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Pollination of Lowbush Blueberry (*Vaccinium angustifolium*) in Newfoundland by native and introduced bees

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ABSTRACT

Lowbush blueberry, *Vaccinium angustifolium* Aiton (Ericaceae), requires insects (mainly bees) for successful and adequate pollination. The bee fauna of Newfoundland is not well known but native bees have been shown to be important to blueberry pollination in this province. The diversity and abundance of native bees was greatest in managed blueberry plots compared to unmanaged plots but this did not manifest into greater fruit-set. The supplementation of blueberry plots with imported bees *Bombus impatiens* and *Apis mellifera* did not increase fruit-set and the diversity of native bee species was decreased in the supplemented plots.

RÉSUMÉ

La pollinisation du bleuet, *Vaccinium angustifolium* Aiton (Ericaceae), depend des insectes (surtout les abeilles). La faune des abeilles de Terre Neuve n'est pas bien connue mais joue un rôle important pour la pollinisation du bleuet. La diversité et l'abondance des abeilles sauvages étaient plus importantes dans les parcelles de bleuet cultivées que dans les parcelles sauvages mais cette différence ne s'est pas reflétée dans la quantité de fruit. L'ajout de bourdons *Bombus impatiens* ou d'abeilles domestiques, *Apis mellifera*, dans certaines parcelles de bleuet n'a pas augmenté la quantité de fruits et la diversité des abeilles sauvages a diminué.

INTRODUCTION

Many species of insects visit flowers in search of nectar and pollen. In return for these foods, the insects inadvertently pollinate the flowers. Many native insect species (especially bees) are important pollinators of commercial food crops. About 20,000 species of bees are known throughout the world (Finnamore and Michener 1993). Presently, around 50 species occur in Newfoundland representing 5 families: digger bees (Andrenidae), sweat bees (Halictidae), cellophane bees (Colletidae), leafcutting bees (Megachilidae), and bumble and cuckoo bees (Apidae) (Hicks 2009). The number of bee species recorded from Newfoundland differs considerably compared to mainland Atlantic Canada where 159 species have been recorded (Sheffield et al. 2003). As native Newfoundland bee species have not been well studied the list of bees found in Newfoundland will undoubtedly continue to grow.

Many native bee species are natural pollinators of lowbush blueberry in Newfoundland (Lomond and Larson 1983). Most species are solitary, with the exception of non-parasitic social bumble bees and some primitively social members of the Halictidae. Although many bee species are excellent pollinators of lowbush blueberry, the negative impact of year to year weather fluctuations results in a need for many blueberry growers to supplement native bee populations with imported bee species such as honey bees (*Apis mellifera*), bumble bees (*Bombus impatiens*), or leafcutting bees (*Megachile*

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rotundata). In many areas of North America, blueberry producers supplement pollination with commercial bees due to low numbers of native bees (Boulanger et al. 1967; Desjardins and de Oliveira 2006). In Nova Scotia, pollen collecting bees such as *Bombus* spp. and *Andrena* spp. were more efficient at pollinating blueberry flowers than nectar collecting *Apis mellifera* and *Megachile rotundata* (Javorek et al. 2002). Meanwhile, a study of blueberry pollination on Newfoundland's coastal barrens showed that *Apis mellifera* supplementation increased fruit set (Lomond and Larson 1983) and that native bee abundance was similar between treatment and control plots. The importation of non-native bee species to increase pollination may result in the transmission of bee diseases that could seriously impact the diversity and abundance of native bee species.

Wild lowbush blueberry, *Vaccinium angustifolium* Aiton, is indigenous to northeastern North America. It has become an important commercial product in Nova Scotia, Newfoundland, New Brunswick, Prince Edward Island, Quebec, and Maine. While Quebec and Maine are the largest producers, Newfoundland is the smallest producer in North America (Statistics Canada 2011; Yarborough 2009) although it is an important agricultural crop there. In 2008, Newfoundland and Labrador had 809 ha of area for blueberry cultivation accounting for over half of the total acreage of planted fruits and vegetables (Statistics Canada 2011). Major production areas included Conception Bay North, Bonavista North, and Central Newfoundland. In the growing season of 2003, 12 commercial producers harvested 274,428 kg on 485 ha of land (Ricketts 2004). Production has slowed in recent years with 122,500 kg in 2006 (Government of Newfoundland 2011) and 181,500 kg in 2008 (Statistics Canada 2011). Harvests from the limited number of managed blueberry farms represent only a fraction of the total volume produced in the province. In 2004, the total amount harvested from wild blueberries was estimated to be 823,265 kg (Ricketts 2004).

As the native bee fauna of Newfoundland is so poorly known, it is important to investigate the diversity of bees and their ecology. Therefore, we investigated the following three questions:1) Is there a difference in the biodiversity and abundance of native bee species between managed (farm) and unmanaged (wild) blueberry plots? The hypothesis is that the cultivated plots have higher abundance and diversity of native bees. 2) What is the impact of the introduced bumble bee, *Bombus impatiens*, on blueberry pollination in eastern Newfoundland? In this case the hypothesis is that fields supplemented with pollinators show increased pollination and berry production. 3) What is the impact of the introduced honey bee, *Apis mellifera*, on blueberry pollination in eastern Newfoundland? The hypothesis is that fields supplemented with pollinators show increased pollination and berry production.

