

CUTOVERS AS POTENTIAL SUITABLE BEE HABITATS

by

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The undersigned certify that they have read, and recommend to the Environmental Science Unit (School of Science and the Environment) for acceptance, a thesis entitled “Cutovers as Potential Suitable Bee Habitats” submitted by Jasmine R. Pinksen in partial fulfillment of the requirements for the degree of Bachelor of Science, Honours.

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Abstract

Bees are of great importance for pollinating agricultural crops and wild plant communities. Direct human activities such as urbanization, pesticide use, pollution, and introduction of species and pathogens as well as climate change are resulting in habitat loss and fragmentation for bees, causing declines in bee populations worldwide. Lack of suitable habitat is considered to be one of the main factors contributing to these declines. Commercial logging practices, such as clear-cutting, can potentially produce suitable bee habitat. Higher light levels after clear cutting may increase flowering plant diversity and abundance, and new nesting sites may be created in debris or exposed soil. Bees were collected in 2015 and 2016 in cutovers between 1 and 11 years post-harvest near Corner Brook, NL to assess bee abundance. Cutovers several years post-harvest had higher bee abundance than newly logged cutovers or those which were fairly old (i.e. 11 years post-harvest). These bee communities were made up mostly of *Bombus borealis* Kirby (Hymenoptera: Apidae), a large, long-tongued bumble bee. The vegetation of the cutovers was surveyed to determine what characteristics made a cutover most suitable for bee populations. Cutovers harvested between 2010 and 2013 had high amounts of forage vegetation while the newly logged and older cutovers had low flowering plant abundance and high unvegetated ground, making them less suitable for bees. Logging practices such as clear-cutting, considering both spatial and temporal scale to ensure appropriate successional stages and the continuous availability of suitable bee habitats within the dispersal range of target species, may help in the recovery of declining bee populations.

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Literature Review

Introduction

Bees are known to be the most important pollinator of agricultural crops and wild plant populations worldwide (Potts et al., 2010; Cameron et al., 2011; Watson et al., 2011). As pollinators, they serve a key ecological function vital for a species to persist and thus ensure ecosystem function and food for human consumption. A problem in recent years is that bee populations are dramatically declining due to human influences such as habitat loss, habitat fragmentation, pesticide use, environmental pollution, invasive species, pathogens, agricultural intensification, and urbanization (Romey et al., 2007; Goulson et al., 2008; Potts et al., 2010; Cameron et al., 2011; Hanula et al., 2015), compounded by climate change. Although there are many contributing factors to bee declines, some believe it is the lack of suitable habitats, containing essential resources, that is primarily leading to this problem (Romey et al., 2007; Goulson et al., 2008; Hanula et al., 2015).

Conservation efforts to reduce deforestation and wild fires have led to large amounts of old growth forest which lack any type of disturbance, either anthropogenic or natural (Goulson et al., 2008; Hanula et al., 2015). Forests of early succession are vital for the sustainability of bees, and methods for producing such habitats are of increasing interest (Cartar, 2005; Romey et al., 2007; Wojcik and Buchmann, 2012; Rubene et al., 2015). One option is logging, yet little is known about the impacts of logging on pollinators (Korpela et al., 2015). In order to build successful conservation strategies that will offset recent bee declines, the factors affecting patterns of species diversity and abundance in managed landscapes must first be understood.

Importance of Bees

A large number of wild and agricultural plants are pollinated predominantly or exclusively by bumble bees, honey bees, or solitary bees. In a few cases, particularly in the tropics, some plants may only be pollinated by just one species of bee (Renner and Feil, 1993). In boreal forests, plants are more commonly pollinated by small pollinator communities (Goulson et al., 2008), making each of those bee species important for the persistence of certain plants. Globally, it is the honey bee species *Apis mellifera* that accounts for the majority of agricultural pollination, increasing crop yields by up to 96% (Klein et al., 2007), which may pose a problem if the species declines.

It has been documented that native wild pollinators also play a considerable role in the pollination of agricultural crops (e.g. Goulson et al., 2008; Potts et al., 2010; Cameron et al., 2011). The value of native bee pollinators is becoming increasingly evident as populations of feral and domestic honey bees decline (Ricketts et al., 2008). Pollination by bees is necessary for 75% of all economically important crops that are used for human consumption worldwide (Klein et al., 2007). Bees are responsible for pollinating almost all fruit crops including apple, melon, and various types berries (Potts et al., 2010), and are known to be the most efficient pollinators (Hanula et al., 2015). For instance, it has been noted that bumble bees (*Bombus* Latreille (Hymenoptera: Apidae)) are more effective pollinators of some types of berries, including blueberries, than are honey bees (Cane, 1997). Pollinators play an important functional role in terrestrial ecosystems and are critical components of forest environments where wild plants, such as trees, shrubs, and understory plants, depend on pollination for fruit and seed set (Ashman et al., 2004; Potts et al., 2010; Hanula et al., 2015).

Within native plant communities, bumble bees are considered to be one of the essential wild pollinators found throughout temperate and boreal ecosystems. Bumble bees are effective pollinators due to their specific pollination behaviour, known as buzz pollination. During this pollination technique, the bee vibrates its flight muscles at a high frequency to release pollen from flowers (Harder and Barclay, 1994). This technique is important, as some plant species release very little pollen by any other method due to their morphology, making pollination unlikely by wind or other insect pollination behaviours. It is this technique that has boosted bumble bee's economic importance and recent domestication for pollinating crops such as tomatoes, that require buzz pollination (Cameron et al., 2011). Also, for some bumble bees their size and long tongue contribute to their pollinator effectiveness. Given the reputation of bumble bees as pollinators of wild and agricultural plants, steps must be taken to prevent further declines of bumble bees and other bee species as they fulfill a key ecosystem service.

Decline of Bees

Many studies focusing on bee declines have been centred around honey bees in Europe and North America (e.g. vanEngelsdorp, 2008; Jaffee et al., 2010; Potts et al., 2010; Cameron et al., 2011), perhaps due to people's familiarity with honey bees. In both the USA and Europe, an invasive species of ectoparasitic mite, *Varroa destructor* (Acari: Varoidae), has caused most wild and feral honey bees to vanish (Jaffee et al., 2010). Native bees are being indirectly affected by these commercial bees, which bring disease and accidentally introduce non-native parasites (Goulson et al., 2008). The industry of beekeeping has been increasing in recent years, but not enough to meet the increasing demand for agricultural pollination services (Aizen and Harder, 2009). Pollinator declines

reduce pollination services which can cause negative economic and ecological impacts, such as significantly affecting the maintenance of ecosystem stability, wild plant diversity, and crop production, resulting in decreased food for human consumption (Biesmeijer et al., 2006; Klein et al., 2007; Potts et al., 2010). Since bees represent the greatest source of pollination worldwide, the concern over bee declines has been increased (Williams and Osborne, 2009; Potts et al., 2010). Declining bee populations can result in reduced pollinator diversity, which has a wide range of effects on agricultural systems and natural plant communities.

