burgess and Wood, 2012). Fungicides were the most expensive chemicals, ranging from $11.11/acre to $136.55/acre (Mr. MacKenzie, Cavendish Agriculture, 2013, pers. comm.).

Table 6. Range of predicted potential costs related to using pesticides commonly used in lowbush blueberry farming in PEI assuming an average yield of 6000 lbs/acre, a wholesale price of $0.66 (BB means blueberry), and a range of 26% (Table 4) to 66% of total yield due to bees (Jordan, 2003). Price of pesticide/acre was an average of the cost in 2012 and 2013 (Mr. MacKenzie, Cavendish Agriculture, 2013, pers. comm.).

Pesticide Name	Toxicity Level	Eliminated Pests	Time of day for Spraying	$ of Pest./ Acre	Ave % Potent. Yield Lost to Pest./ Acre	Ave $ Potent. Yield Lost to Pest./ Acre	Tot Potent $ of Pest.
Actara 25 WG	High Toxicity	Weevils	Anytime of day	$36.04	15.78%	$625.06	$661.10
Actara 25 WG	High Toxicity	Weevils	Anytime of day	$36.04	71.03%	$2,812.79	$2,848.83
Decis 5 EC	High Toxicity	BB leaftier	Anytime of day	$5.95	15.78%	$625.06	$631.01
Decis 5 EC	High Toxicity	BB leaftier	Anytime of day	$5.95	71.03%	$2,812.79	$2,818.74
Entrust	High Toxicity	BB spanworm, BB flea beetle	Anytime of day	$64.16	15.78%	$625.06	$689.22
Entrust	High Toxicity	BB spanworm, BB flea beetle	Anytime of day	$64.16	71.03%	$2,812.79	$2,876.94
GF-120 NF	High Toxicity	BB fruit fly	Anytime of day	$25.23	15.78%	$625.06	$650.29
GF-120 NF	High Toxicity	BB fruit fly	Anytime of day	$25.23	71.03%	$2,812.79	$2,838.01
Imidan 50 WP	High Toxicity	BB spanworm, BB fruit fly	Anytime of day	$32.63	15.78%	$625.06	$657.69
Imidan 50 WP	High Toxicity	BB spanworm, BB fruit fly	Anytime of day	$32.63	71.03%	$2,812.79	$2,845.42
Lagon 480 E	High Toxicity	BB fruit fly	Anytime of day	$9.21	15.78%	$625.06	$634.27
Lagon 480 E	High Toxicity	BB fruit fly	Anytime of day	$9.21	71.03%	$2,812.79	$2,821.99
Pounce 384 EC	High Toxicity	BB thrips	Anytime of day	$4.88	15.78%	$625.06	$629.94
Pounce 384 EC	High Toxicity	BB thrips	Anytime of day	$4.88	71.03%	$2,812.79	$2,817.67
Sevin XLR	High Toxicity	BB fruit fly	Anytime of day	$33.83	15.78%	$625.06	$658.89
Sevin XLR	High Toxicity	BB fruit fly	Anytime of day	$33.83	71.03%	$2,812.79	$2,846.62

Success 480 SC	High Toxicity	BB spanworm, BB flea beetle	Anytime of day	$50.70	15.78%	$625.06	$675.76
Success 480 SC	High Toxicity	BB spanworm, BB flea beetle	Anytime of day	$50.70	71.03%	$2,812.79	$2,863.49
Assail 70 WP	Mod. Toxicity	BB flea beetle, BB thrips, BB spanworm, BB fruit fly	During the day	$33.73	15.78%	$625.06	$658.79
Assail 70 WP	Mod. Toxicity	BB flea beetle, BB thrips, BB spanworm, BB fruit fly	During the day	$33.73	71.03%	$2,812.79	$2,846.52
Delegate WG	Mod. Toxicity	BB spanworm, BB flea beetle	During the day	$23.12	15.78%	$625.06	$648.18
Delegate WG	Mod. Toxicity	BB spanworm, BB flea beetle	During the day	$23.12	71.03%	$2,812.79	$2,835.91
Assail 70 WP	Mod. Toxicity	BB flea beetle, BB thrips, BB spanworm, BB fruit fly	Dusk/Dawn	$33.73	0.00%	$0.00	$33.73
Assail 70 WP	Mod. Toxicity	BB flea beetle, BB thrips, BB spanworm, BB fruit fly	Dusk/Dawn	$33.73	35.51%	$1,406.20	$1,439.93
Delegate WG	Mod. Toxicity	BB spanworm, BB flea beetle	Dusk/Dawn	$23.12	0.00%	$0.00	$23.12
Delegate WG	Mod. Toxicity	BB spanworm, BB flea beetle	Dusk/Dawn	$23.12	35.51%	$1,406.20	$1,429.32
DiPel 2X	Low Toxicity	BB spanworm	Anytime of day	$30.35	0.00%	$0.00	$30.35
DiPel 2X	Low Toxicity	BB spanworm	Anytime of day	$30.35	35.51%	$1,406.20	$1,436.55
Foray 48 B	Low Toxicity	White-marked tussock moth	Anytime of day	$35.00	0.00%	$0.00	$35.00
Foray 48 B	Low Toxicity	White-marked tussock moth	Anytime of day	$35.00	35.51%	$1,406.20	$1,441.20

Third Objective

The third objective was to determine the baseline budget for lowbush blueberry farming, to evaluate the link between inputs normally used by wild blueberry farmers and their central output (blueberries). The contribution of bee pollination to overall yield was estimated to be 66% in Table 7 (Jordan, 2003), which assumes bee pollination as the sole contributor to yield other than autosemination. The bee contribution to yield was estimated to be 26% in Table 8 (estimated from Table 3), to illustrate the impact that other environmental factors could have had on yield. This range was then added to the baseline budget (Table 9), as the true yield due to bee pollination was unknown, but is likely to be somewhere within that range (Jordan, 2003; and this thesis).

Based on the pollination rates (Equation 1), hours above threshold (Government of Canada, 2013), and proportion of bee abundances of each bee species (S. Javorek, May 2012, Agriculture Canada, Pers. Comm.), bumblebee species was theoretically the greatest contributor to blueberry yield, contributing approximately one third to one half of the total blueberry yield when using Jordan's (2003) bee contribution estimate of 66% and a fourth of total blueberry yield when using the estimate of 26% in each field (Table 7 and 8). *Andrena* was a significant contributor to yield even though both bumblebee and *Andrena* species did not have the highest abundances out of all the species collected. Contributions of honeybees and leafcutting bees to yield were relatively small (Table 7 and 8). However, other environmental factors other than bee pollination and autosemination could have contributed to the farmer's yield, which could not be assessed in this study. With all of the information collected in the third objective, a baseline budget was made for each farmer in the study for 2005, 2007, and 2009 (Table 9).

Table 7. Theoretical contribution of each bee species (bumblebee, *Andrena*, honeybee, leafcutting bee (LCB)) to the actual yield (lbs/acre) and gross gains ($) of each field per crop year 2005, 2007, 2009, a wholesale price of $0.66 based on the theoretical pollination rates of each bee species (Equation 1), temperature hours above threshold (Government of Canada, 2013), a yield estimate due to pollination of 66% (Jordan, 2003) and the amount of bees caught per species (S. Javorek, May 2012, Agriculture Canada, Pers. Comm.) for 2005, 2007, and 2009 respectively.

Field Name	**Year**	**Actual Yield**		**Estimated yield w/o Bees**		**Yield due to *Andrena***		**Yield due to Bumblebee**		**Yield due to Honeybee**		**Yield due to LCB**	
		lbs/acre	**$**	**lbs/acre**	**$**	**lbs/acre**	**$**	**lbs/acre**	**$**	**lbs/acre**	**$**	**lbs/acre**	**$**
1	2005	N/A											
	2007	700	$462	233	$154	124	$82	301	$199	42	$27	0	$0
	2009	2877	$1,899	959	$633	351	$232	1411	$932	155	$102	0	$0
2	2005	N/A											
	2007	N/A											
	2009	2215	$1,462	738	$487	317	$209	996	$657	147	$97	17	$11
3	2005	2489	$1,643	830	$548	304	$201	1177	$777	157	$104	21	$14
	2007	1494	$986	498	$329	239	$157	632	$417	106	$70	19	$13
	2009	2096	$1,383	699	$461	269	$178	945	$624	154	$102	29	$19
4	2005	118	$78	39	$26	23	$15	46	$30	9	$6	0	$0
	2007	22	$15	7	$5	4	$3	9	$6	2	$1	0	$0
	2009	95	$63	32	$21	19	$12	37	$24	8	$5	0	$0
5	2005	2422	$1,599	807	$533	293	$193	1162	$767	148	$98	12	$8
	2007	3293	$2,173	1098	$724	391	$258	1585	$1,046	192	$127	28	$19
	2009	3323	$2,193	1108	$731	404	$267	1586	$1,047	201	$132	25	$16
6	2005	392	$259	131	$86	64	$42	165	$109	32	$21	0	$0
	2007	478	$315	159	$105	122	$80	150	$99	43	$29	4	$2
	2009	5123	$3,381	1708	$1,127	1418	$936	1525	$1,007	449	$296	23	$15
7	2005	3545	$2,340	1182	$780	205	$136	1985	$1,310	173	$114	0	$0
	2007	2947	$1,945	982	$648	144	$95	1664	$1,098	137	$90	19	$13
	2009	3923.08	$2,589	1307.69	$863	170.14	$112	2227.18	$1,470	191.74	$127	26	$17

Table 8. Theoretical contribution of each bee species (bumblebee, *Andrena*, honeybee, leafcutting bee (LCB)) to the actual yield (lbs/acre) and gross gains ($) of each field per crop year 2005, 2007, 2009, a wholesale price of $0.66 based on the theoretical pollination rates of each bee species (Equation 1), temperature hours above threshold (Government of Canada, 2013), a yield estimate due to pollination of 26% (Table 3) and the amount of bees caught per species (S. Javorek, May 2012, Agriculture Canada, Pers. Comm.) for 2005, 2007, and 2009 respectively.