METHODS

Biodiversity of native bees in blueberry fields

Location of plots

In 2006, four blueberry plots were chosen on a farm near Colliers, Avalon Peninsula, Newfoundland (47°27'30"N, 53° 15' 20"W). Two of the plots had additional nesting habitat around the periphery of the blueberry field, while two plots had soil-nesting sites restricted to the blueberry field due to rock soil and bog land bordering the plots. Plots were spaced at 250m intervals and located on top of a small hill (elevation = 150 m) with south-westerly exposure. Two additional uncultivated plots with rocky soil located 4.76 km from the farm (47°25'55"N, 53°18'11"W), were chosen to represent a natural barren habitat. Along with blueberry other common plants included: *Kalmia angustifolia* L.(Ericaceae), *Rhododendron groenlandicum* (Oeder) K.A. Kron & W.S. Judd (Ericaceae), Caribou lichen, *Cladonia rangiferina* (Cladoniaceae),and *Larix laricina* (Du Roi) K. Kock (Pinaceae). These natural sites were located on top of a small ridge and were exposed to wind in all directions.

In 2007, two different blueberry plots were selected near Colliers (47°26'31"N; 53°18'52"W). Two additional plots were chosen 26 km to the north of these plots on a farm near Harbour Grace (47°40'21"N; 53°21'06"W). Two plots representing a natural habitat were selected in the same location as 2006.

Fruit-set

Four 5m-long transects were established in each plot with two transects arranged in an east–west direction and two in a north–south direction. In each year, 10 stems, touching or closest to the transect line at 0.5m intervals, were chosen and tagged. On each tagged stem, the number of flowers was counted on 16 June 2006 and on 26 June 2007 and the number of developed fruit on 25 July 2006 and 13 August 2007.

Sampling of Bees

Starting on 26 June 2006, five yellow bowl traps (10 cm in diameter and 4 cm deep) (Solo Cup Company, Toronto, Ontario) were placed in each plot. Bees were only collected on warm, sunny or partly sunny days when temperatures were greater than 18 °C. No bees were sampled during the blooming period. The bees that were captured over a 24-hr period were removed and pinned for later identification. Traps were not placed in the plots if inclement weather was forecasted. The plots were sampled 10 times over July and August.

In 2007, five traps were set out in each plot starting on 5 July 2007. The plots were sampled six times over July and August. In each plot, on sampling days in all years, air temperature, relative humidity, and wind speed were recorded. Verification of bee identification was by Cory Sheffield (York U, Toronto, Ontario) with voucher specimens being housed in the insect collection at the College of the North Atlantic, Carbonear Campus.

The impact of the introduced bumblebee, *Bombus impatiens* and honey bee, *Apis mellifera*, on blueberry pollination

Location of plots

In 2008 and 2009, one blueberry field was selected on each of four farms located near Colliers and Harbour Grace (Table 1). In 2008, one blueberry field was supplemented with a box (also known as a quad) of four colonies of *Bombus impatiens* with ca 200 bees per colony at a stocking rate of 4 colonies/ha; one blueberry field at a stocking rate 8 colonies/3.8 ha, and two other plots were not supplemented. In addition, two natural habitat sites not supplemented and located <3 km from supplemented fields were chosen. In 2009, eight *Apis mellifera* hives were placed in two fields, one at a stocking rate of 4 hives/3 ha and one at a stocking rate of 4 hives/2 ha. The hives contained from 40,000 to 60,000 bees and were oriented with their entrances facing south.

Table 1. The location of blueberry plots in 2008 and 2009.

Treatment	2008	2009
Supplemented*	47°25'56"N; 53°19'32"W	47°26'08"N; 53°19'50"W
Un-supplemented	47°26'32"N; 53°15'40"W	47°25'21"N; 53°17'38"W
Supplemented	47°40'18"N; 53°21'13"W	47°26'28"N; 53°19'14"W
Un-supplemented	47°40'04"N; 53°20'30"W	47°25'14"N; 53°17'48"W
Natural habitat	47°25'55"N; 53°18'11"W	47°25'55"N; 53°18'11"W
Natural habitat	47°26'49"N; 53°15'26"W	47°27'38"N; 53°14'31"W

* In 2008 supplemented fields had *Bombus impatiens*; 2009 the supplemented fields had *Apis mellifera*

Sampling of Bees

Starting on 2 July 2008 and 16 June 2009, five yellow bowl traps (10cm in diameter and 4cm deep) (Solo Cup Company, Toronto, Ontario) were placed in each plot (total = 10/site). The bees that were captured over a 24-hr period were removed and pinned for later identification. The traps were not placed into the plots if inclement weather was forecasted. In 2008 and 2009, the plots were sampled six times. In addition, on 3 June 2009, two Malaise traps were set up perpendicular to a forest edge, one trap 100 m from the *Apis mellifera* hives and one trap in a natural site. The traps stayed in place until 28 July 2009 and the bottles on the traps were changed every two weeks.

Fruit set, berry weight and seed count

Fruit set was evaluated as above in 2008 and 2009 with flowers counted on 27 June 2008 and 16 June 2009 and developed fruit on 8 August 2008 and 24 July 2009. After fruit developed, 10 berries along the transects were chosen randomly, placed in a Ziploc bag, labeled and transported back to the lab in an ice box. At the laboratory, each berry was weighed using an analytical balance (0.001 g) and the diameter of the each berry was measured using digital calipers (0.01 mm). Each berry was crushed, washed with water and passed through a suction filter to harvest seeds. The seeds were counted under 5x magnification.