As a result of global trade of domesticated bumble bee colonies from Europe to North America, commercially reared bees being used for pollination of greenhouse crops are causing serious declines in native bee populations (Kosior et al., 2007; Goulson et al., 2008). For example, studies in the United Kingdom (Goulson et al., 2008) and the United States (Cameron et al., 2011) found that one species suffering from declining populations is *Bombus terricola* Kirby (Hymenoptera: Apidae). This bee is host to parasitic bumble bee species, one of which is *Bombus ashtoni* Cresson (Hymenoptera: Apidae). Therefore, the decrease in *B. terricola* can indirectly result in the decline of its parasitic species, which relies on the host nest for a place to lay its eggs (Goulson et al., 2008; Bartomeus et al., 2013). Other specific species declines were documented in *Bombus affinis* Cresson (Hymenoptera: Apidae), and *Bombus occidentalis* Greene (Hymenoptera: Apidae) for similar reasons (Goulson et al., 2008; Cameron et al., 2011). In the United States, one hypothesis is that bumble bees are declining due to the spread of the introduced pathogen, *Nosema bombi* (Microsporidia: Nosematidae) (Larsson, 2007; Otti and Schmid-Hempel, 2008; Cameron et al., 2011).

Lack of genetic diversity may also contribute to bee declines. Within small populations, genetic diversity is often low and therefore less able to respond to stochastic environmental events because the limited genetic variation decreases the chances of individuals having appropriate adaptations. A study of North American bee species concluded that small population sizes and reduced gene flow might result in a detrimental loss of genetic diversity (Cameron et al., 2011). In small populations, there are increased risks of inbreeding and genetic drift, which could lead to increased susceptibility to environmental pressures (Zayed, 2009), making these populations more at risk of further declines.

Of the causes of bee declines, human activity appears to be the most prominent, specifically those which cause habitat loss (Brown and Paxton, 2009). Habitat fragmentation due to agricultural intensification and urbanization, climate change, pesticide use, environmental pollution, decreased resource diversity and abundance, and human introduced threats are among the factors concluded to be negatively affecting bee populations (Kremen et al., 2002; Steffan-Dewenter et al., 2002; Biesmeijer et al., 2006; Klein et al., 2007; Goulson et al., 2008; Stout and Morales, 2009; Neumann and Carreck, 2010; Potts et al., 2010; Winfree, 2010; Cameron et al., 2011; Hanula et al., 2015). Two conservation goals of the early 20th century, extensive reforestation and reduced wildfire, have led to protected forest areas in an effort to reduce cutting and limit natural disturbances such as fire (Hanula et al., 2015). This has resulted in a large increase of old growth forests (Siitonen, 2001). The problem with the lack of natural or artificial disturbance is the constant increase of forest cover, tree density, and canopy density which are not suitable habitats for bees. This has left the majority of the pollination

responsibility to the domesticated honey bees, but these bees are also declining (vanEngelsdorp et al., 2008; Jaffee et al., 2010).

Declines in bee populations may cause a negative feedback loop whereby the decrease in bees causes a decrease in pollination and thus plant populations, which would negatively affect bees, resulting in further declines. Although human activity creates potential bee habitat such as roadsides, field margins, agricultural crops, and people's flower gardens, bees are still stressed through excessive agricultural intensification, pesticide use, habitat fragmentation, and resource reductions. Cutovers might represent a novel habitat that bees could use, which could in part mitigate some of our negative impacts on them.

Logging Practices Promote Flowering Plant Diversity and Abundance

The clear cutting of forests is considered a drastic disturbance. In some cases, cutting of trees is done in a particular way to attempt to mimic natural disturbance because it is crucial to some species that rely highly on disturbed areas for nesting and food resources (Esseen et al., 1997; Angelstam, 1998). In boreal forests, fire is considered a key ecological process needed in order to maintain biodiversity (Zackrisson, 1977). Logging may be an analogue to fire, as a considerable number of forest plant and animal species rely on natural disturbance to thrive. Logging may be a suitable option to increase the desired characteristics of disturbed forests in an effort to increase flowering plant richness, and abundance, as well as general biodiversity. Clear cutting can also mimic natural disturbance, as it may uproot trees, leave soil exposed, or leave trees fallen, creating sheltered areas (Ulanova, 2000). Vegetation such as herbaceous flowering plants thrive in clear-cuttings similar to that of natural disturbance, owing to the increased

canopy opening, sunny conditions, and bare soil (Pykälä, 2004). Species richness of vascular plants has been found to be the highest at the early stages of succession (Pitkanen, 2000), like those created by clear cutting. These conditions, in some cases, are the only environments in which some rare species can flourish (Pykälä, 2004).

Like most forms of disturbance, logging results in rapid successional changes which encourages some species, but if large quantities of slash, i.e. debris such as branches left by logging activities, remain it may prolong the vegetative development (Olsson and Staaf, 1995). The strength of the slash barrier decreases over time as the slash decomposes, e.g. in Sweden there was a 30% decrease in visible cover within 6 years after logging (Olsson and Staaf, 1995). The major influence of slash on a cutover site is related to the nutrient contribution which comes from the slash itself as it decomposes, and from the mineralization of the organic matter in the underlying soil. The vegetation found on cutovers typically consists of species which favor disturbance and high nutrient availability. Other species which prefer closed canopy forest are not commonly found in logged areas, at least not during the early successional stages after the cut. These particular plants are out-colonized by the more stress-tolerant species (Olsson and Staaf, 1995). Grubb (1994) adds that the increased light reaching ground level and the decreased competition with trees may also be important contributing factors to increased plant species richness. Likewise, it has been found that logging increases the availability of nectar and pollen plants, which are crucial for promotion of several aspects of bee habitats (Korpela et al., 2015).

Bee Utilization of Disturbed Forest Areas

The idea of using logging areas as potential suitable bee habitats is of growing interest due to the awareness of the importance of open and semi-open areas for biodiversity. Many studies found that bee species diversity is highest in cleared or open forest areas due to the increase in early successional flowering plants (Cartar, 2005; Romey et al., 2007; Hanula et al., 2015; Rubene et al., 2015). This is mainly attributed to that fact that logging affects understory flowering plant communities by enhancing plant densities and species diversity resulting in an increase in bee's visiting these flowering communities (Cartar, 2005). Rubene et al. (2015) noted that the size of the clear cut was positively related to bee species richness.