Field Name	**Year**	**Actual Yield**		**Estimated yield w/o Bees**		**Yield due to *Andrena***		**Yield due to Bumblebee**		**Yield due to Honeybee**		**Yield due to LCB**	
		lbs/acre	**$**	**lbs/acre**	**$**	**lbs/acre**	**$**	**lbs/acre**	**$**	**lbs/acre**	**$**	**lbs/acre**	**$**
1	2005	N/A											
	2007	700	$462	104	$68	55	$36	134	$88	19	$12	0	$0
	2009	2877	$1,899	426	$281	227	$149	550	$363	77	$51	0	$0
2	2005	N/A											
	2007	N/A											
	2009	2215	$1,462	328	$216	174	$115	423	$279	59	$39	8	$5
3	2005	2489	$1,643	368	$243	196	$129	476	$314	66	$44	8	$6
	2007	1494	$986	221	$146	118	$78	286	$188	40	$26	5	$3
	2009	2096	$1,383	310	$205	165	$109	401	$264	56	$37	7	$5
4	2005	118	$78	17	$12	9	$6	23	$15	3	$2	0	$0
	2007	22	$15	3	$2	2	$1	4	$3	1	$0	0	$0
	2009	95	$63	14	$9	7	$5	18	$12	3	$2	0	$0
5	2005	2422	$1,599	358	$236	191	$126	463	$305	65	$43	8	$5
	2007	3293	$2,173	487	$322	259	$171	629	$415	88	$58	11	$7
	2009	3323	$2,193	492	$324	262	$173	635	$419	89	$58	11	$7
6	2005	392	$259	58	$38	31	$20	75	$49	10	$7	0	$0
	2007	478	$315	71	$47	38	$25	91	$60	13	$8	2	$1
	2009	5123	$3,381	758	$500	403	$266	979	$646	137	$90	17	$12
7	2005	3545	$2,340	524	$346	279	$184	677	$447	95	$62	0	$0
	2007	2947	$1,945	436	$288	232	$153	563	$372	79	$52	10	$7
	2009	3923.08	$2,589	580	$383	309	$204	750	$495	105	$69	13	$9

The best method of conducting this baseline budget would be to have a short workshop with every farmer individually. First, I would only include the breakdown of how much of the farmer's total yield was due to the pollination of each bee species if caught bee abundances of their field for the given crop/sprout cycle was collected for the field in question (b: Table 9).

Second, I would explain how to calculate the unit price (lbs/acre) of the chemicals (fertilizers, fungicides, herbicides, pesticides), bee rentals, and harvesting time they used on their fields for sprout and/or crop years (c,d,e: Table 9). As such, I would remove any input they did not use in the baseline budget (ex. honeybee rentals and herbicides in crop year). Finally, I would explain what losses in yield from pesticide use are (a: Table 9) and how to calculate this impact with the help of Table 6, which I would have provided to the farmer. This would give the farmer an idea to what degree pesticides may negatively affect their yield through losses in bee abundance but would remind the farmer of the limitations and potential overestimations of these findings.

Table 9. Baseline budget of average farmer in this study for an average year extrapolated from Mussels et al. (2013) with added values and suggestions from farmers' data. Blueberry price per pound was 40% of retail price of $1.65 for 2005 (Province of Nova Scotia, 2013). Bee contribution breakdown range calculated using 26% (Table 3) and 66% (Jordan, 2003) estimates.

	Units	**Units/acre**	**$/Unit**	**Total Cost/Acre**
Income				
Blueberry Yield	lbs	2086.71	$0.66	$1,377.23
Losses in yield from Pest. use[a]	lbs	To be estimated	$0.66	To be estimated
Breakdown:[b]				
Andrena	lbs	439.74 - 999.41	$0.66	$290.23 - $659.61
Bumblebee	lbs	111.55 - 251.02	$0.66	$73.62 - $165.67
Honeybee	lbs	57.51 - 129.42	$0.66	$37.96 - $85.42
Leafcutting bee	lbs	4.81 - 10.81	$0.66	$3.17 - $7.13
Autosemination (estimate Jordan, 2003)	lbs	695.57	$0.66	$459.08
Expenses				
Sprout Year				
Mowing	acre	1	$52.50	$52.50
Fertilizers[c]	acre	1	$101.06	$101.06
Fungicides[c]	acre	1	$41.50	$41.50
Herbicides[c]	acre	1	$119.34	$119.34
Pesticides[c]	acre	1	$14.83	$14.83
Transportation	acre	1	$37.00	$37.00
Land Improvements	acre	1	$71.00	$71.00
Crop Year				
Scouting (Pest./Diease)	acre	1	$32.50	$32.50
Fertilizers[c]	acre	1	$94.67	$94.67

Fungicides[c]	acre	1	$60.33	$60.33
Herbicides[c]	acre	1	$43.33	$43.33
Pesticides[c]	acre	1	$32.42	$32.42
Honeybee rental[d]	hive	0.2	$100.00	$20.00
Bumblebee rental[d]	quad	0.06	$260.00	$15.60
Leafcutting bee[d]	gallon	1.61	$75.00	$120.75
Harvesting[e]	hours	4.00	$75.00	$300.00
Crop Insurance premiums	acre	1	$35.00	$35.00
Transportation	acre	1	$37.00	$37.00
Mowing	acre	1	$52.50	$52.50
Marketing and association fees	acre	1	$7.00	$7.00
Total Expenses				**$1,288**
Income – Expenses		**$1,377.23**	**$1,288**	**$88.90**
Income-Expenses w/o Pesticide[a]		To be estimated		To be estimated

a,c,d,e: Removed/modified depending on farmer's practices b: Removed if bees were not caught farmer's field for given years

The three major variables altering farmers' profit margins in the baseline budgets of this study were yield, wholesale price, and costs related to bee hive rentals (Table 9). Relatively small increases in yield and wholesale price both greatly increased farmer's income. The costs of renting bee hives was also a major variable as farmers used a variety of rented bee species, although there seemed to be little consensus regarding how many rented hives should be placed per acre of land. The use of chemicals also varied among farms. For example, Farmer 7 applied approximately the same chemicals from year to year as he uses chemicals as a preventative measure on his fields, whereas Farmer 3 applied different chemicals as well as different amounts of these chemicals depending on what was occurring on his field for that given year.

It was also common practice among farmers in PEI to spray their fields with Decis and Imidan, which are pesticides that are highly toxic to bees (Farmer 3 pers. comm.; Farmer 7 pers. comm.). Interview results suggested that these farmers have been unaware that they were

actively killing many valuable native and rented bees in their fields. All other variables in the baseline budget did not greatly influence the overall cost of production in this study.

Fourth Objective

The fourth objective was to discuss the results of the study with two farmers to get their feedback in order to increase the accuracy of my results and ensure the results were communicated in a manner that farmers easily understand. The first farmer who owns field 7 (Farmer 7), was interviewed on Saturday April 26, 2014 and the second farmer, who owns field 3 (Farmer 3), was interviewed on Sunday April 27, 2014. These interviews took place in their respective homes.

Farmer 3 and Farmer 7 were not surprised with most of the study results regarding the links between bees and blueberry yield. They already knew that smaller fields tend to have larger abundances of bees/acre than larger fields through observations during their 20+ years of practice (Figure 1a and b). Farmer 7 was also not surprised to see that native bees had lower abundances/acre than managed bees (Figure 1a and b) and suggested that this may be due to farmers' lack of knowledge of the importance of native bees. Farmer 3 and 7 believe that most blueberry farmers in PEI, and maybe even farmers in general, do not take the native bees on their fields into consideration, so they stock their field(s) with enough managed bees to pollinate all of their crops. Farmer 7 also thought that as farmers disregard native bees, they do not provide enough habitat for native bees around their fields, and spray ditches and tree lines around fields with chemicals potentially harmful to bees in order to prevent any diseases or plants taking over their field.