Pollen deposition on blueberry stigmata

The protocol for the assessment of pollination and pollen deposition was modified from Javorek et al. (2002). Percent pollination of blueberry flowers was accomplished by randomly cutting 40 stigmata from flowers (mid-style) from each site (80 per treatment). Groups of five stigmata were placed in a drop of basic fuschin gel (250 ml water, 75 ml glycine, 7 g gelatin and a few crystals of basic fuschin stain) on a microscope slide, viewed under light microscopy (400x), and assessed as pollinated if more than two pollen tetrads were present. Pollen load was classified as low (3–20 pollen tetrads/stigma), moderate (21–40), or heavy (>40).

Data handing

Shannon-Wiener diversity indexes were calculated for each treatment and year using PAST online calculator (Hammer et al. 2001). PAST was used to compare the diversity indexes within years using a *t*-test described by Poole (1974). A one-way analysis of variance was used to compare means of variables (i.e., fruit-set, pollination and environmental measurements) after the variance was checked for normality. Proportional data and data that did not turn out to have the variance normally distributed were transformed (arcsin and Log_{10}). In cases where transformation could not achieve normality, nonparametric tests were employed (Mann-Whitney for two-sample tests and Kruskal-Wallis for more than two-sample tests). All statistical tests were performed in Minitab Version 15.

RESULTS

Biodiversity of native bees in blueberry fields

Sixteen bee species were collected over the two years and from all sites combined (Table 2). The species richness and abundance of bees were higher in the farm habitat compared to the unmanaged habitat for both years (Table 3). In 2006, while the natural habitat had the lowest diversity of bees, fruit-set did not differ significantly between either.

In 2007, percent fruit-set was statistically different among the sites (Table 3). The managed field (F1) had the same fruit-set as in the natural habitat, but the fruit-set at F2 had a significantly lower fruit-set compared to the other two sites. As in the previous year, there was no difference in the Shannon-Weiner diversity index or among the measured environmental variables. Comparison of the data between the years (2006 and 2007) was not possible as there were varying levels of sampling effort and the sites between the years were different.

The impact of the introduced bees, *Bombus impatiens* and *Apis mellifera*, on blueberry pollination

The species richness and abundance was considerably lower in 2008 and 2009 than in the previous years and that is reflected in the lower Shannon-Weiner diversity indices (Table 4). However, the sampling effort was not the same during the four years of sampling (10 samples in 2006; 6 samples in 2007, 2008 and 2009).

In the fields supplemented with *Bombus impatiens*, only four of the six species of bees collected were native pollinating species. The remaining two were the imported bee, *Bombus impatiens* and the cleptoparasite, *Bombus (Psithyrus) fernaldae*. The species richness and abundance in the natural sites was lower compared to the un-supplemented field, a trend that was observed in previous years (Table 4 & 5). In 2009, the supplemented (*Apis mellifera*) and natural sites had three and six pollinating species, respectively. The social parasite *Nomada cressona* was also collected in both the supplemented and natural sites. The supplemented sites had the lowest abundance and least species richness among the sites studied, reflected in the significantly lower Shannon-Weiner diversity index.

Table 2. Bee species and their abundance in managed and unmanaged blueberry plots in eastern Newfoundland during 2006 and 2007. For 2006: F1 = M. Walsh farm with suitable nesting nearby; F2 = M. Walsh farm with unsuitable nesting nearby; Nat = natural habitat. For 2007: F1 = M. Wlash farm; F2 = D. Howell farm.

Bee species	Family	2006			2007		
		F1	F2	Nat	F1	F2	Nat
Andrena carolina	Andrenidae	35	34	13	27	31	1
Andrena rufosignata	Andrenidae	14	13	26	2	1	-
Andrena thaspii	Andrenidae	4	3	-	-	1	1
Andrena wilkella	Andrenidae	1	2	1	-	-	-
Osmia inermis	Megachilidae	-	-	1	-	-	-
Hylaeus modestus	Halictidae	1	1	-	-	2	-
Lasioglossum (*Dialictis*) sp.	Halictidae	34	29	13	20	-	17
Lasioglossum (*Evylaeus*) *quebecense*	Halictidae	35	55	17	18	13	15
Lasioglossum (*Evylaeus*) *foxii*	Halictidae	7	7	6	-	-	-
Lasioglossum (*Evylaeus*) *rufitarsus*	Halictidae	13	3	3	-	-	-
Sphecodes solonis	Halictidae	4	5	-	1	3	-
Nomada cressonii	Anthophoridae	2	-	1	1	4	-
Bombus borealis	Apidae	-	1	-	-	-	-
Bombus frigidus	Apidae	4	-	-	2	1	1
Bombus vagans bolsteri	Apidae	3	6	3	2	3	2
Bombus terricola	Apidae	3	14	1	4	4	-

Table 3. Bee species diversity, abundance, and selected environmental variables in managed and unmanaged blueberry plots in eastern Newfoundland during 2006 and 2007.