Recently, there has been an increase in practices combining forest conservation goals with favorable pollinator conditions (Hanula et al., 2015). The combination of forested and cleared areas are beneficial to a variety of plants species as well as pollinators which could be considered a joint conservation goal like that of conservation goals of agricultural practices and pollinators (Ovenden et al., 1998; Kleijn and Sutherland, 2003). Several studies have shown that agricultural practices and urbanization have positive effects on bee abundance and richness (Winfree et al., 2007; Carre et al., 2009). For example, suburban areas and agricultural fields support a greater abundance of bees than forests. The greater the forest cover in an area, the lower the abundance and richness of local bee communities. This suggests that bee species richness would be maximized at an intermediate level of disturbance due to agriculture, urbanization, and logging (Winfree et al., 2007).

Other human disturbances, such as power line clearings, can be managed to provide important habitats for bees (Sydenham et al., 2016). The special characteristic of power line sites that makes them so beneficial is the removal of debris after cutting, allowing for ground exposure. In forested areas, the maintenance of power line cuts promotes an early successional vegetation habitat which is crucial for bees (Wojcik and Buchmann, 2012). This management strategy of open canopy areas increases sun exposure, benefitting thermophilic organisms like bees and enhances species richness (Sydenham et al., 2014). In addition to increased local temperature, the direct sun exposure at ground level also increases the amount of flowering plants, their density, and therefore bee foraging resources (Cartar, 2005; Sydenham et al., 2016). Since different types of bees have particular flower preferences, the increased diversity of flowering plants could attract more diverse groups of bees (Potts et al., 2003). It is thus evident that cleared areas in forested landscapes can be suitable habitats for bees. Since bee populations utilize power line clearings, it would make logical sense that logging areas may be just as, if not more, beneficial.

Fire may also increase bee diversity and abundance as it is a natural disturbance which creates early successional stages within the forest landscape. The combination of burned areas and trees left behind create a landscape more flexible to a variety of species (Pengelly and Cartar, 2010). This landscape type can possibly, to some extent, be mimicked using different logging techniques to benefit those species that thrive in this environment. One way that this can be achieved is through variable retention methods, in which a proportion of trees is left standing (Cartar, 2005; Pengelly and Cartar, 2010). Some studies have suggested that selectively cutting certain percentages of trees is more

beneficial for bees than clear cutting (Cartar, 2005; Pengelly and Cartar, 2010). Cartar (2005) suggests that the ideal level of logging for bee communities is leaving 50-75% unlogged, while Pengelly and Cartar (2010) suggests leaving 10-20% unlogged. Either way there is evidence suggesting that moderate levels of logging may be more beneficial for bees as large floral diversity and abundance still occurs under these circumstances and it normally has less negative impact. By having logged areas near fully intact forest, Pengelly and Cartar (2010) documented a decrease in bees found in forest compared to before logging occurred. This is likely attributed to the rapid increase in food and nesting resources in the logged areas. In addition to the cleared area, the fallen debris left behind after logging not only increases flowering plant diversity and abundance but may also offer suitable nesting areas for bee species which nest above ground or among the leaf litter (Watson et al., 2011; Korpela et al., 2015; Rubene et al., 2015). Both Cartar (2005) and Pengelly and Cartar (2010) concluded that the preference for moderately logged sites only occurred within the first year of cutting. Bees were found to be more abundant in the year following logging in clear cut sites compared to any moderate level of logging. The initial increase in bees is due to warmer initial temperatures in the cut areas and ease of flower detection by bees (Cartar, 2005).

With most goal oriented practices there is always a possibility of negative side-effects. Logging may disrupt and compact soil nesting sites, alter soil moisture or even lead to losses of natural cavities to be used as potential nesting sites (Romey et al., 2007). When logging does occur however, other types of nesting sites are more abundant than in forested or non-logged areas. Consequently, if logged areas are not maintained by some amount of cutting every few years, or new nearby logging areas are not created when the

older logged areas reach a dense young stage, the bees will no longer be able to stay in the area due to unsuitable habitat (Hanula et al., 2015). Yet, bees are highly mobile organisms adapted to using patchy resources (Potts et al., 2010).

Clear cut areas appear to be more favorable to most bee species than forested areas since several studies found lower bee abundance in forested areas compared to logged areas (Winfree et al., 2007; Watson et al., 2011; Hanula et al., 2015), and higher forest cover has been linked with lower bee abundance (Romey et al., 2007; Winfree et al., 2007). This is likely because bees favor early successional habitats, like those of logged forests. Cartar (2005) points out that in forested areas bees may find it more difficult to encounter flowers and therefore prefer to forage in logged areas when they are nearby. Lastly, it should be noted that forests were found by Kreyer et al. (2004) to not act as a barrier for foraging bees. Regardless of the logging method and despite the unsuitable foraging habitat of forests, bees are still able to pass either through or over patchy sections of forest in clear-cut landscapes. Therefore, the patchy network of forest areas and logging areas should not pose a problem to bees and is actually a preferred habitat for many pollinators such as bees. Finally, another positive characteristic of clear cut areas is that flowering plants are more visible to bees at a distance (Cartar, 2005). This allows for those flowers to be more frequently visited than the same flowers in a dense forest (Cartar, 2005). The overall positive effects of using logging practices as a potential habitat conservation method are that it allows for intermediate levels of disturbance and increases available resources, including nesting and foraging, for many different bee species (Winfree et al., 2007). Understanding how bees use cutovers could lead to changes in harvesting strategies leading to the maximization of their utility for bees.

Introduction

The immense importance of bees as pollinators of agricultural crops and wild plants constitutes a need for conservation methods to prevent the constant decline of bee populations. There are several practices found to have positive effects on bees, such as agriculture, urbanization, fire, logging and even power line cuts (Winfree et al., 2007; Carre et al., 2009; Pengelly and Cartar, 2010; Sydenham et al., 2016). Of these, logging seems to be of particular interest as it creates a habitat that will last several years in an area away from the negative disturbances of other human activities. Logging practices bring about early successional habitats which have high flowering plant diversity and abundance, sun exposure, and new nesting sites, which provide ample resources for pollinators (Cartar, 2005; Watson et al., 2011; Korpela et al., 2015; Rubene et al., 2015; Sydenham et al., 2016). In an area where logging occurs, bees can typically rely on another suitable habitat to appear every few years as an old cutover starts to become too dense, depending on harvesting practices and cutover distribution. Bees are able to thrive in areas with patchy landscapes such as those with clear cuts and forests intermixed (Potts et al., 2010). Remaining intact forest does not act as a barrier between suitable habitats (Kreyer et al., 2004), but greater forest cover has been linked with lower bee abundance (Romey et al., 2007; Winfree et al., 2007). Due to the need for a relatively specific habitat by bees, logging methods such as tree removal should be considered as a potential strategy to create suitable habitat and incorporated as part of sustainable land management strategies to reduce bee declines. Therefore, it makes sense to study how bees are using cutovers and what optimal features lead to high bee abundance.