Farmer 7 was also not surprised to see a stronger correlation between the number of rented honeybee hives and yield (Figure 3) than total rented hives and yield (Figure 2). He believes this may also be caused by the strong bias of seeing honeybees as the only viable managed bee for lowbush blueberry pollination. As such, the farmers that use honeybee to pollinate their crops would tend to only use honeybee hives.

When the farmers were presented with the number of flowers each bee species pollinates per season (Table 1), Farmer 7 was very interested in the results as they were different from what had been told to him thus far. Farmer 3 was also surprised and a little taken back as to the magnitude in differences between the amounts of flowers pollination per season between species. Both Farmer 3 and 7 said the common knowledge of the agricultural industry is that honeybees are the best pollinator for all blueberry crops and even Farmer 7 has consistently been told that 2 bumblebee hives are equivalent to 1 honeybee hive.

When I explained to farmers how this study calculated these pollination rates, the differences in the number of hours each species has to pollinate their crop for a given season, and how bumblebees and *Andrena* sonicate the flower to retract more pollen from a flower, they understood why bumblebees were actually the best pollinator. Farmer 7 even confirmed part of my theory saying that he has often noticed only bumblebees and *Andrena* pollinating his crops in colder temperatures while honeybees and leafcutting bees stayed in their hives. Farmer 3 found this knowledge particularly interesting as he has switched to using uniquely leafcutting bees as his managed bee, which theoretically pollinate much fewer flowers per season than *Andrena* or bumblebees. Farmer 3 said that he will reconsider which bee species he will rent next season and will evaluate if this change will help increase his yield for next season.

Farmer 3 and Farmer 7 were very interested with the breakdown of how different toxicity levels of pesticides affect bees, and more importantly, how that translated to theoretical yield losses (Table 5). Both thought that translating pesticide use into percent decline of bees and calculating actual values for losses in yield was very helpful as this made an abstract concept much more concrete especially when expressed in terms that made sense to them. They both understood that these calculations did not take into consideration the losses in crop due to pest infestation that spraying was trying to eliminate, but still allowed them to get a more concrete sense of what pest infestation threshold should be met before spraying in order to prevent any further losses in yield.

Farmer 7 found that the time of day for spraying pesticides drastically change the toxicity of a moderately toxic pesticide to bees (Table 5) was very intriguing. He was very interested in understanding the difference between bees being in direct contact with a pesticide compared to being in contact with residuals of a pesticide. This also prompted the conversation about how different species could be affected differently from moderately toxic pesticides as some bees such as *Andrena* live in the soil within the blueberry field whereas others live on the edges of the field. The conversation then lead to the toxicity levels to bees of other chemicals such as herbicides and fungicides to know whether those chemicals should only be sprayed at dusk and dawn as well. More specifically, both Farmers spray Decis and Bravo on the edges of their fields as a preventative measure, therefore Farmer 7 was wondering about the impacts of these being sprayed on native habitat.

When looking at Table 2, Farmer 7 mentioned that a representative from Bragg's Harvester came to a blueberry conference in PEI in early April, 2014 to talk about the increased

efficiency of their harvester due to new technology. Peter Schwinkle, the main engineer on the study, said that average blueberry losses with this newer technology was between 17-23 %, but these losses can be cut to only 8 % when tractors drive at an optimum speed of 1.14 km/h and a harvester head speed of 26 RPM (Faculty of Agriculture, Dalhousie University, 2014). This was good news for Farmer 7 as he plans to continue to use the Bragg's Harvester to harvest his crop and is eager to see how this new optimum efficiency speed will affect his cultivated yield.

Farmer 3, on the other hand, was not as enthusiastic about the results as he calculated that at 1.14km/h, he would only be able to harvest 1-2 acres per day. This is a problem as he has more total acreage in crop than Farmer 7 so this would increase the pressure on him to harvest all of his producing fields before the end of the season. As such, he is actively looking for other harvester options that would allow him to harvest more acreage per day with a relatively high harvesting efficiency.

As for the study itself, Farmer 7 thought the study's approach of laying out a detailed baseline budget related to costs and blueberry yield was a significant innovation (Table 9) as he and many other of his colleagues have a hard time calculating all of their costs, especially on a per acre basis. In the past it has been a challenge for most farmers to determine what yield they need in order to break even. Many of the older farmers are not overly computer literate so many of their calculations are done by hand, limiting the level of analysis necessary to improve yields.

Farmer 7 did suggest that the study should incorporate both sprout year and crop year into the same baseline budget as any given field only provides income every 2nd year, whereas the study originally only had costs for crop year (Table 9). His other recommendation was to incorporate labour cost into chemical application cost as this is the industrial standard practice

for billing in PEI (Table 9). Wyman's, which does most of Farmer 7's chemical spraying, bills him for a flat rate per hour which incorporates the cost of the chemical, and the man hours it takes to apply the chemical on his field. Farmer 7 said that it is common practice to get Wyman's to spray family run fields as much of the machinery needed costs too much for a single farmer to buy and it is easier to get Wyman's to spray their field than getting all the family farmers to collaborate in buying the expensive equipment and coordinating which farmer uses the equipment when.

In order to make his life easier, Farmer 3 also thought that if an easy baseline budget skeleton was created where the farmer could simply input their costs into designated boxes, this would help farmers calculate their projected yields (Table 9). As with Farmer 7, Farmer 3 thought that both sprout and crop years should be incorporated into the same baseline budget. However, Farmer 3 does not use Wyman's services nearly as much as Farmer 7 because he feels that Wyman's heavy trucks destroy much more of his crop than his own machinery, and that Wyman's is not as careful as to when they come to spray his fields and spray in areas that are not supposed to be sprayed.

Farmer 3 does, however, buy his chemicals from Wyman's as he gets a much better deal through them than buying from chemical distributors as Wyman's buys in bulk and therefore gets a better deal. Farmer 3 then sprays as much of the chemicals needed on his field with his smaller tractor and only gets Wyman's to spray the chemicals that absolutely need larger equipment to spray. He is not sure if he has been saving or losing money this way as it is difficult to factor in equipment maintenance and set up times, and taking into consideration the time for trial and error in finding the optimum way to spray his fields.

One piece of crucial information provided by both farmers in helping to improve the results of this study is the fact that the selling price of blueberries that I originally quoted was actually the retail price and not the actual price they receive. Both Farmer 3 and 7 say that they receive approximately 40% of the retail price. This means that when the retail price of blueberries was $1.65/lbs in 2005, their revenue was roughly $0.66/lbs.

Both farmers mentioned that the hired labour harvesting their crop was paid by the hour before 2011. Farmer 7 said that it takes roughly 4 hours to harvest a single acre at a rate of $75/hour ($300/acre). After 2011, the labourer was paid $0.19/lbs of blueberry harvested (ranging from $133 to $973/acre for the yields in this study). In theory, paying by the hour was cheaper than per pound harvested especially for high yielding crops but Farmer 3 and 7 said that farmers found that paying by the pound made harvesters more efficient and they took less time harvesting the same amount of crop. Farmer 3 as well as other farmers also tried paying harvesters by the number crate of blueberries filled but found that the crates were not filled to capacity by the harvesters.

Finally, during the interviews, both farmers repeatedly expressed their gratitude for sharing my findings with them as both had had other research projects occur on their fields with little feedback from the researcher(s) once the projects were completed. On the few occasions where scientific results were provided to them, they found reports difficult to understand as they used scientific terminology, and graphs and tables that were not easy to interpret by an untrained person. Furthermore, both farmers stated that they, like many of their peers, have limited knowledge of computers and the internet, so making such results available on the internet was not a suitable means of dissemination for them.

Chapter 5: Discussion

First Objective

The difference in pollination rates between bee species was an important aspect of this study. Bumblebee species were the most effective and *Andrena* the second most effective lowbush blueberry pollinators out of all the species examined in this study (Table 1) (Ricketts et al., 2008). This is partly because native bees such as *Andrena* sp. and *Bombus* sp. have evolved to sonicate blueberry flowers to dislodge and harvest the pollen within the flower (Javorek et al., 2002; Rhodes, 2006). Native bees are also less affected by bad weather conditions than managed bees (Javorek et al., 2002), which made a large difference in Prince Edward Island where the average temperatures during blueberry bloom are often too cold for honeybees or leafcutting bees (Government of Canada, 2013). Furthermore, blueberry flowers are not particularly attractive to honeybees as most blueberry species do not have the flower characteristics that are best suited for the honeybee, which are nectar harvesters (Rhodes, 2006).

These observations are contrary to agricultural standards, as North American farmers and bee keepers predominantly use honeybees as the main pollinator species for their crops, and believe that honeybees are the best pollinator of any agricultural crop (Vance 2011; Farmer 3 pers. comm.; Farmer 7 pers. comm.). This belief stems from the fact that honeybees live in hives that can easily be moved among fields, and they are not particular about which flower species they feed on (Vance, 2011). Both Farmer 3 and 7 were very surprised that honeybee pollination rates were much lower than the native bee pollinators as it was contrary to what was accepted industry practice for the past 20 years or more. As such, this is probably why farmers did not take native bees into consideration as a viable pollinator for their crops, therefore relying solely

on managed bees to provide the pollination service that is so crucial to them (Naug et al., 2009; Mullin et al., 2010).