Year	Site	No. of species	Total abundance	H´	Fruit-set (%)	Air temp (°C)	Wind speed (m/s)	RH (%)
2006	F1	14	157	2.09a	65.8(80) a	23.8(28) a	2.6(28) a	80.0(26) a
	F2	13	168	1.98a	58.2(78) a	24.2(28) a	2.1(28) a	81.1(25) a
	Nat	11	61	1.89a	66.8(75) a	24.6(28) a	2.3(28) a	78.8(26) a
2007	F1	9	77	1.61a	73.0(39) a	22.5(9) a	2.1(9) a	75.2(9) a
	F2	10	63	1.62a	51.7(40) b	23.2(7) a	2.8(7) a	75.1(7) a
	Nat	6	37	1.17a	70.2(37) a	21.9(9) a	1.6(9) a	75.2(9) a

NOTE: Number of sampling days: 2006 = 10, 2007 = 6. H´ = Shannon-Weiner diversity index. The numbers in brackets indicate the number of samples taken. Values followed by same letter indicate no significant difference P = 0.05

Table 4. Bee species and their abundance in blueberry plots supplemented with *Bombus impatiens* (2008), *Apis mellifera* (2009), managed sites that were un-supplemented and natural sites also un-supplemented in eastern Newfoundland during 2008 and 2009. Site 1= supplemented; Site 2 = un-supplemented; Nat = un-supplemented natural site.

Bee species	Family	2006			2007		
		F1	F2	Nat	F1	F2	Nat
Andrena carolina	Andrenidae	19	15	15	21	30	43
Andrena rufosignata	Andrenidae	1	-	-	-	-	-
Andrena thaspii	Andrenidae	-	1	-	-	-	1
Andrena wilkella	Andrenidae	-	1	-	-	-	-
Andrena frigida	Andrenidae	-	-	1	-	-	-
Andrena sp.	Andrenidae	-	1	-	-	-	-
Lasioglossum (*Evylaeus*) *quebecense*	Halictidae	-	5	1	2	7	10
Lasioglossum (*Evylaeus*) *foxii*	Halictidae	-	1	-	-	-	-
Sphecodes solonis	Halictidae	-	-	-	-	-	6
Sphecodes levis	Halictidae	-	-	-	-	-	1
Lasioglossum (*Dialictis*) sp.	Halictidae	-	-	-	1	7	14
Bombus frigidus	Apidae	1	-	-	-	-	-
Bombus vagans bolsteri	Apidae	4	4	1	2	2	1
Bombus terricola	Apidae	-	-	1	-	-	-
Bombus impatiens	Apidae	4	-	-	-	-	-
Bombus (*Psithyrus*) *fernaldae*	Apidae	1	-	-	-	-	-
Apis mellifera	Apidae	-	-	-	1	-	-
Nomada cressonii	Anthophoridae	-	-	-	-	4	3

Table 5. Measurement of selected environmental variables in blueberry plots supplemented (Sup) with *Bombus impatiens* (2008) and *Apis mellifera* (2009), un-supplemented (Un-sup) and natural habitat in eastern Newfoundland.

Year	Treatment	No. of species	Total abundance	H´	Air Temp (°C)	RH (%)	Wind speed (m/s)
2008	Sup	6	31	0.89a	22.8 (8)a	82.9 (8)a	2.9 (8)a
	Un-sup	7	28	1.40a	22.4 (8)a	84.0 (8)a	3.8 (8)a
	Natural	5	19	0.81a	21.1 (8)a	81.9 (8)a	3.1 (8)a
2009	Sup	4	26	0.69a	23.5 (10)a	58.9 (10)a	2.8 (10)a
	Un-sup	4	43	1.19b	23.0 (10)a	64.3 (10)a	2.8 (10)a
	Natural	7	65	1.39b	22.4 (10)a	64.4 (10)a	2.4 (10)a

NOTE: Values are means; the number of measurements taken are in the brackets. Number of sampling days: 2008 = 6, 2009 = 6. H´ = Shannon-Weiner diversity index. Values followed by same letter indicate no significant difference P = 0.05.

Four species, *Andrena carolina*, *Bombus vagans bolsteri*, *Lasioglossum* (*Evylaeus*) *quebecense* and *Nomada cressonii* were captured in Malaise traps in both the supplemented site and the natural site. In addition, *Bombus* (*Psithyrus*) *fernaldae* was captured from only the natural site. The abundance of bees captured over the sampling period was surprisingly low; 18 specimens in the supplemented site and 25 in the natural site. During both study years, the air temperature, RH and wind speed were not significantly different between the study sites (Table 5).

Percent fruit-set was lowest in the sites that were supplemented with *Bombus impatiens* and *Apis mellifera* while the un-supplemented and natural sites had similar fruit-set in both years (Table 6). Measurement of berry diameter and mass was not significantly different among the sites in 2008 (Table 6). However, while the berry mass was the same in 2009, there was a difference in berry diameter, with the un-supplemented site having the largest diameter and the natural sites the smallest diameter. In 2008, the number of seeds per berry, fully developed and aborted seeds, was significantly lower in berries collected from the natural habitat compared to the other sites. In 2009, there was no difference in the fully developed seeds per berry between the sites. However, the supplemented sites had significantly lower pollination than the other two sites (supplemented vs. un-supplemented $P < 0.001$; un-supplemented vs. natural $P = 0.022$). The un-supplemented and natural sites had similar pollen deposited ($P = 0.258$). In 2008, the examination of the amount of pollen transferred to the stigmata of flowers showed that the supplemented sites had significantly more blueberry pollen tetrads deposited on the stigmata than in the un-supplemented or natural sites (supplemented vs. un-supplemented $P = 0.003$; un-supplemented vs. natural $P = 0.005$). The un-supplemented and natural sites had similar pollen deposited ($P = 0.79$). The supplemented site had significantly more flowers pollinated than the two other sites.