Early successional habitat, such as that produced by logging, has higher vascular plant abundance (Pitkanen, 2000), due to the canopy opening, sunny conditions, and bare soil (Pykälä, 2004). For these reasons, bee abundance should be highest in cutovers which had had enough time post-harvest for vegetation regrowth. Other studies on the effects of logging disturbance on bee populations, such as Cartar and colleagues' research (Cartar, 2005; Pengelly and Cartar, 2010) on bumble bees in Alberta's boreal hardwood forests, found higher bee abundance in logged areas. In Newfoundland, there has not been any research on the effects of logging coniferous boreal forests on bee abundance. This study aims to determine if cutovers in western Newfoundland have more floral resources to support higher bee populations, and if there is an optimal cutover post-harvest age at which this occurs by addressing the following hypotheses:

- 1) Cutovers several years post harvest will have the highest amount of vegetation foraged on by bees, while recently logged cutovers and intact forest will have more unvegetated ground.
- 2) Bee abundance will be highest in the cutovers with the largest amounts of forage vegetation.
- 3) Bee abundance will differ between the collection years of 2015 and 2016, and among the cup trap colours.

Materials and Methods

Study Location

The research was conducted in commercial forestry areas logged by Corner Brook Pulp and Paper Limited near Corner Brook, Newfoundland and Labrador (48.95°N, 57.95°W; Figure 1). The forest in the region is dominated by balsam fir (*Abies balsamea* (L.) Mill. (Pinaceae)) and black spruce (*Picea mariana* (Mill.) (Pinaceae)), with limited hardwood stands dominated by white birch (*Betula papyrifera* Marshall (Betulaceae)). Industrial logging targets primarily softwood, for paper production. In 2015, six sites were selected in two areas. Along Logger School road, there were sites logged in 2010 (LOG-10) and 2014 (LOG-14) and a site that was logged at least 40 years ago, i.e. intact forest (LOG-FO). Along Ladyslipper road, sites logged in 2009 (LAD-09) and 2013 (LAD-13) were used along with a site of intact forest (LAD-FO). In 2016, three new sites were added, located near Massy Drive. These were two different logged sites from 2005 (MAS-5A & MAS-5B) along with a site of intact forest (MAS-FO). The three forested sites were characteristically mature forests, logged at least 40 years ago.

All sites chosen were selected using logging maps the advice provided by Mr. Barry Elkins with Corner Brook Pulp and Paper Limited, to identify areas which had not been treated with herbicides.

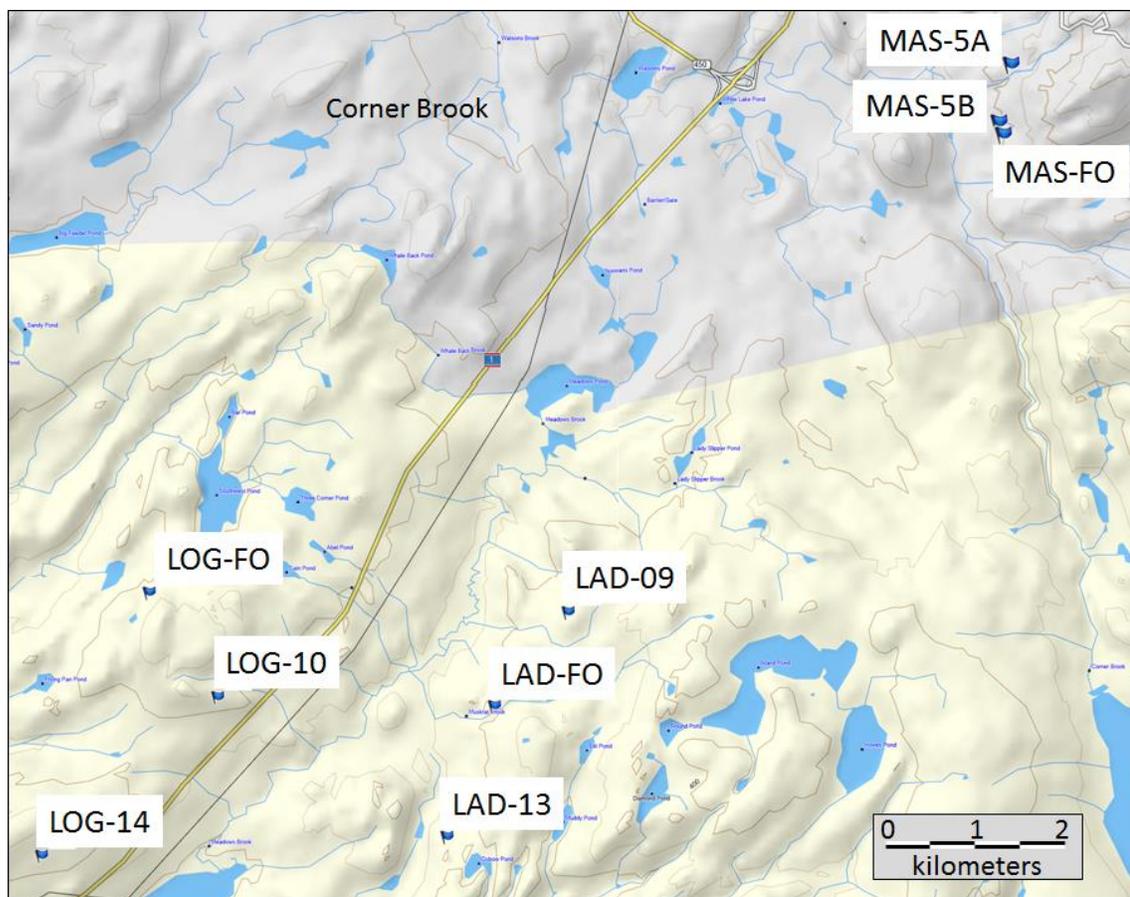


Figure 1. Location of study sites near Corner Brook NL. Map generated in Garmin BaseCamp version 2.0.4.