There was a positive correlation between yield and total bee abundance. Fields that had increased presence of one type of bee also had increased presence of all other bee species examined in this study (Figure 1b). This may suggest that areas that are favourable for any given bee species are also favourable for other bee species, and that none of these fields are saturated by bees, which would force them to compete for limited resources. This is congruent with literature as fields that have a large abundance of bees also tend to have large diversity of bee species (Tscharntke et al., 2005; Ricketts et al., 2008; Steffan-Dewenter and Westphal, 2008; Garibaldi et al., 2011). This is important because bee diversity is essential to sustaining pollination services as there are natural year to year variations in bee community composition (Kremen et al. 2002).

There was a significant negative correlation between logged field size and bee abundance (Figure 1a). This result is consistent with the literature as larger fields have larger field to edge ratio, which decreases the amount of available nesting areas and diversity of floral resources for many native bees (Garibaldi et al., 2011). This is because social native bees only nest in natural and semi-natural habitats, which are located in the field margins and shrubby wooded areas surrounding the crop field (Ricketts et al., 2008). This is unfavourable for farmers because as crop field size increases, fewer plants in the center of the field are adequately pollinated by native bees (Ricketts et al., 2008).

However, the difference in caught bee abundances of bumblebees and *Andrena* in small fields compared to larger fields were minimal from a farmer's standpoint. There was only a

decline of approximately 33% in bumblebee individuals and 23% in *Andrena* individuals between the smallest field of 11 acres and the largest field of 34 acres (Figure 1b). Therefore, even though there were significant negative correlations between bee species and field size, decreasing field size in an effort to increase yield may result in only small increases in yield.

In the fields of my study, honeybees were not the only species rented for their pollination services (Figure 2 and 3). In some cases, no bees were rented (Figure 3), generally because prices of renting honeybees have gotten too expensive due to honeybee shortages (Naug et al., 2009; Mullin et al., 2010; Farmer 3 pers. comm.; Farmer 7 pers. comm.). As such, if honeybee hive rental prices ever decreased, I would predict that farmers would revert to mostly or exclusively using honeybees as the managed bee on their field. However, this might actually decrease financial gains as honeybees are not the best pollinator for lowbush blueberry crops (Javorek et al., 2002). A more efficient alternative might be to rent bumblebee hives and to promote native bee populations to increase on their fields (Ricketts et al., 2008; Garibaldi et al., 2011).

There was a large difference in the proportion of blueberry yield that was due to bee pollination between Jordan's experiment in 2003 and the calculations I conducted with my data. He calculated that bees contribute to 66% of the total yield whereas my data suggested that on average, bees contributed to only 26% of the total yield (Table 2 and 3). His rates might be higher as his experiment was constructed to test this specific interaction whereas my results were extracted from field data, and therefore have more noise. He had total exclusion plots and was able to control and account for many more environmental factors than my study; therefore, he was able to test the specific interaction between bee pollination and lowbush blueberry yield.

However, covers may have resulted in edge effects that may decrease yield within covers, or other unknown negative effects of covers. Jordan was able to control spring frost, disease, harvest efficiency, the number of bee pollinators, and predator invasion (Jordan, 2003). Because the effect of covers on yield other than their effects on pollinators is unknown, it is possible that Jordan's study overestimated effects of pollinators on overall yield.

Another issue that makes it difficult to extrapolate from Jordan's study to my study is that all the plots in Jordan's study had the same percent cover. In contrast, in the fields I studied, sites had between 30-90% blueberry cover, which would have influenced variance in yield and perhaps rates of yield due to pollinators. My study was unable to distinguish between environmental factors and effects of pollinators on yield, so I could not estimate how much of an effect each environmental factor had on my results. My results also do not include any exclusion plots so I have no baseline to compare my results with. However, my results do incorporate environmental factors, and therefore emulate more realistically what actually occurs on the fields. It seems likely that the true estimate for the amount of yield due to bee pollination lies somewhere between 26% and 66% of total yield. Jordan (2003) may have over-estimated the true effect of bee pollination on yield due to effects of cages on yield. The 26% estimate may have under-estimated yield as my study was not designed to test this interaction, and could not distinguish between impacts of environmental effects on yield, and impacts of pollinators on yield.

In either case, whether bees contribute to only 26% or as high as 66% or somewhere in between, bees were still an integral part of blueberry yield and farmer's profitability. Blueberry plants poorly autoseminate as their pollen is sticky and relatively heavy, and the bell shape and

position of the flower makes pollination through wind unlikely (Meyers and Cline, 1997). Furthermore, blueberry plants are not very self-compatible which means that these plants rely heavily on bees' pollination services for fertilization (Bobiwash, 2012). Also, even when autosemination does occur, there are less fruit per plant and these fruits are considerably smaller (Meyer and Cline, 1997), which greatly decreases the marketablility of a farmer's yield.

Second Objective

The majority of pesticides (9/13) commonly used in lowbush blueberry farming in PEI were highly toxic to bees (Table 6). Spraying these chemicals on fields results in high bee mortality, which in turn substantially decreases yield (Devillers et al., 2003; Rabea et al., 2009; IFAS, 2012). Less toxic pesticides used in lowbush blueberry farms are DiPel and Foray, as well as Assail and Delegate if sprayed at dusk and dawn.

Pesticides have a positive effect on yield as they eliminate pests that destroy the farmer's crop. However, this increase in yield due to the use of a pesticide was rarely quantified in the literature. There was extensive precise data on the pest threshold needed to start spraying pesticides through various Integrated Pest Managements and independent studies (Meyer and Cline, 1997; Agriculture, Aquaculture, and Fisheries, 2011; Agriculture, Aquaculture, and Fisheries, 2012; Burgess and Wood, 2012; Agriculture, Aquaculture, and Fisheries, 2013; D'Apollonio-Cote et al., 2013), but less information on how much reduction of yield will occur or even the percentage of plants in the crop that would be damaged in the event of an infestation.

An exception was a study that showed that blueberry thrips usually only need spot treatments but the pest may cause up to 50% loss in yield if a large infestation occurs (Pest

Management Centre, 2011). The other few papers that mention yield when describing pest infestation merely mention that the presence of a pest above the pest threshold will decrease blueberry yield (Yarborough and Drummond, 2009; Ramanaida, 2010; Pest Management Centre, 2011; Agriculture, Aquaculture, and Fisheries, 2013). One reason for this is that there are many other factors that affect yield including diseases, weeds, and even other pests (Ramanaida, 2010), and thus it is difficult to quantify effects of specific pests on yield. Therefore, it is difficult to compare the potential loss of yield to pests with the potential loss of yield to pesticides.

One consequence of pesticide application could be local extirpation of an entire bee community. However, this could create a sink which would attract other bees to colonize the area as soon as the residue from the pesticide vanishes. Accounting for the possibility of re-colonization was beyond the scope of this project. As such, the effects of the pesticide toxicity on yield may be overestimated; therefore further research on this topic should be conducted.

Two of the pesticides that Farmer 3 and 7 used frequently between 2005 and 2009 were Imidan and Decis, which are both categorized as highly toxic to bees. When interviewed, neither farmer knew the toxicity levels of the pesticides they used on bees even though they instinctively understood how pesticides and chemicals in general could be harmful to bees (Farmer 3 per. comm.; Farmer 7 per. comm.). This is congruent with the literature, which suggests a lack of awareness and concern about the side effects of pesticides by conventional farmers (McCann et al., 1997; Thompson, 2001). This is a concern as the farmers did not search for the information before using the products even though this information is available to consumers on the internet and sometimes on the pesticides labels themselves. Labels can be difficult to interpret due to the technical terminology and being unsure if the warnings are relevant or only worse case scenarios.

Therefore, making comparative charts, such as one based on Table 6, widely available to farmers could help farmers make smart choices with regards to pesticide use in the future.

Imidan and Decis affect bees in different ways, even though both pesticides are considered highly toxic to bees. Imidan is an organophosphate, which is an older class of pesticides commonly used on blueberry crops. It is used to control blueberry spanworm and blueberry fruit fly outbreaks (D'Apollonio-Cote et al., 2013) on contact within the first 24 hours of the product being sprayed (Barry et al., 2005), and only require 1-2 field treatments of Imidan per year to keep the pest under control (Gowan Company, 2014). This class of pesticide uses a toxin that broadly affects multiple species by inhibiting the breakdown of a very abundant and important neurotransmitter, acetylcholine, which is found in many animal species (Fjordboge et al., 2013). This makes organophosphates highly toxic to mammals, aquatic life and insects, including all bees (Fjordboge et al., 2013) and therefore Imidan should be completely avoided if fields are close to streams, wetlands, and ponds.

However, the upside of organophosphates is that they have a short environmental persistency as they quickly biodegrade in soil and through chemical hydrolysis of dissolved compounds (Fjordboge et al., 2013). As such, if farmers still want to use Imidan, they should try to spray this chemical at early dawn when many insects and mammals, including bees, are still dormant for the night. This will allow for the Imidan to evaporate quickly as the sun rises and reduce contact with non-target species as much as possible. Furthermore, these chemicals should not be sprayed in high winds as this could result in the spread of the chemical over the edges of the field and onto other fields surrounding the target area.