DISCUSSION

The bee fauna associated with lowbush blueberry in Newfoundland is small compared to mainland North America. Boulanger et al. (1967) and Vander Kloet (1976) showed that the solitary bees *Andrena regularis, Andrena carlini, Andrena nivalis* and *Andrena vicina* and the bumble

Table 6. Fruit set, berry size, seed count and percent pollination in managed blueberry plots supplemented with *Bombus impatiens* (2008) and *Apis mellifera* (2009), managed sites that were un-supplemented and natural sites also un-supplemented.

Treatment	Fruit-set (%)	Berry diameter (mm)	Berry mass (g)	Seed count per berry	Percent pollination
2008					
Supplemented	47.5 (80)a	9.26 (40)a	0.426 (40)a	34.6 (40)a	91.0 (67)a
Un-supplemented	57.4 (80)b	9.38 (40)a	0.448 (40)a	39.7 (40)a	83.6 (73)b
Natural habitat	57.7 (80)b	9.35 (40)a	0.421 (40)a	28.5 (40)b	84.3 (70)b
2009					
Supplemented	52.5 (80)a	9.46 (40)ab	0.409 (40)a	17.0 (40)a	55.3(56)a
Un-supplemented	72.7 (80)b	9.95 (40)a	0.467 (40)a	18.7 (40)a	87.3(63)b
Natural habitat	69.7 (80)b	9.23 (40)b	0.403 (40)a	18.1 (40)a	73.6(53)b

NOTE: Values are means; the number of measurements taken are in the brackets. Values followed by same letter indicate no significant difference P = 0.05.

bees *Bombus bimaculatus, Bombus terricola* and *Bombus ternarius* are all important pollinators of blueberry in mainland areas. However, only *Bombus terricola* and *Bombus ternarius* are known to occur in Newfoundland. The bees most associated with blueberry in Eastern Newfoundland include: *Andrena carolina, Lasioglossum (Evylaeus) quebecense* and *Bombus vagans bolsteri*.

In 2006, 2007 and 2008 the managed plots had higher diversity than the natural plots, as shown by Shannon-Weiner diversity index. While 2007 was the only year that showed a significant increase in fruit set in the natural site compared to one of the managed sites (Table 3), there was no significant overall affect among sites. As there is considerable year to year variation in bee abundance, plus the sampling effort between years was different, year to year comparisons could not be made.

The percent fruit set that was recorded (range = 51.7–73.0%) was higher than that reported by Lomond and Larson (1983) from an area close by. They had a fruit set of 39% in un-supplemented managed fields and suggested that an average fruit set over 35% was rare. However, Lomond and Larson (1983) utilized a destructive sampling technique for counting flowers and berries compared with our non-destructive tagged stems.

Of the sampling methods available (e.g., Malaise trap, bowl trap or sweep netting), bowl trapping is considered the most efficient, cost effective and eliminates bias of collectors (Westpal et al. 2008). While Leong and Thorp (1999) showed that generalist bees are attracted to yellow bowls, the recent literature suggests that a combination of blue, white and yellow bowls should be used in studies on bee diversity and abundance (Toler el et. 2005; Campbell and Hanula 2007). The present study was limited to using yellow bowls. However, during the summer of 2011, transects of alternating blue, white and yellow bowls (12 per each colour) where placed in the blueberry farms. The yellow bowls captured over twice the halictid and *Bombus* bees compared to the blue bowls but similar numbers to the white bowls (Hicks, unpublished data). Thus, it appears that the exclusive use of yellow bowls, while not ideal, should provide valuable information on the relative diversity and abundance among the plots. It must be noted here that bowl trapping generally fails to capture larger bodied bees such as bumblebees and honey bees at frequencies that are reflective of their perceived natural abundance (Toler et al. 2005). Smaller and medium sized bees are captured more readily in the trap fluid while the larger species may have the ability to escape the fluid. This appears to be case during this study as the proportion of bumble bees captured by the Malaise traps was greater than that trapped in the bowls. Therefore, it is possible that the bowl trapping underestimated the number of large bees in the habitats. The number of bees in general collected by the Malaise trap was considerably lower compared to the bowl traps. Campbell and Hanula (2007) suggested that bowls are better than Malaise traps for bee sampling mainly because their flight abilities may allow them to avoid capture in the Malaise trap.

Despite the greater abundance of bees in the bowls in the managed plots compared to unmanaged plots in 2006 & 2007 there was no increase in the number of fruit produced. Notwithstanding the biases of bowl traps to underestimate the abundance of large bees in the habitat, the lower fruit set in the managed sites could be the result of the differences in the density of the flowers between the two types of plots. While it was not measured directly, the managed plots had a much greater flower density than the natural plots. It is possible that while the bee abundance was greater in the managed plots, it was not great enough to pollinate all of the flowers available. In contrast, the natural plots had a low abundance of bees but those bees did not have as many flowers to visit and thus they pollinated those flowers with greater ease.