Bee Census

Bees were collected during the colony growth period, between June and August. In 2015, sampling began on 8 June and ended on 24 August; in 2016 sampling took place between 23 June and 25 August. A transect of 9 cup traps, alternating white, blue, and yellow placed at 5m intervals, was placed near the centre of each site. The traps consisted of 450ml plastic beer cups; white cups were unpainted, while blue or yellow cups were painted. In 2015, locally available paint was used (Painter's Touch, navy blue and sun yellow) while in 2016 fluorescent paint was used, which has been shown to be attractive

to bees (blue or yellow fluorescent pigment in silica flat base, Guerra Paint and Pigment, NY; Droge, 2015). The cups were placed in a stand made by attaching a ring made of 3 in diameter ABS pipe to a ~30 cm length of ½ in diameter PVC conduit placed over a piece of rebar. Cups were ~1/3 filled with propylene glycol (Prestone plumbing antifreeze) decoloured using household bleach (~5 ml/10 l). Traps were emptied and refilled weekly, with any collected insects preserved in ethanol and brought back to the lab. All bees were washed in soapy water and rinsed in water, this process was repeated 3 times before being further rinsed with ethanol. They were then patted dry with paper towels, blown dry inside a glass jar with strips of KimWipe* using a domestic hairdryer, pinned, identified and labelled. Non-*Bombus* individuals were identified to genus using Packer et al. (2007), and *Bombus* were identified to species using Lavery and Harder (1988).

Vegetation surveys

In 2015, vegetation was surveyed on a transect parallel to the cup sampling transect, by point count method. This data was not analysed as it only existed for six of the nine sites, and the sampling protocol was improved for 2016. Vegetation surveys in 2016 were conducted in an L shape, running parallel to the cups transect then turned 90° to the left or right, randomly chosen. Four 1 × 1 m quadrats were placed parallel to the cups transect at 5 m intervals, with a further three quadrats at 5 m intervals perpendicular to the cup transect. Vegetation was identified to the lowest possible taxonomic level (usually genus or species) and recorded as number of individuals or percent cover. The ground cover was characterized as one of three types. 1) Forage: the vegetation foraged on by bees, including both herbaceous annuals and perennials and flowering shrubs; 2) Non-forage: the vegetation not foraged on by bees, such as non-vascular plants; and 3)

Unvegetated, which included either exposed ground or dead vegetation. Trees over 0.25 m were identified, counted and measured. Trees less than 0.25 m were not included in the measurements as they are not tall enough to contribute to canopy cover (Snohomish County, 2015).

Temperature and Light

HOBO Pendant[®] temperature/light loggers (Onset Computer Corporation, Bourne MA) were placed at one end of each transect, recording temperature and light intensity every 15 minutes. Mean temperature was calculated for daytime (defined as the three hours before and after solar noon, i.e. between 10:00 and 16:00 h, Newfoundland Daylight Time) and nighttime (the corresponding hours at night, i.e. 22:00 – 04:00 h), while average light levels were calculated only in daytime. Maxima and minima for temperature and light were found over the entire sampling period, at any time of day.

Data Analysis

Intact forest yielded very few bees, only 3 over two years among all sites (Appendix 1), thus were excluded from further analysis. Sampling effort differed between years (77 days in 2015, 63 in 2016) thus counts were standardized to 70 days by dividing actual bee abundance by sampling effort (77 or 63) and multiplying by 70. All analyses were conducted on standardized data. Cup trap disturbance was not an issue that need be accounted for as only two cups were slightly disturbed during the two field seasons, both of which were in intact forest sites.

Data were analyzed in R (version 3.3.2, R Core Team) using lme4 package (Bates et al., 2015) to create linear mixed effects models. Likelihood ratio tests were completed

by removing one individual factor each time from the full model to create a reduced model. Each reduced model was compared to the full model using analysis of variance, to determine the effect of that factor on total bee abundance and *Bombus* abundance. In both cases the full model included harvest year, collection year, cup colour, site as a random factor, and harvest year squared to account for non-linearity:

$$\text{Bee Abundance} \sim \text{Harvest Year} + \text{Harvest Year}^2 + \text{Collection Year} + \text{Cup Colour} \\ + (1|\text{Site})$$

Individual based estimated bee taxon richness (S_{est}) was calculated using EstimateS (Colwell 2013) to determine bee diversity for each harvested site.

Results

Site Characteristics

Different aged sites had distinct vegetation characteristics (Table 1). The vegetation in sites harvested in 2014 was made up entirely of forage plants. There was a moderate percentage of unvegetated ground, most of which was covered in debris, and any trees present were small, i.e. there was virtually no canopy cover. Sites harvested in 2013 and 2010 had the highest forage vegetation of the harvested sites, little non-foraging vegetation and small trees. The site harvested in 2009 had moderate levels of forage vegetation and unvegetated ground, but the highest amount of non-forage vegetation of all harvested sites. Both 2005 harvested sites had the greatest amount of unvegetated ground as well as relatively tall trees. The three intact forested sites, logged at least 40 years ago, had well-spaced mature trees; none over 4m were within the quadrats, although they were common enough to create a nearly fully enclosed canopy cover. The understory was dominated by bare ground and vegetation not foraged on by bees, although one site (LAD) had surprisingly high cover of forage vegetation.

Sites also differed in physical variables (Table 2). Among harvested sites, average temperatures were virtually identical. Intact forests, in comparison, had lower daytime and warmer nighttime average temperatures than the cutovers, with minimum values at least 2°C higher than those of harvested sites. The 2010 harvested site had slightly lower nighttime average temperature and was the cutover that experienced below freezing temperatures, reaching -0.21°C on 9 July. At the intact forested site in Massey Drive, some anomalous readings were recorded as the light intensity levels were extremely variable. This site recorded reaching its highest maximum light intensity on two

occasions during 25 July and 16 August, which was far greater than any other readings for the site. Although these values were included in calculating the mean, intact forest daytime light intensity levels were clearly lower than the harvested sites, which were relatively similar to one another. All maximum day temperatures were recorded between 12:00 and 16:00. All minimum temperatures were recorded between 04:00 and 06:00.

Table 1. Vegetation characteristics of the sites in commercial logging operations near Corner Brook NL. Forage and non-forage plants include herbaceous annual and perennial species. Unvegetated refers to both bare ground and areas of logging debris. Only trees ≥ 0.25 m were measured. LOG, LAD, and MAS are intact forest sites.

Site Harvest Year	Percent cover			Mean Tree Height (m)
	Forage	Non-Forage	Unvegetated	
2014	19.78	0.00	43.50	0.38
2013	27.82	8.75	34.33	0.60
2010	23.13	6.67	33.89	0.9
2009	15.94	25.83	38.57	0.68
2005A	17.91	2.60	69.86	1.93
2005B	12.90	13.78	59.50	0.71
LOG	13.00	32.86	47.38	0.99
LAD	32.43	47.14	23.83	0.98
MAS	10.06	27.73	46.80	0.88

Table 2. Physical variables of the sites in commercial logging operations near Corner Brook NL, recorded using HOBO Pendant[®] temperature (°C) and light (lux) loggers between June and August 2016. Daytime includes the 6 hours around 13:00 (solar noon) and nighttime includes the 6 hours around 1:00. LOG, LAD, and MAS are intact forest sites.