Decis is a pyrethroid pesticide, which is a synthetic pesticide extensively used in agriculture including blueberry crops, mostly to remove blueberry leaftiers (Johnson et al., 2006). Decis kill blueberry leaftiers on contact within the first 24 hours of the product being sprayed (Ramanaidu et al., 2011), and only require 1-2 field treatments per year to keep the pest under control (Bayer, 2014). This type of pesticide disrupts the insects' nervous system by prolonging the time sodium is allowed to enter the neuron, which results in muscle spasms and paralysis, leading to death (Johnson et al., 2006; Gill et al., 2012). Pyrethroids, including Decis, do not harm as many non-target species as the organophosphate Imidan (Johnson et al., 2006). However, they persist in nature for a long time, therefore there is no time of day that this pesticide could be sprayed to try to avoid contact with any of the non-target species.

I suggest that the use of both Imidan and Decis should be avoided. Assail and Delegate, which are only moderately toxic to bees, also control blueberry spanworms and blueberry fruit flies as well as an array of other pests (IFAS, 2012). These chemicals could be sprayed at dawn and dusk to avoid direct contact of these pesticides with bees while still effectively eliminating the target pests. Furthermore, Dipel, which has low toxicity to bees, also control blueberry spanworms (IFAS, 2012), and because its toxicity is low, it can be sprayed at any time of day while having much less negative effect on bees and other non-target species as Imidan.

Unfortunately, Decis is the only pesticide in this study that controls blueberry leaftier (Table 6). As such, farmers who have an outbreak of blueberry leaftiers must continue to use Decis to control this outbreak. However, due to its toxicity to bees, I suggest that this pesticide should only be used if there is an outbreak and not applied every year as a preventative measure as Farmer 7 has done on his field from 2005 to 2009 in this study.

Furthermore, pesticides that had high toxicity to bees tend to only eliminate 1 to 2 types of pests such as Imidan and Decis, whereas some moderate and low toxic pesticides eliminated up to 4 types of pests, such as Assail and Delegate (Table 6). This further increases the benefits of using moderate and low toxic pesticides to bees as multiple pests can be eliminated by a single pesticide. This would reduce costs of pesticides and labour. Moreover, reducing the number of pesticides applied would reduce the necessity of washing the boom sprayer to remove any cross-contamination of chemicals and changing the type or distance between the nozzle heads.

Third Objective

The 3 main factors that altered farmer's profit margins in the baseline budget were yield, wholesale price, and bee hive rentals. Farmers could use chemicals only when an outbreak occurs instead of applying set amounts as a preventative measure to influence their profits, and this would greatly vary the yearly costs. Some costs are inflexible, such as bee rental costs a number of hives they should rent per acre as the Canadian Honey Council (2013) recommends 2 hives of honeybees should be placed on every acre. Current prices of honeybee hive rentals are $90-$120 /hive and may even be higher if honeybee shortages occur (Canadian Honey Council, 2013). This results in a cost of $180-$240 /acre. Farmer's do, however, have the option of looking to rent other bee species to pollinate their crops, such as leafcutting bees (Stubbs et al., 2007).

The main concern for the farmers who were interviewed was crop yield. This is because there is a strong and direct link between yield and income. The common practices that Farmers 3 and 7 used to increase their profit margins were to increase the amount of hives rented per acre, rent different bee species in the same year, spray chemicals that prolong blueberry growth, and

making more suitable habitats for native bees to settle around their fields. The farmers also attempted to increase yield by using chemicals for weed control, fertilization, pest control, and for bee hive rentals, which was congruent with farmers' practices in the literature (Yarborough, 2004). Choosing to rent different bees species, increasing suitable habitat for native bees and using Bravo to prolong blueberry growth all seem to be relatively novel ideas that were either mentioned to them during conversations with Steve Javorek or through their own observations.

The farmers interviewed had never made baseline budgets for their blueberry production, and found it difficult to estimate relative costs and yields of individual fields. This is probably due in part to lack of training. All that really mattered to Farmer 3 and 7 was increasing yield from year to year. It is a common practice for yield to be the driving factor in agricultural production (Yarborough, 2004; Strik and Yarborough, 2006). As such, farmers tend to increase chemical use, bee rentals, field size, and even dictate the configuration of their field in hopes that it will increase their yield (Yarborough, 2004; Strik and Yarborough, 2006). However, if farmers were trained how to conduct bi-yearly baseline budgets for every field, they would have a better idea of what cost-effective changes could be made to have the largest effect on yield. These budgets would also benefit them by helping identify whether they are making or losing money, where their largest costs reside and, how much money they need as crop revenue in order determine their breakeven point.

Fourth Objective

Interviews with Farmer 3 and 7 indicated that there has historically been a disconnect between research that was done on their fields and the communication of the results to the participant farmers. Descriptions of the gap between science and implementation have often been

noted (Eagle et al., 2003; Temperton et al., 2004; Wandersman et al., 2008; Green et al., 2009). To amend this issue in my thesis, I will include a dissemination component at the end of my research project. Dissemination is the conscious effort to spread new knowledge, policies, practices learned to either specific audiences or to the public at large (Green et al., 2009). However, when dissemination of a project does occur, it often misses the mark of what the target audience wants and needs as the implementation was developed without considering the context in which it would be applied (Green et al., 2009). My interviews with farmers regarding their interpretation of my study results demonstrate that communicating with a sample of the target audience before dissemination would reduce this gap by allowing scientists to tailor the project dissemination to what the target audience really wants and needs.

Furthermore, reviewing results with producers can also benefit scientists as it may enrich the quality of the researcher's results. The farmers noticed that the original price for blueberries in the analyses was the retail price and not the wholesale price, which was corrected in the analysis of this Thesis. Farmer 3 provided a presentation on how the blueberry harvesters became more efficient than before. Farmer 3 also mentioned that adding sprout year to the baseline budget would be helpful. In addition, both farmers provided lots of information about the cost of chemicals and services, making the budget much more accurate than it would have been without their help. These were all included in the baseline budget (Table 9). These interviews also indicated their lack of knowledge on how to prepare baseline budgets, and whether the farmer was making or losing money on their field for any given year.

These interviews also demonstrated relatively low computer literacy. It is not unusual for farmers to have poor computer skills (Doye et al., 2000; Doye, 2004; Alvarez and Nuthall,

2006). This is especially true for older and less educated farmers (Doye et al., 2000; Doye, 2004; Alvarez and Nuthall, 2006). Therefore, scientists cannot assume that farmers are computer literate or even have internet access for disseminating results. As such, communicating with farmers before the research is done, and understanding the knowledge base of the target audience, would be extremely important to any research. Researchers would be able to ensure that the results would be presented to practitioners or managers in a manner that is easily understood, relevant to their audience, and tailored to the audience's needs.

Study limitations

I was unable to evaluate the impact that a single bee species had on the yield of the 7 fields in my study due to colinearity. The colinearity was probably due to the small sample size as well as the fact that there was a close positive relationship between the abundance of one bee species with the abundance of all the other bee species examined. Furthermore, factors that influenced yield other than bee pollination in Table 6 could not be accurately calculated due to my inability to account for potential bee recolonization after pesticides were sprayed, as well as the potential loss in yield due to pest infestation if pesticides were not used. This test should be conducted at a later date when more data has been collected and an experiment has been designed specifically to test the true contribution of these factors.

I was also unable to determine the effects of other environmental factors, such as the frequency of high winds preventing bee foraging, late spring frost killing crops, high winds in the winter damaging crops, disease and pest infestation, and crop loss due to predators eating the blueberries on blueberry yield. Furthermore, increasing field margins would increase native bee abundances and thereby increase yield through pollination. However, it is unknown whether

increasing field margins might have other unintended negative consequences such as, increase chances of pest infestation and plant invasion.

Potential Trade Offs Between Linear Fields and Square Fields

Switching from a more conventional square field to a linear, or long and narrow field, might have both positive and negative consequences. Long and narrow fields would decrease the distance of the middle of the field to the edge of the field. As such, the native bees that live along the field margins would be able to forage and pollinate the middle of the field, thereby reducing their dependence on hive rentals (Ricketts et al., 2008). This is a considerable benefit for a farmer as hive rentals was one of the most expensive factors in the baseline budget that greatly affected their profit margins (Table 9). A change to linear fields would also increase the amount of edges around the field, which is very beneficial to bumblebees as they nest in natural and semi-natural habitats located in the field margins and shrubby wooded areas surrounding the crop field (Ricketts et al., 2008). Furthermore, these edges support a diverse array of plants and flowers that help sustain bumblebees and other native bee communities, by providing alternate food sources once the blueberry bloom is over and during sprout year when the blueberry plants do not flower (Steffan-Dewenter and Westphal, 2008; Garibaldi et al., 2011).