In 2009, the greater abundance and diversity of bees in the natural plots compared to that in the un-supplemented managed plots, opposite to what was observed in previous years of sampling, could be explained by the fact that one of the natural plots chosen in that year was structurally very different than the natural plots from pervious years. The soil at the 2009 natural site was considerably less rocky and had ground cover composed of grasses and numerous herbaceous plants. In the previous years, the natural sites were composed mostly of bare rocky soil with patches of the ericaceous shrubs and conifer trees. These differences in habitat could account for the difference in abundance in the natural site compared to the managed sites for 2009 and supports the study by Steffan-Dewenter et al. (2002) who showed that structurally more complex habitats had increased species richness and abundance of wild bees.

Supplementation of blueberry fields in eastern Newfoundland with *Bombus impatiens* or *Apis mellifera* did not increase fruit set in those fields. In fact, there was significantly lower fruit set when the fields were supplemented with either species (Table 7). In 2008, the number of *Bombus impatiens* captured in the bowl traps was low and may have been an artifact of bowl sampling. While fruit set was lower in the supplemented field, the percent pollination was significantly higher in that field in 2008. In other words, *Bombus impatiens* seemed to be good at transporting pollen between flowers but those flowers did not produce fruit. In this case, it may be possible that the pollen transferred may have come from flowers of the same clone. The "near-neighbor" model of pollen distribution suggests that plants are expected to receive much of their own pollen and that of their nearest neighbors (Turner et al. 1982). In this case, a clone of blueberries, which is generally genetically homogeneous (Bell et al. 2009), dominates almost exclusively in patches ranging from 7–23 m^2 (Yarborough 2009). The results from the present study, where significantly more pollen was transferred to flower stigmata but where the flowers failed to produce fruit may have been caused by these flowers receiving incompatible pollen from their nearest neighbor. Lowbush blueberry is considered to be generally self-incompatible (Aalders and Hall 1961; Wood 1968; Hall et al. 1979). While significant amounts of pollen were transferred, this pollen was not compatible and due to physiological barriers to self-pollination, aborted fruit production. This fruit abortion of self-infertile clones was shown by Aalders and Hall (1961).

Supplementation of farms with *Apis mellifera* did not show increased transfer of pollen or an increase in fruit-set (Table 6). In this case, the transects were close to the hives but only a small proportion of the collected bees were *Apis mellifera*. Bowl sampling may have underestimated the abundance of honey bees in the fields, however, the Malaise trap placed 100 meters from the hive did not collect any *Apis mellifera* during the blooming period. The recommended stocking rate for honey bees on Maine blueberry farms is 7.5–10 hives/ha (Stubbs and Drummond 2001). The present study may not have had adequate number of hives available (1.5–2 hives/ha), although Lomond and Larson (1983) showed an increase in the rate of blueberry pollination using a stocking rate of 1.7 hives/ha. Generally, the abilities of native bees to buzz-pollinate the blueberry flowers is an advantage over honey bees which take nectar and do not sonicate (Javorak et al. 2002). While honey bees are not considered to be the most efficient bees for pollinating blueberry, some authors found that their higher abundances made up for their inefficiencies and increased fruit-set (Lomond and Larson 1983; Eaton 1992; Aras et al. 1996; Dedej and Delephane 2003). In contrast, Wood (1961) did not find an increase in blueberry fruit-set with increased honey bee density (stocking rate up to 3.6 hives/ha). Results from the present study do not support the idea that increased honey bee density increases fruit production, at least in eastern Newfoundland during that particular year and at the stocking rate used.

Unlike others who have shown that supplementation of blueberry fields with bees increased fruit-set (Lomond and Larson 1983; Eaton 1992; Aras et al. 1996; Stubbs and Drummond 2001; Desjardins and de O'liveira 2006; Tuell et al. 2009), supplementation with *Bombus impatiens* and *Apis mellifera* did not increase fruit set but was actually detrimental as percent fruit-set was significantly lower in the supplemented fields compared to the un-supplemented fields. Intuitively, it would seem logical that supplementation with bees should combine with the pollination activities of native bees and thus show an overall increase. Greenleaf and Kremen (2006) showed that pollination of hybrid sunflowers by honey bees caused a 5-fold additive affect on pollination efficiency. In addition, while honey bees are not aggressive toward other insects while foraging, they do compete with other species for floral resources (Goulson 2003 and references therein). Thomson (2004) showed that honey bees competitively suppressed a native social bee known to be an important pollinator. Winfree et al. (2007) suggested that native bees alone can provide sufficient pollination and that supplementation may not be required in some agro-ecosystems.

The supplementation of blueberry fields with *Bombus impatiens* is thought to be better than supplementation with honey bees (Stubbs and Drummond 2001; Desjardins and de Oliveira 2006). However, in eastern Newfoundland, the stocking rates of *Bombus impatiens* and *Apis mellifera* observed in this study failed to increase fruit set compared to un-supplemented areas and thus does not support their use by farmers in eastern Newfoundland. However, increasing the stocking rates may increase pollination, but presently it is unknown if that would result in greater fruit production. As the bee fauna throughout Newfoundland is not well known, additional studies should be initiated to determine whether supplementation with introduced bees in those areas is worthwhile.