Harvest Year		Temperature (°C)			Light intensity (lux)	
		Average Daytime	Average Nighttime	Minimum	Average Maximum	Average Daytime
2014	34.90	23.02	13.24	1.55	57867.00	16595.50
2013	35.65	23.11	13.04	1.55	46844.80	11043.78
2010	28.05	22.94	12.59	-0.21	57867.00	12888.63
2009	39.28	23.74	12.91	1.44	79911.6	21162.56
2005A	41.23	23.87	13.45	2.20	71644.90	18793.11
2005B	39.96	23.58	12.99	1.55	57867.00	15976.12
LOG	27.47	18.33	14.14	4.93	18600.10	1626.18
LAD	35.97	20.24	14.10	4.73	38578.00	4636.15
MAS	40.42	20.96	13.63	4.21	115734.10	9455.07

Bee Census

Bumble bees (*Bombus* spp.) made up 80% of the standardized count of bees collected between June and August of 2015 and 2016. The bumble bee *B. borealis* was the most commonly occurring bee, contributing to 68% of the collection and 85% of the *Bombus* species. The only other bee taxa's with more than 10 in individual collected

between both years was *B. ternarius* Say (Hymenoptera: Apidae), *Lasioglossum* spp. Curtis (Hymenoptera: Halictidae) and *Andrena* spp. Fabricius (Hymenoptera: Andrenidae) (Appendix 1; Appendix 2). The rest of the collection was composed of 6 other genera, which were represented by fewer than 10 individuals total, or not collected at all of the cutover sites. A total of 3 bees were collected in the intact forests, for this reason they were not included in further analysis.

Total bee abundance was significantly influenced by all factors assessed. Total bee abundance was significantly higher in 2016 ($\chi^2(1)=19.10$, $p<0.001$), with 3.5 more bees collected in the sites that were sampled in both years. Total bee abundance was also significantly affected by year of harvest ($\chi^2(1)=10.04$, $p=0.002$) and cup colour ($\chi^2(1)=14.49$, $p<0.001$). The majority of the bees were found in the sites harvested in 2013, 2010, and 2009, accounting for 82% of the combined 2015 and 2016 standardized bee collection (Figure 2). White coloured cups collected 55% of the bees, far greater than the 13% collected in yellow (Figure 2).

Bombus abundance was similarly, and significantly influenced by all factors assessed. The colour preference ($\chi^2(1)=21.36$, $p<0.001$) appeared stronger, with 59% of *Bombus* individuals collected in white traps, and only 8% in yellow (Appendix 3). The collection year significantly affected *Bombus* abundance ($\chi^2(1)=13.26$, $p=0.0003$), as well as the year of harvest ($\chi^2(1)=8.91$, $p=0.003$), with nearly three times as many *Bombus* collected in 2016 and 89% of *Bombus* across both years collected from sites harvested between 2009 and 2013.

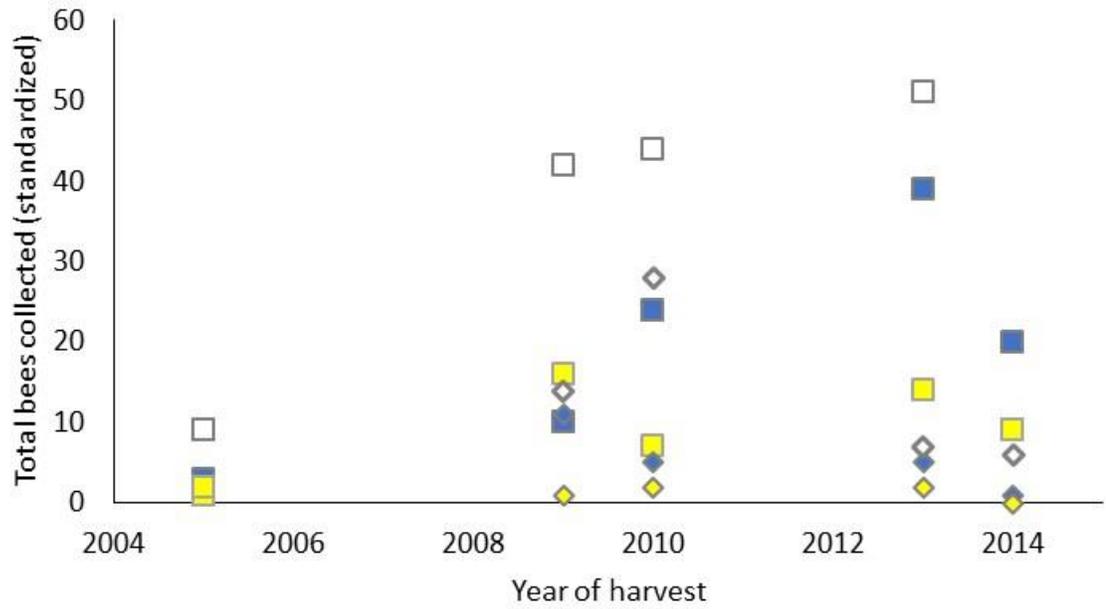


Figure 2. Total bees collected, standardized to 70 trap-days, in 2015 (diamond symbols) and 2016 (square symbols) in white, blue, and yellow cup traps, indicated by the symbol colour.