Field shape is unlikely to change habitat area for *Andrena* species as they are soil nesting bees that live within the blueberry fields (Javorek et al., 2002). However, *Andrena* bees would also benefit from the increase in wild flowers in the field margins, as this bee species would be able to sustain their population size during sprout year when the blueberries do not flower, by foraging in the field margins.

However, having more edges around a field may also increase the chance of pest infestation, fungal growth, and especially plant invasion (Hoehn et al., 2010). Pests and fungi often enter fields through the surrounding forest and field margins (Mize et al., 2008; Dzybov, 2007). Similarly, vascular plant invasion is probably the most common problem when increasing field margins as there is no barrier preventing the plants living along the field from expanding into the field (Hoehn et al., 2010). As such, increasing field margins by having linear fields may increase pesticide expenses, which may outweigh savings from reducing hive rentals.

Trees surrounding the field, especially a forest, can be very beneficial to the farmer. During the winter, these trees block much of the high winds that often occur in PEI, which reduces the damage on the blueberry plant foliage (Mize et al., 2008; Dzybov, 2007). These trees also trap the snow and increase snow deposits on the field which increase the plant foliage protection from the high winds as well as increase the hydration of the field during spring when the snow melts (Mize et al., 2008). During blueberry bloom, these trees continue to block the wind, which allow bees to fly and forage even on days of high winds and also increase the temperature on the field (Hoehn et al., 2010; Mize et al., 2008), which further helps bees with less tolerance to temperature to forage. These positive effects of trees are greatly increased in linear fields compared to square fields as the distance between tree lines are closer.

Furthermore, the configuration of the linear field may also bring about some downfalls. If the field is an irregular shape with many twists and turns, it may be harder to mow the crop down, spray the chemicals evenly across the field, and also increase harvesting time due to difficulties in managing large commercial farm machinery. As such, farmers should take these points into consideration when buying land and determining the configuration of linear fields.

Chapter 6: Management Implications

Identifying the most effective pollinators for other agricultural crops, as done in the study Javorek et al. conducted in 2002, would be recommended as honeybees may not be the best pollinator for many agricultural crops. To ensure that scientific results can be applied to management decisions on the ground, results should be communicated to land managers and practitioners using clear simplified language free of scientific terminology.

Farmers who want to increase their field size should consider increasing the amount of edges in their field as well as try to decrease the amount of the field that is inaccessible by native bees (Garibaldi et al., 2011). Otherwise, farmers who increase field size in attempt to increase their production output may also increase their dependence on renting managed bees to pollinate the middle of their crops (Ricketts et al., 2008). One easy way to increase edges and decrease the amount of field size inaccessible to native bees would be to make the crop area long and narrow while maintaining lots of field margins and shrubby wooded areas available around the field.

Farmers should try to use low toxic pesticides such as pesticides that use *Bacillus thuringiensis* (Bt) as the active agent, or should use moderately toxic pesticides that are sprayed at dusk or dawn when they will have less direct contact with bees (Devillers et al., 2003; George and Neil, 2012). This will reduce the negative impact of pesticides on bees and therefore increase the pollination of their crops.

All the chemicals commonly used in lowbush blueberry farming in PEI should be aggregated together in a spreadsheet similar to Table 6 of the toxicity levels to bees and distributed as part of the welcome package for each farmer that attends the annual blueberry

farming conference. This would be a cheap and easy method for spreading the information in a way that is more accessible to farmers as they do not have to go on a computer nor would have to look at all of their pesticide labels that they have already purchased. According to Farmer 3 and 7, most of the blueberry farmers attend this conference every year so this would be a convenient venue to distribute such information to the largest amount of farmers possible.

Lowbush blueberry farmers would benefit from conducting bi-yearly baseline budgets for every field that they own. In the ideal case, I suggest that a short workshop should be conducted with each farmer individually to learn how to fill out a baseline budget either on the computer or using print out copies of the budget. If the time and money is not available for this, then the skeleton baseline budget should be provided to every farmer with a short 1-2 page explanation on how to fill out the budget for future use. Again, providing this skeleton and explanation as part of farmers welcome package for the annual blueberry conference might be a very good way to provide the information to as many farmers as possible in an easy and inexpensive manner.

My research demonstrated a disconnect between scientific research and farmers' knowledge. First, my results show that the notion of native bees being the best pollinator is contrary to agricultural standards as North American farmers and bee keepers have always believed that honeybees were the best pollinator for their crops (Vance 2011; Farmer 3 pers. comm.; Farmer 7 pers. comm.). Second, farmers were not aware of the toxicity level of the pesticides they used on bees. Third, farmers indicated that they found it difficult to understand research results presented to them from previous studies. This could be resolved by disseminating results of scientific studies to the study participants and the targeted audience in a manner that is understandable to the audience given their background. To accomplish this goal in

the context of the present study, I will disseminate my results to the participants of my research in a short 3-4 page paper with attractive pictures and layout while ensuring all terminology, and tables are easy to understand and useful to farmers.

In general, farmers would benefit from concentrating their efforts on promoting bumblebee and *Andrena* populations to flourish in their fields for maximum pollination effects. This relationship is facilitated by having small or narrow fields so that the native bees are able to pollinate the entire field. Furthermore, farmers should use pesticides with low toxicity levels to bees as to ensure the propagation of their bees. To ensure that farmers are aware of these recommendations, venues other than scientific journals should be used to communicate scientific research results with the target audience.

References

Agriculture and Agri-Food Canada. 1988. Soil of Prince Edward Island. Prince Edward Island Government.

Agriculture, Aquaculture and Fisheries. 2010. Growth and development of the wild blueberry. New Brunswick Provincial Government.

Agriculture, Aquaculture, and Fisheries. 2011. Wild blueberry weed control selection guide. New Brunswick Provincial Government.

Agriculture, Aquaculture and Fisheries. 2012. Wild blueberry IPM weed management guide. New Brunswick Provincial Government.

Agriculture, Aquaculture, and Fisheries, 2013. Blueberry spanworm: *Speranza agrillacearai* (Packard). New Brunswick Provincial Government.

Alvarez, J., and P. Nuthall. 2006. Adoption of computer based information systems: The case of dairy farmers in Canterbury NZ, and Florida, Uruguay. *Computers and Electronics in Agriculture*. 50:48-60.

Barry J.D., W.J. Sciarappa, L.A.F. Tiexeira, and S. Polavarapu. 2005. Comparative effectiveness of different insecticides on organic management blueberry maggot (*Diptera: Tephritidae*). *Journal of Economic Entomology*. 98:1236-1241.

Bayer. 2014. Bayer Crop Science: Decis Horticulture. www.cropscience.bayer.ca

Bobiwash, K. 2012. Pollination ecology of lowbush blueberry (*Vaccinium angustifolium*): The role of introduced pollinator communities, self-fertilization, and somatic mutations on fruit set response. McGill University.

Bowring, F. 2003. Manufacturing scarcity: Food biotechnology and the life sciences industry. *Capital and Class*. 79:107-146.

Burgess, P., and S. Wood. 2012. Guide to weed management in wild blueberry. Agra Point International.

Community Action Publications. 2012. True Costs of Pesticides. Retrieved from: http://www.organicvalley.coop/fileadmin/pdf/ag_costs_IJAS2004.pdf

Canadian Honey Council. 2013. Managing Bees For Pollination. Retrieved from: http://www.honeycouncil.ca/managing_bees_for_pollination.php

Cavuta, G. 2006. Environmental goods valuation: The total economic value. University of Chieti, Italy.

Creswell, J. W. 2003. Research Design: Qualitative, Quantitative and Mixed Methods Approaches. 2nd Edition. Sage Publications Inc. Thousand Oaks, California.

D'Apollonio-Cote, J., D.E. Yarborough, F. Drummond. 2013. 2013 Maine wild blueberry pesticide chart. University of Maine Cooperative Extension.

De Groot, 1992. Functions of nature, evaluation of nature in environmental planning, management and decision making. Wolters-Noordhoff, Netherlands.

Delbridge, R., and D. Rogers. 2012. Wild blueberry insect & disease management schedule. Agra Point International.

Demscombe, M. 2008. Communities of practice: A research paradigm for mixed methods approach. *Journal of Mixed Methods Research*. 2:270-284.

Devillers, J., A. Decourtye, H. Budzinski, M.H. Pham-Delegue, S. Cluzeau and G. Maurin. 2003. Comparative toxicity and hazards of pesticides to Apis and non-Apis bees. Achemometrical Study. SAR and QSAR in Environmental Research. 14:389-403.

Doye, D.R.2004. The use of electronic technology in teaching farm record technology. American *Journal of Agricultural Economics*. 86:762-766.

Doye, D., R. Jolly, R. Hornbaker, T. Cross, R. P. King, W. F. Lazarus, and A. Yeboah. 2000. Case studies of farmers' use of information systems. *Applied Economic Perspectives and Policy*. 22:566-585.

Dreisig, H. 1995. Ideal free distributions of nectar foraging bumblebees. *Oikos*. 72: 161-172.