Presently, Newfoundland is in an enviable position regarding its population of *Apis mellifera*. The province has strict importation regulations and because of its geographical isolation it does not harbour the same parasites that plague honey bees in other areas worldwide (Williams et al. 2010). Honey bees can not survive as feral populations in Newfoundland thus limiting the possibilities of disease transmission. The parasites and diseases of native *Bombus* spp have not been studied and we are unsure of their impact on these vulnerable populations. However, *Bombus* spp. in other areas of North America are known to harbor several pathogens. Pathogen spillover from commercial *Bombus impatiens* colonies to native species has been documented in other areas (Colla et al. 2006). In Newfoundland, several specimens of native *Bombus* species including *Bombus tarnarius*, *Bombus vagans bolsteri*, *Bombus terricola* and *Bombus (Psithurus) fernaldae* have been found inside the colony boxes of imported *Bombus impatiens* at the end of the season (personal observation). While it is unclear what impact the parasites and diseases may have on native bee species, they have been implicated as the cause of the decline of important bee pollinators in North America (Berenbaum et al. 2007).

With the decline in native species for various reasons (see Colla and Packer 2008), it may open up new niches that may be filled by exotic species. With global warming, Newfoundland may be at greater risk of having non-native bees establish here as the climate becomes milder. In Newfoundland, many of the spring and fall flowering plants rely on native *Bombus* species for their pollination. The loss of native species by diseases and competition with exotic species may result in significant changes to the island's ecosystem. We may see substantial changes in the availability of seeds and berries that will negatively impact biodiversity of birds and mammals (Winter et al. 2006).

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REFERENCES

Aalders, L.E., and Hall, I.V. 1961. Pollen incompatibility and fruit set in lowbush blueberries. Canadian Journal of Genetics and Cytology **3**: 300-307.

Aras, P., de Oliveira, D., and Savoie, L. 1996. Effect of a honey bee (Hymenoptera: Apidae) gradient on the pollination and yield of lowbush blueberry. Journal of Economic Entomology **89**: 1080-1083.

Bell, D.J., Rowland, L.J., Zhang, D., and Drummond, F.A. 2009. Spatial genetic structure of lowbush blueberry, *Vaccinium angustifolium*, in four fields in Maine. Botany **87**: 932-949.

Berenbaum, M., Bernhardt, P., Buchmann, S., Calderone, N.W., Goldstein, P., Inouye, D.W., Kevan, P.G., Kremen, C., Medellin, R.A., Ricketts, T., Robinson, G.E.A., Snow, A., Swinton, S.M., Thien, L.B., and Thompson, F.C. 2007. Status of Pollinators in North America. The National Academies Press, Washington, D.C.

Boulanger, L.W., Wood, G.W., Osgood, E.A., and Dirks, C.O. 1967 Native bees associated with lowbush blueberry in Maine and Eastern Canada. Maine Agricultural Experimental Station. Technical Bulletin 26. Orono, Maine.

Campbell, J.W., and Hanula, J.L. 2007. Efficiency of Malaise traps and colored pan traps for collecting flower visiting insects from three forested ecosystems. Journal of Insect Conservation **11**: 399-408.

Colla, S.R., Otterstatter, M.C., Gegear, R.J., and Thomson, J.D. 2006. Plight of the bumble bee: pathogen spillover from commercial to wild populations. Biological Conservation **129**: 461-467.

Colla, S.R., and Packer, L. 2008. Evidence for decline in eastern North American bumble bees (Hymenoptera: Apidae), with special focus on *Bombus affinis* Cresson. Biodiversity and Conservation **17**: 1379-1391.

Dedej, S., and Delaplane, K.S. 2003. Honey Bee (Hymenoptera: Apidae) pollination of rabbiteye blueberry *Vaccinium ashei* var. 'climax' is pollinator density-dependent. Journal of Economic Entomology **96**: 1215-1220.

Desjardins, E.C., and de Oliveira, D. 2006. Commercial bumble bee *Bombus impatiens* (Hymenoptera: Apidae) as a pollinator in lowbush blueberry (Ericale: Ericaceae) fields. Journal of Economic Entomology 99: 443-449.

Eaton, L.J. 1992. Effect of pollinator number on fruit set and yield of lowbush blueberry. Canadian Beekeeping **17**: 32-34.

Finnamore, A.T., and Michener, C.D. 1993. Superfamily Apoidea. *In* Hymenoptera of the World: an identification guide to families. *Edited by* H. Goulet, and J.T. Huber. Agriculture Canada Publication 1894/E. pp. 279-357.

Goulson, D. 2003. Effects of introduced bees on native ecosystems. Annual Review of Ecology, Evolution and Systematics **34**: 1-26.

Government of Newfoundland. 2011. Available from http://www.nr.gov.nl.ca/nr/agrifoods/crops/berries/blueberry.html [accessed 18 December 2011].

Greenleaf, S.S., and Kremen, C. 2006. Wild bees enhance honey bee's pollination of hybrid sunflower. Proceeding of the National Academy of Sciences, **103**: 13890-13895.

Hall, I.V., Aalder, L.E., Nickerson, N.L., and Vander Kloet, S.P. 1979. The Biological Flora of Canada. 1. *Vaccinium angustifolium* Ait. Sweet Lowbush Blueberry. Canadian Field-Naturalist **93**: 415-430.

Hammer, Ø., Harper, D.A.T., and Ryan P. D. 2001. PAST: Paleontological Statistics Software Package for Education and Data Analysis. Palaeontologia Electronica 4(1). Available from http://palaeo-electronica.org/2001_1/past/issue1_01.htm [accessed 22 December 2010].