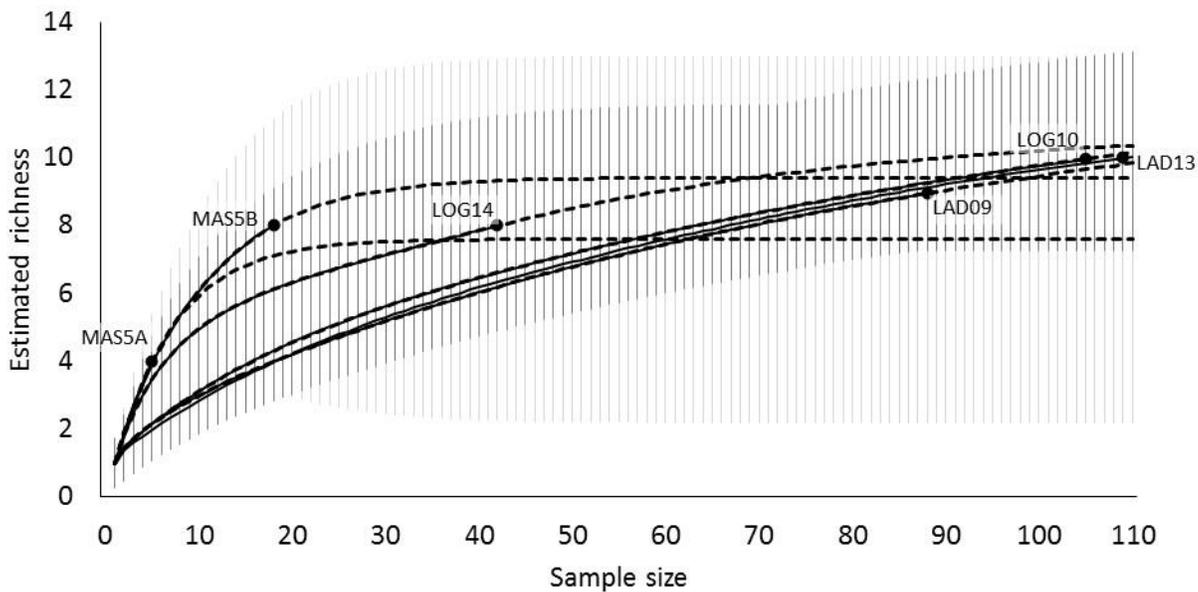


Figure 3. Expected number of species for sample sizes up to the maximum observed (109 individuals) at each harvested site. Individual-based rarefaction and extrapolation (Colwell et al. 2012) with standard deviation. Dots represent actual sample size at site, beyond that point is an extrapolation. The paler error bars are for site MASSA, from which only 5 individuals were collected. Error bars for the other sites also overlap.

One site (MAS5A) yielded only 5 individuals, of 4 taxa, which made it impossible to obtain a meaningful richness estimate (Figure 3). The other sites appear to have similar taxon richness.

Discussion

All of the cutovers had far more bees than intact forest. The highest abundance was in cutovers harvested in 2013, 2010, and 2009, which corresponds with the largest coverage of herbaceous vegetation, including many plants that are highly attractive as pollen and nectar sources. This indicates that cutovers do provide suitable resources for bees, and importantly, that bees are able to reach them. The dominant bees collected, *Bombus* spp., showed a preference for white cups over yellow in both years, which had not previously been demonstrated.

Site Characteristics

Intact forest sites, dominated by tall trees, high canopy cover, and little understory vegetation had very few bees, presumably due to a lack of essential resources such as forage plants and nesting sites. This is consistent with patterns found in boreal hardwood forest (Cartar, 2005; Winfree et al., 2007; Watson et al., 2011), in which intact forests supported smaller, less diverse bumble bee populations than did cutovers. Although bees did not appear to be using intact forests as a habitat, forested areas are not believed to act as barriers between habitats used by bees (Kreyer et al., 2004).

Due to the lack of variation in temperature and light intensity among sites in 2016, it is unlikely that these physical differences had an effect on bee abundance. Vegetation differences are more likely to have caused the observed differences in bee abundance. The vegetation characteristics of each harvested site are assumed to be due to vegetation regrowth since logging occurred. The clear difference in bee abundance among harvested sites can be attributed to the differences in vegetation characteristics of these sites.

Studying cutovers of different ages makes it possible to infer the pattern of succession in the Corner Brook area. In newly harvested cutovers, the unvegetated areas were composed largely of slash (i.e. the tree branch remains left behind after logging). Dense slash initially acts as a barrier, retarding vegetation regrowth, but this effect decreases over time as it decomposes (Olsson and Staaf, 1995). The decomposition of slash and mineralization of underlying organic matter increases soil nutrient levels, which favours species that are adapted to disturbance and high nutrient availability (Esseen et al., 1997; Angelstam, 1998). Over several years, vegetation cover increases as slash breaks down, as seen in the sites harvested in 2013, 2010, and 2009 had less unvegetated ground and nearly twice the plant cover compared to the 2014 site, due to the lack of canopy cover, sunny conditions and newly exposed soil (Pykälä, 2004; Hanula et al., 2015). Earlier in succession, represented by the sites harvested in 2010 and 2013, most of this vegetation consisted of flowering plants on which bee's forage. As the cutover continues to age, there is a shift from predominantly forage vegetation to non-forage species, as was seen in the shift from the 2010 harvested site to the 2009. These shifts were typically from *Cornus canadensis* and *Rubus* sp., the most common forage vegetation, to various grasses and ferns. This may represent the point at which cutovers begin to decline as prime bee habitat. By the time a cutover is 11 years post-harvest, it has dense young trees, much more bare ground, and few floral resources.

Cutovers harvested in 2005 had similar amounts of forage vegetation to those harvested in 2009, but had more unvegetated ground and greater canopy cover resulting in low bee abundance. Cartar and Pengelly (2010) found similar results in their study of bee population several years post-logging where logged sites 7-8 years post-harvest no

longer acted as “bee attractors” due to extensive vegetation re-growth. Although older cutovers may not lack food resources in comparison to more recently harvested ones, they may have limited nesting resources, and greater tree cover may slow bees searching behaviour. Forested areas bees may find it more difficult to encounter flowers, where in cutovers they would be more visible at a distance (Carter, 2005). For bees that nest above ground, logging residues offer important nesting sites within the debris left behind (Watson et al., 2011; Korpela et al., 2015). The decomposing slash in early to mid aged cutovers may be a valuable resource for these types of bees. Logging activities can also provide nesting sites for ground nesting bees such as *B. borealis* (Colla et al., 2011), as the increase in exposed soil opens new burrowing areas.

Bee abundance and diversity

Bees appeared to be responding to these changes in vegetation. The sites that had the most bees were the sites harvested in 2013, 2010, and 2009, characterized by larger amounts of vegetation which can be foraged by bees, low canopy cover, and little unvegetated ground. Pollinator communities benefit from greater flowering plant cover and diversity, open canopies, and reduced shrub cover (Hanula et al., 2015). The newly harvested site (2014 harvest) and old cutovers (11 years post-harvest) had high amounts of unvegetated ground making them unappealing to bees.

Bumble bees largely drove the pattern of bee abundance. Almost 80% of the total bees collected were bumble bees (*Bombus* spp.) and 84% of these were *B. borealis* (two thirds of all the bees), although they are generally considered rare (Colla et al., 2011). This bee is relatively large (Colla et al., 2011) compared to other bees which may be a contributing factor to their high abundance, possibly due to competition and their ability

to travel a distance to find new habitats. Since *B. borealis* is a long-tongued bee (Colla et al., 2011), and the long-tongued bees appear to be declining (Goulson et al., 2005; Bommarco et al., 2012), it is beneficial that this species does well in cutover habitats. Besides *Bombus* spp. there was only two other taxa, *Lasioglossum* spp. and *Andrena* spp., of which more than 8 individuals were collected in any cutover (Table 1). *Lasioglossum* spp. and *Andrena* were likely abundant because of their ground nesting behaviour (Wcislo et al., 1993, Packer et al. 2007). *Lasioglossum* were predominantly found in the cutover harvested in 2014 when surveyed in 2016 (Appendix 2), which had a high amount of bare ground compared to other harvested sites that year (Table 1). *Andrena* were found mostly in the cutover harvested in 2010, which had less bare ground, however, some *Andrena* species will nest in soil covered in dense grass (Packer et al. 2007).