Drummond, F.A., J.A. Collins, B. Choate, D. Woodman, D.T. Jannings, H.Y. Forsythe, Jr. and J.C. Cokendolpher. 2010. Harvestman (Opiliones) fauna associated with Maine lowbush blueberry fields in the major production areas of Washington and Hancock counties. *Entomological Society of America*. 39:1428-1440.

Drummond, F.A., J.M. Sagula, D. Yarborough and S. Annis. 2012. Organic lowbush blueberry research and extension in Maine. *International Journal of Fruit Science*. 12:216-231.

Dukas, R. and L. Edelstein-Keshet. 1998. The spatial distribution of colonial food provisioners. *Journal of Theoretical Biology*. 190:121-134.

Dzybov, D.S. 2007. Steppe field shelterbelts: A new factor in ecological stabilization and sustainable development of agrolandsacpes. *Russian Agricultural Science*. 2:51-53.

Eagle, K.A., A.J. Garson, and C. Sennett. 2003. Closing the gap between science and practice: The need for professional leadership. *Health Affairs*. 22:196-201.

Eaton, L.J. and V.O. Nams. 2006. Second cropping of wild blueberries: Effects of management practices. *Canadian Journal of Plant Science*. 86:1189-1195.

Encyclopedia of Canadian Provinces. 2007. Prince Edward Island. Retrieved from: http://www.nationsencyclopedia.com/canada/Nunavut-to-Yukon/Prince-Edward-Island.html

Faculty of Agriculture, Dalhousie University. April 8th, 2014. Improving the efficiency of commercial wild blueberry harvester using precision agriculture technologies: Precision agriculture research program. Engineer Depertment.

Fielding, N. 2010. Mixed methods research in the real world. *International Journal of Social Research Methodology*. 13:127-138.

Find The Best©. 2013. Vaccinium angustifolium Plant: Lowbush Blueberry. Retrieved from: http://plants.findthedata.org/l/1593/Vaccinium-angustifolium

Fjordboge, A.S., A. Baun, T. Vastrup, and P. Kjeidsen. 2013. Zero valent iron reduces toxicity and concentrations of organophosphate pesticides in contaminated ground water. Chemosphere. 90:627-633.

Food and Agriculture Organization of the United Nations (FAO). 2006. Economic valuation of pollination services: Review of methods.

Gallai, N. J.-M. Salles, J. Settele and B.E. Vaissiere. 2007. Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. *Ecological Economics*. 68:810-823.

Garibaldi, L.A., I. Steffan-Dewenter, C. Kremen, J.M. Morales, R. Bommarco, S.A. Cunningham, L.G. Carvalheiro, N.P. Chacoff, J.H. Dudenhoffer, S.S. Greenleaf, A. Holzschuch, R. Isaacs, K. Krewenka, Y. Malndelik, M.M. Mayfeild, L.A. Morandin, S.G. Potts, T.H. Ricketts, H. Szentgyorgyi, B.F. Viana, C. Westphal, R. Winfree and A.M. Klein. 2011. Stability of pollination services decreases with isolation from natural areas despite honey bee visits. *Ecology Letters*. 14:1062-1072.

George, Z. and N. Crickmore. 2012. *Bacillus thuringiensis* Biotechnology. Chapter 2: Bacillus thuringiensis applications in agriculture. Estibaliz San Sinenea Editor. pp 19-39.

Gervais, J-P., R. Lambert and F. Boutin-Dufresne, 2001. On the demand for information services: An application to lowbush blueberry producers in eastern Canada. *Canadian Journal of Agriculture Economics.* 49:217-232.

Gill, R.J., O. Ramos-Rodriguez and N.E. Raine. 2012. Combined pesticide exposure severely affects individual- and colony-level traits in bees. *Nature*. 491:105-109.

Government of Canada. 2013. Daily Data Report. Retrieved from: http://climate.weather.gc.ca/climateData/dailydata_e.html?StationID=6526&timeframe=2&Year=2005&Month=5&cmdB1=Go#

Gowan Company. 2014. Imidan 70-W. www.gowanco.com

Grant, S.M. 2008. The importance of biodiversity in crop sustainability: A look at monoculture. *Journal of Hunger and Environmental Nutrition*. 1:101-109.

Green, L.W., J.M. Ottoson, C. Gracia, and R.A. Hiatt. 2009. Diffusion theory and knowledge dissemination, utilization, and integration in public health. *Annual Review of Public Health.* 30:151-174.

Hardin, J. W. & Hilbe, J. M. 2003. Generalized Estimating Equations. Chapman and Hall, New York.

Hoehn, P., I. Steffan-Dewenter, and T. Tscharntke. 2010. Relative contribution of agroforestry, rainforest and openland to local and regional bee diversity. *Biodiversity Conservation*. 19:2189-2200.

Ivankova, N.V., Creswell, J.W. and S.L. Stick. 2006. Using mixed-methods sequential explanatory design: From theory to practice. *Field Methods*. 18:3-20.

Javorek, S.K., K.E. MacKenzie and S.P. Vander Kloet. 2002. Comparative pollination effectiveness among bees (Hymenoptera: Apoidea) on lowbush blueberry (Ericaceae: *Vaccinium angustifolium). Ecology and Population Biology*. 95:345-351.

Johnson, R.B. and A.J. Onwuegbuzie. 2004. Mixed methods research: A paradigm whose time has come. *Educational Researcher*. 33:14-26.

Johnson, R.M., Z. Wen, M.A. Schuler, and M.R. Berenbaum. 2006. Mediation of pyrethroid insecticide toxicity to honeybees (Hymenoptera: Apidae) by Cytochrome P450 Momooxygenases. *Journal of Economic Entomology*. 99:1046-1050.

Jordan, Chris. 2003. Pollination demonstration plots in PEI lowbush blueberry fields. Agriculture and Forestry. Prince Edward Island Government.

Keough, S.M. and K.J. Shanahan. 2008. Scenario planning: Towards a more complete model for practice. *Advances in Developing Human Resources*. 10:166-178.

Koper, N., and M. Manseau. 2009. Generalized estimating equations and generalized linear mixed-effect models for modelling resource selection. *Journal of Applied Ecology*. 46:590-599.

Koper, N., and M. Manseau. 2010. A guide to developing resource selection functions from telemetry data using generalized estimating equations and generalized linear mixed models. *Rangifer*. 20:195-204.

Kremen, C., S.W. Adelman, B. Bugg and R. Thorp. 2001. Conserving and restoring pollination services in organic farms of Yolo and Solano Counties, North California, Wildlife Conservation Society. Department of Biological Sciences, Stanford University.

Kremen, C., N. M. Williams, and R. W. Thorp. 2002. Crop pollination from native bees at risk from agricultural intensification. *Proceedings of the National Academy of Science*. 99:16812-16816.

Leech, N.L. and A.J. Onwuegbuzie. 2009. A topology of mixed methods research designs. *Quality and Quantity*. 43:265-275.

MacKinnon, W. August 31, 2011. Provincial government develops honey bee initiative. Prince Edward Island Government. Retrieved from: http://www.gov.pe.ca/agriculture/index.php3?number=news&newsnumber=8012&dept=&lang=E

MacNulty, C. 1977. Scenario development for corporate planning. *Futuribles.* 9:128-138.

Mayes, M.A., G.D. Thomson, B. Husband, M.M. Miles. 2003. Spinosad toxicity to pollinators and associated risk. *Reviews Environmental Contamination and Toxicology*. 179:37-71.

McCann, E., S. Sullivan, D. Erickson, and A De Young. 1997. Environmental awareness, economic orientation, and farming practices: A comparison of organic and conventional farmers. *Environmental Management*. 21:747-758.

Mertens, D.M. 2007. Transformative paradigm: Mixed methods and social justice. *Journal of Mixed Methods Research*. 1:212-225.

Meyer, J.R., and W.O Cline. 1997. Blueberry pest management: A seasonal overview. North Carolina State University.

Millennium Ecosystem Assessment. 2003. Ecosystem and human well-being a framework working group of the Millennium Ecosystem Assessment. Island Press, Washington, DC.

Mize, W.C., J.R. Brandle, M.M Schoeneberger, and G. Bentrup. 2008. Towards Agroforestry Design Volume 4. Chapter 3: Ecological Development and Function of Shelterbelts in Temperate North America. Shibu Jose and Andrew M. Gordon. pp 27-54.

Molina-Azorin, J.F. 2011. The use and added value of mixed methods in management research. *Journal of Mixed Methods Research*. 5:7-24.

Morandin, L.A., M.L. Winston, M.T. Franklin and V.A. Abbott. 2005. Lethal and sub-lethal effects of spinosad on bumble bees (*Bombus impatiens* Cresson*). Pest Management Science*. 61:619-626.

Mullin, C.A., M. Frazier, J.L. Frazier, S. Ashcraft, R. Simonds, D. van Engelsdorp and J.S. Pettis. 2010. High levels of miticides and agrochemicals in North American apiaries: Implications for honey bee health. *Pest Management Science*. 5:1-19.

Mussell, A., I. Rajcan, J. Sweetland, and P. Burgess. 2013. Benchmarking Atlantic blueberry farms. George Morris Centre.