Hicks, B.J. 2009. Observations of the nest structure of *Osmia inermis* (Hymenoptera: Megachilidae) from Newfoundland, Canada. Journal of the Acadian Entomological Society **5**: 12-18.

Javorek, S.K., McKenzie, K.E., and Vander Kloet, S.P. 2002. Comparative pollination effectiveness among bees (Hymenoptera: Apoidea) on lowbush blueberry (Ericaceae: *Vaccinium angustifolium*). Annals of the Entomological Society of America **95**: 345-351.

Leong, J.M., and Thorp, R.W. 1999. Colour-coded sampling: the pan trap colour preferences of oligolectic and nonoligolectic bees associated with a vernal pool plant. Ecological Entomology **24**: 329-335.

Lomond, D., and Larson, D.J. 1983. Honey bees, *Apis mellifera* (Hymenoptera: Apidae), as pollinators of lowbush blueberry, Vaccinium angustifolium, on Newfoundland coastal barrens. The Canadian Entomologist **115**: 1647-1651.

Michener, C.D. 2007. The bees of the world. The John Hopkins University Press, Baltimore.

Poole, R.W. 1974. An introduction to quantitative ecology. McGraw-Hill, New York.

Ricketts, R. 2004. An overview of the Newfoundland and Labrador Agrifoods Industry. Available from http://www.nr.gov.nl.ca/nr/publications/agrifoods/overview04.pdf, Government of Newfoundland and Labrador, Department of Natural Resources [accessed 4 January 2011].

Sheffield, C.S., Kevan, P.G., Smith, R.F., Rigby, S.M., and Rogers, R.E.L. 2003. Bee species of Nova Scotia, Canada, with new records and notes on bionomics and floral relations (Hymenoptera : Apoidea). Journal of the Kansas Entomological Society **76**: 357-384.

Statistics Canada. 2011. Available from http://www.statcan.gc.ca/pub/22-003-x/22-003-x2010001-eng.htm [accessed 18 December 2011].

Steffan-Dewenter, I., Münzenberg, U., Bürger, C., Thies, C., and Tscharntke, T. 2002. Scale-dependent effects of landscape context on three pollinator guilds. Ecology **83**: 1421-1432.

Stubbs, C.S., and Drummond, F.A. 2001. *Bombus impatiens* (Hymenoptera: Apidae): An alternative to *Apis mellifera* (Hymenoptera: Apidae) for lowbush blueberry pollination. Journal of Economic Entomology **94**: 609-616.

Thomson, D. 2004. Competitive interactions between the invasive European honey bee and native bumble bees. Ecology **85**: 458-470.

Toler, T.R., Evans, E.W. and Tepedino, V.J. 2005. Pan trapping for bees in Utah's west desert: the importance of color diversity. Pan-Pacific Entomologist **81**: 103-113.

Tuell , J.K., Ascher, J.S., and Isaacs, R. 2009. Wild bees (Hymenoptera: Apoidea: Anthophila) of the Michigan highbush blueberry agroecosystem. Annals of the Entomological Society of America **102**: 257-287.

Turner, M.E., Stephens, C., and Anderson, W.W. 1982. Homozygosity and patch structure in plant populations as a result of dearest-neighbor pollination. Proceedings of the National Academy of Science **79**: 203-207.

Vander Kloet, S.P. 1976. Nomenclature, taxonomy and biosystematics of *Vaccinium* section Cyanococcus (the blueberries) in North America. 1. Natural barriers to gene exchange between *Vaccinium angustifolium* Ait. and *Vaccinium corymbosum* L. Rhodora **78**: 503-515.

Westpal, C., Bommarco, R., Carré, G., Lamborn, E., Morrison, N., Petanidou, T., Potts, S.G., Roberts, S.P.M., Szentgyörgyi, H., Tscheulin, T., Vaissière, B.E., Woyciechowski, M., Biesmeijer, J.C., Kunin, W.E., Settele, J., and Steffan-Dewenter, I. 2008. Measuring bee diversity in different European habitats and biogeographical regions. Ecological Monographs **78**: 653-671.

Williams, G.R., Head, K., Burgher-MacLellan, L., Rogers, R.E.L., and Shutler, D. 2010. Parasitic mites and microsporidians in managed western honey bee colonies on the island of Newfoundland, Canada. The Canadian Entomologist **142**: 584-588.

Winfree, R., Williams, N.M., Dushoff, J., and Kremen, C. 2007. Native bees provide insurance against ongoing honey bee losses. Ecology Letters **10**: 1105-1113.

Winter, K., Adams, L., Thorp, R., Inouye, D., Day, L., Ascher, J., and Buchmann, S. 2006. Importation of non-native bumble bees into North America: potential consequences of using *Bombus terrestris* and other non-native bumble bees for greenhouse crop pollination in Canada, Mexico and the United States. A White Paper of the North American Pollinator Protection Campaign. 33pp.

Wood, G.W. 1961. The influence of honey bee pollination on fruit set of the lowbush blueberry. Canadian Journal of Plant Sciences **41**: 332-335.

Wood, G.W. 1968. Self-fertility in the lowbush blueberry. Canadian Journal of Plant Science **48**: 433-434.

Yarborough, D. 2009. Wild Blueberry culture in Maine. Wild Blueberry Fact Sheet No 220. Available from http://umaine.edu/blueberries/factsheets/production/wild-blueberry-culture-in-maine/ University of Maine, Orono, Maine [accessed 4 January 2011].