Collecting in two years accounted for some of the year-to-year variation that would be missed in a single year study. Since the 2016 collection contained a greater number of bees, it allowed for better estimates of actual taxonomic richness, although little difference in richness, using an individual-based richness estimator. Carter and Pengelly's (2010) study on the effects of variable retention on bee population, found that clear-cuts support much greater diversity of both bees and flowering plants. Likewise, with this study, this trend may be because most bee taxa are able to locate new cutovers fairly quickly. If cutovers and other similar disturbances begin to decline in attractiveness to bees within eight years, as these data suggest, then bees must locate them rapidly to take advantage of the new habitat.

Cup Trap Colour and Bee Abundance

The significant difference in total bee abundance among cup colours was likely driven largely by *Bombus* spp., which made up most of the bees collected. The difference with collection based on colour may be attributed to flower colour preferences of *B. borealis*, which made up two thirds of the collection. While this study has shown a possible flower colour preference by *B. borealis*, to the best of my knowledge, a colour preference has not previously been documented for this species. A study comparing bees trapped in white pan traps compared to yellow found over two times more bees from the family Apidae in white traps than yellow (Gollan et al., 2011), the family which includes bumble bees. The trend was mostly due to the species *Apis mellifera* Linnaeus (Hymenoptera: Apidae). This suggests a preference for white flowers among the Apidae, as a study by Buchholz et al. (2010) also concluded that by far the highest number of individuals from the family Apidae were collected in white traps than yellow. One other consideration in this study leading to the high abundance of bees in white cups is that white cups were not painted, therefore may have a physical characteristic making them more attractive to bees, for example they may have been more light reflective.

Limitations

The cutovers available for sampling, even though they were sampled over two years, did not represent the entire range of years since harvest. There were no sites that were four years old, or between eight and ten years old. Short-term sampling also meant that the successional patterns must be inferred. Ideally, bee abundance should be monitored over time in multiple cutovers as they age. This would also allow greater flexibility and power in statistical analysis.

Future Research

Future sampling should include the full range of site ages up to approximately 10 years post-harvest to more precisely pinpoint the range of ages most attractive to bees. In Newfoundland, variable retention logging should be compared with clearcutting in terms of producing bee habitat and harvest patterns need to be explored to ensure a continuous supply of suitable habitat, since these aspects have been studied elsewhere (e.g. Carter, 2005; Cartar and Pengelly's, 2010; Rubene et al., 2015) and found to have positive effects on bee populations but the methods to maximize bee abundance have not yet been achieved.

Conclusion

Cutover sites harvested in 2013, 2010, and 2009, supported the highest bee abundance. Most of the bees collected were *Bombus borealis*, a large-bodied, long-tongued bumble bee. The sites with the highest bee abundance were characterized by having high vegetation cover, which was mostly bee forage vegetation in early aged cutovers, little unvegetated ground, and low canopy cover. As expected, logging reduced canopy cover and promoted the growth of forage vegetation. The decomposing slash may have been used as nesting sites for bees residing in these highly vegetated, open cutovers. More bees were collected in 2016 than in 2015, however there was a consistent preference for white cup traps over yellow, which may reflect a flower colour preference among the dominant family, Apidae.

Bees are using cutovers in the Corner Brook area, but further work could explore ways to conduct logging operations to maximize the value of these habitats to bees. Logging practices create suitable bee habitats within a few years after harvesting occurs as ample food and nesting resources become available, but this quality declines after several years. Further research could support forestry planning to ensure a consistent supply of suitable, accessible habitat in support of native bee populations.

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Appendix 1. Total (unstandardized) numbers of each bee taxon collected at each site over the 77 days surveyed in 2015. LAD was the only intact forest site at which bees were recorded.

Taxon	2014	2013	2010	2009	LAD
Andrenidae					
<i>Andrena</i> spp.					1
Apidae					
<i>B. borealis</i>	1	7	31	17	
<i>B. ternarius</i>	2	3		7	1
<i>B. terricola</i>			1		
<i>Bombus vagans bolsteri</i> Smith			2	1	
<i>Bombus fernaldae</i> Franklin		1			
Colletidae					
<i>Hylaeus</i> spp. Fabricius	4		1	2	
Halictidae					
<i>Lasioglossum</i> spp.	1	3	3	1	
Megachilidae					
<i>Megachile</i> spp. Latreille		1			

Appendix 2. Total (unstandardized) numbers of each bee taxon collected at each site over the 63 days surveyed in 2016. MAS was the only intact forest site at which bees were recorded.

Taxon	2014	2013	2010	2009	2005	MAS
Andrenidae						
<i>Andrena</i> spp.	1		8	1	4	
Apidae						
<i>B. borealis</i>	13	79	48	48	1	
<i>Bombus frigidus</i> Smith					1	
<i>B. ternarius</i>	5	4	2	6	6	1
<i>B. terricola</i>				1		
<i>B. vagans bolsteri</i>		2	1		3	
<i>B. fernaldae</i>					1	
<i>Nomada</i> spp. Scopoli	4	2				
Colletidae						
<i>Hylaeus</i> spp.	1	1	1			
Halictidae						
<i>Halictus</i> spp. Latreille		1				
<i>Lasioglossum</i> spp.	8	3	5	2	4	
<i>Sphecodes</i> spp. Latreille		2	1	1	1	
Megachilidae						
<i>Megachile</i> spp.			1			
<i>Osmia</i> spp. Panzer	1		1	2	2	

Appendix 3. Total (unstandardized) numbers of each bee taxon collected, across all sites, by cup colour, in 2015 (six sites, 77 days) and 2016 (nine sites, 63 days).

Taxon	2015			2016		
	White	Blue	Yellow	White	Blue	Yellow
Andrenidae						
<i>Andrena</i> spp.				6	7	1
Apidae						
<i>Bombus borealis</i>	36	19	1	105	67	17
<i>B. frigidus</i>				1		
<i>B. ternarius</i>	11	1	1	17	5	2
<i>B. terricola</i>	1					1
<i>B. vagans bolsteri</i>	3				3	3
<i>Bombus fernaldae</i>		1			1	
<i>Nomada</i> spp.				1		5
Colletidae						
<i>Hylaeus</i> spp.	7	1		1	2	
Halictidae						
<i>Halictus</i> spp.				1		1
<i>Lasioglossum</i> spp.	5		3	5	9	8
<i>Sphecodes</i> spp.				3	1	1
Megachilidae						
<i>Osmia</i> spp.				1		5
<i>Megachile</i> spp.		1		1		