Naug, D. 2009. Nutritional stress due to habitat loss may explain recent honey bee colony collapse. *Biological Conservation*. 10:2369-2372.

Paredes-Lopez, O., M.L. Cervantes-Ceja, M. Vigna-Perez and T. Hernandez-Perez. 2010. Berries: Improving human health and healthy aging, and promoting quality life – A review. *Plant Foods Human Nutrition*. 65:299-308.

Parsons, C. February 23, 2012. Bee supply better for 2012 almond pollination. Western Farm Press. Retrieved from: http://westernfarmpress.com/markets/bee-supply-better-2012-almond-pollination

Pearce, D.W. and R.K. Turner. 1990. Economics of natural resources and the environment. Harvester Wheatsheaf, Herfordshire, UK.

PEI: Department of Agriculture. 2011. Agriculture for Prince Edward Island. Retrieved from: http://www.gov.pe.ca/af/agweb/index.php3?number=71208

Pest Management Center. 2011. Crop profile for lowbush blueberry in Canada. Agriculture and Agri-Food Canada.

Prouse, C. 1996. Identifying and assessment blueberry land. PEI Department of Agriculture and Forestry.

Province of Nova Scotia. 2013. Frozen berry report. Retrieved from: http://www.novascotia.ca/agri/marketing/wmreport/frozblue.shtml

Rabea, E.I., H.M. Nasr and M.E.I. Badawy. 2010. Toxic effect and biochemical study of chlorfluazuron, oxymatrine, and spinosad on honey bees (*Apis mellifera*). *Archives of Environmental Contamination Toxicology*. 58:722-732.

Ramanaida, K. 2010. Blueberry spanworm, *Itame agrillacarai* (Packard) and bumblebee, Bombus impatiens (Cresson) susceptibility to new biorational insectidices. Nova Scotia Agricultural College.

Ramanaidu, K., JM. Hardman, D.C. Percival, G.C. Cutler. 2011. Laboratory and field susceptibility of blueberry spanworm (Lepidoptera: Geometridae) to conventional and reduced-risk insecticides. *Crop Protection*. 30:1643-1648.

Rhodes, J. 2006. Honey bee pollination of blueberries. NSW Department of Primary Industries.

Ricketts, T.H., J. Regetz, I. Steffan-Dewenter, S.A. Cunningham, C. Kremen, A. Bogdanski, B. Gemmill-Herren, S.S. Greenleaf, A.M. Klein, M.M. Mayfield, L.A. Morandin, A. Ochieng and B.F. Viana. 2008. Landscape effects on crop pollination services: Are there general patterns? *Ecology Letters*. 11:499-515.

Sanderson, K., L. Eaton, M. Melanson, S. Wyand, S. Fillmore and C. Jordan. 2008. Maritime provinces wild blueberry fertilizer study. *International Journal of Fruit Science*. 8:52-62.

Santiago, J.P. and J.M. Smagula. 2012. Gymsum rate evaluation for wild lowbush blueberry (*Vaccinium angustifolium* Ait.) soils. *International Journal of Fruit Science*. 12:23-34.

Steffan-Dewenter, I. and C. Westphal. 2008. The interplay of pollinator diversity, pollination services and landscape change. *Journal of Applied Ecology*. 45:737-741.

Strik, B.C. and D. Yarborough. 2006. Blueberry production trends in North America, 1992 to 2003, and predictions for growth. *HoriTechnology*. 15:391-398.

Summer, D.A. and H. Boriss. 2006. Bee-economics and the leap in pollination fees. University California, Giannini Foundation.

Sylvester, K.M. 2009. Ecological frontiers on the grasslands of Kansas: Changes in farm scale and crop diversity. *Journal of Economic History*. 69:1041-1062.

Szajdek, A. and E.J. Borowska. 2008. Bioactive compounds and health-promoting properties of berry fruits: A review. *Plant Foods Human Nutrition*. 63:47-156.

Taylor and Gerrodette. 1993. The uses of statistical power in Conservation Biology: The Vaquita and Northern spotted owl. *Conservation Biology*. 7:489-500.

Temperton, V.M., R.J. Hobbs, T. Nuttle, and S. Halle. 2004. Assembly Rules and Restoration Ecology: Bridging the Gap Between Theory and Practice. Society for Ecological Restoration International. Island Press. Washington DC.

Thompson, H.M. 2010. Risk assessment for honey bees and pesticides: Recent developments and 'new issues'. *Pest Management Science*. 66:1157-1162.

Thompson, P.B. 2001. The reshaping of conventional farming: A North American perspective. *Journal of Agricultural and Environmental Ethics*. 14:217-229.

Tscharntke, T., A.M. Klein, A. Kruess, I. Steffan-Dewenter and C. Thies. 2005. Landscape perspectives on agricultural intensification and biodiversity: Ecosystem service management. *Ecology Letters*. 8:857-874.

United States Department of Agriculture Forest Service. 1991. Fire effects information system: Vaccinium angustifolium. Retrieved from: http://www.feis-crs.org/beta/

United States Global Resources. 2014. Agribon+ floating cover row for cold and frost protection. Retrieved from: http://www.usgr.com/net-fabrics/agribon_plus_floating_row_covers.php

University of Maine. 2010. Cooperative extension: Maine wild blueberries factsheets. Retrieved from: http://umaine.edu/blueberries/factsheets/

Vance, E. November 28, 2011. Native bees may hold key to world's pollination problems. Western Farm Press. Retrieved from: http://westernfarmpress.com/management/native-bees-may-hold-key-world-s-pollination-problems

Wandersman, A., J. Duffy, P. Flaspohler, R. Noonan, K. Lubell, L. Stillman, M. Blachman. R. Dunville. J. Saul. 2008. Bridging the gap between prevention research and practice. The interactive systems framework for dissemination and implementation. *American Journal of Community Psychology*. 41:171-181.

Western Farm Press. August 8, 2008. Agriculture production costs on the rise, according to new Rabobank report. Western Farm Press. Retrieved from: http://westernfarmpress.com/agriculture-production-costs-rise-according-new-rabobank-report

Westphal, C., I. Steffan-Dewenter and T. Tscharntke. 2006. Foraging trip duration of bumblebees in relation to landscape-wide resource availability. *Ecological Entomology*. 31:389-394.

Wyman's. 2012. A leader in berry growing and processing. Retrieved from: www.wymans.com

Wilson, C. 2000. Environmental and human costs of commercial agriculture production in South Asia. *International Journal of Societal Economics.* 27:816-846.

World Health Organization (WHO). 2002. Reducing risks and promoting healthy life.

Yarborough, D.E. 2004. Factors contributing to the increase in productivity in wild blueberry industry. *Haworth Press Inc.* 3:33-43.

Yarborough, D. and F. Drummond. 2009. A pocket guide to IPM scouting in wild blueberries. University of Maine.

Zhu, Y., Y. Wang, H. Chen and B.-R. Lu. 2003. Conserving traditional rice varieties through management for crop diversity. *Bioscience.* 52:158-163.

Appendix I

Summary of the raw data on bee abundance and blueberry yield for the 7 fields in this study situated in PEI for 2005, 2007, and 2009.

	Bumblebee	**Andrena**	**Honeybee**	**LCB**	**Total Yield**	**Yield/acre**
Average	2.33	8.27	41.55	17.44	44243	2086
Standard Deviation	3.96	8.48	21.96	29.85	27876.52	1518.49
Range	4-47	0-47	17-119	0-105	4898-78174	21-5123

Appendix II

Structured Interview Template:

Show the farmer Figure 1, bee abundances and field size. Explain to him how this figure demonstrated that managed bees were driving total bee abundances.

Show the farmer Figure 2, yield per acre and total rented hives. Explain to him that this was a weak correlation, therefore total rented hives were not a good indicator of yield.

Show the farmer Figure 3, yield per acre and honeybee hives. Explain to him that this was a strong correlation, therefore the number of honeybee hived rented was a good indicator for the farmers that did use honeybees on their field.

Show and explain how the values in Table 1, ratios of pollination rates, were calculated and what do they mean.

- Does this theoretical calculation of pollination rates change your views on which rented bee you may purchase in the future? How?
- Does it change your views on the value of native bees? How?

Show and explain Table 3, bee mortality due to pesticide use. Explain how these values were calculated and what each category represents.

- Did you know about the toxicity levels of the pesticides you use/used on bees?
- In your opinion, is this table a clear way of representing this?

Explain Table 2, the theoretical contribution of each bee species on yield. Explain how this calculation relates to the baseline budgets in the Tables to come.

Present baseline budgets budget for 2005, 2007, 2009 (Table 6, Table 9) with farmer's actual data. Explain how the costs were broken down and where these values came from.

  - What herbicides, fungicides, and pesticides did you use each year?
  - Do the estimated numbers for expenses seem correct to you at a per acre basis?
  - Are there any other major factors related to yield that I have left out?

- Does the entire presentation seem logical to you? Or is there a better way of representing my findings to one of your fellow farmers?