# LOWBUSH BLUEBERRY POLLINATION: LINKING BEE ABUNDANCE AND LANDSCAPE PATTERN

## PROJECT LEADER AND COLLABORATORS

Steven K. Javorek (Agriculture and Agri-Food Canada-Project Leader)
John Ascher (American Museum of Natural History, New York)
Bleuet NB Blueberries (Applicant)
Etienne Thériault (NB Agriculture, Aquaculture and Fisheries)
Maurice Basque (NB Agriculture, Aquaculture and Fisheries)
Michel Melanson (NB Agriculture, Aquaculture and Fisheries)

## SUMMARY

   Pollination is a critical component in the production of lowbush blueberry. Recent declines in honey bee numbers at global, regional and local scales have focused the need to develop a diversified pollination strategy to ensure the sustainable production of lowbush blueberry now and in the future. This involves maintaining healthy honey bee populations, exploring the prudent use of alternative managed pollinators and taking action to understand, conserve and enhance native bee populations. The goal of this research was to develop a new lowbush blueberry land development/restoration model that increases the long term competitiveness of the industry by incorporating landscape conservation elements specifically targeted to increase native bee abundance and, by extension, their pollination contribution.

   Research was conducted in 5 New Brunswick blueberry agroecosystems from 2010-2012. There are close to 60 species of bees associated with lowbush blueberry in NB with *Andrena* (digger bees), *Bombus* queens (bumble bees) and *Lasioglossum* (sweat bees) being the most important pollinating genera. Analysis looking at the relationship between bee abundance on blueberry and the amount and spatio-temporal distribution of floral resources did not reveal significant patterns when the total native bee abundance assessed. However, when genera were analysed separately many significant relationships were found. *Andrena* abundance foraging on blueberry was related to floral availability to a distance of 500 metres around blueberry field during April-May prior to the commencement of blueberry flowering in June. *Bombus* queen abundance was also related to the amount of pre-blueberry forage (to 250 metre) and floral availability at 1000 metres in July and August. These pattern reveal that *Bombus* abundance on blueberry is in part related to spring queen dispersal rather than from resident populations. Forage availability during July when the second generation of *Lasioglossum* is emerging influences the abundance of these genera during the blueberry bloom.

   This research shows the relationship between floral resource availability and native bee abundance on lowbush blueberry. However, in order to have abundant and diverse native bee communities in lowbush blueberry agroecosystems the availability of forage must be tailored to the requirement of the primary pollinating genera as stated above. Using these requirements as guidelines will inform blueberry produces on what (and where) landscape elements should be maintained or encouraged while developing new blueberry land or which elements need restoration on existing land.

**Justification**

Adequate pollination is the cornerstone of blueberry production and speaks directly to the long-term sustainability and competitiveness of the industry. The modern blueberry industry depends strongly on managed honey bees to provide pollination levels required for commercial production. As a response to recent honey bee (*Apis mellifera*) shortages the industry has established the alfalfa leafcutting bee (*Megachile rotundata*) as an alternative managed pollinator. This was especially the case in regions where the pollination deficit caused by inadequate available honey bee units was most severe. The underlying message is clear; in order to maintain production the blueberry industry needs a diversified pollination strategy. This strategy must take full advantage of managed bees and maximize the pollination contribution of native bees. As forecasted in the recent National Academy of Sciences report on the Status of Pollinators in North America (National Research Council 2007), native pollinators will play a much greater role in crop production in the future. The present and future role of native bees as lowbush blueberry pollinator should be must be acknowledged as a key component of economically viable future production.

This project seeks to elucidate the relationship between landscape composition/configuration and the abundance of native bees pollinating blueberry. Understanding the central question; "How much habitat is enough to maintain commercially relevant populations on native bees in blueberry agro-ecosystems?" is the main focus of this research. Guidelines for new land development and restoration of existing land stemming from this research will, for the first time, clearly direct land management decisions to incorporate pollinator habitat. Such an approach speaks directly to the sustainable component of the lowbush blueberry industry pollination strategy. Understanding the relationship between bees and the environment and being able to direct activities to accomplish this will allow the industry to take full advantage ecological goods and services inherent to a *healthy* lowbush blueberry agro-ecosystem. This approach is truly unique as commercial crop production AND native bee conservation follow the same set of guidelines. This creates a sustainable production system that benefits for the presence of native bees as well as a healthy ecosystem where critical pollination services are met. In addition to the obvious benefits to long-term production sustainability and the environment the story of "wild" blueberries and their "wild" pollinators, competitively speaking, should resonate with consumers that are becoming increasing interested and concerned with where their food comes from.

**Introduction**

*Pollinator Decline.* Wild bees are economically and ecologically important as their pollination services are vital to agriculture and essential for maintaining the structure and function of natural and working landscapes. In Canada, there are approximately 800 species of bees, many of which contribute to the pollination of major crops such as apple, cranberry, blueberry, seed crops and oilseeds. Recent declines in honey bees (*Apis mellifera*) related to colony Collapse Disorder (CCD) in the United States has focused attention on the importance of pollinators and the security of pollination services. In Canada,

introduced parasites (*Varroa* and tracheal mites) and pathogens have also contributed to *A. mellifera* decline which has impacted the number of hives available for crop pollination.  Bee decline is not restricted to honey bees.  Pathogen spillover from commercially reared bumble bee (*Bombus impatiens*) colonies, habitat alteration/fragmentation and agricultural intensification appear to be the main contributors to bumble bee decline (National Academy of Sciences Report 2007).  In addition, In Canada, three widespread species (*B. terricola*, *B. affinis*, *B. occidentalis*) have undergone severe declines (Colla et al. 2006).  Social (bumble bees) and solitary wild bees have declined as a result of landscape change; specifically, of habitat loss, fragmentation and deterioration (Biesmeijer et al. 2007).

***Wild Bees in the Landscape Context.***  Wild bees perceive and utilize the landscape at different spatial scales depending on their dispersal abilities and foraging.  The scale of interaction with the surrounding landscape is generally related to body size.  Solitary bees respond to the local landscape features at a radius of 750-1000 metres, whereas social species (bumble bees) respond at a broader scale of 1,500 to 3,000 metres (Steffan-Dewenter et al. 2002).  However, their visitation rate at crops drops to half its maximum at 590 m (solitary bees) and 440 m (social bees) from natural habitat (Ricketts et al. 2008).  Ricketts et al. (2008) in a synthesis of 16 studies on tropical and temperate crops, found a general pattern of declining species richness and visitation rates at crops with increasing distance from natural habitats.  Winfree et al. (2008) indicates that both local habitat characteristics (e.g. habitat size, floral availability) and regional habitat heterogeneity are important factors in determining bee abundance and species diversity.  The spatial arrangement of high-quality habitats is an important factor in determining the distribution of pollinators in the landscape (Banazak 1992).  In intensively managed agricultural systems remnant, high quality habitats sustain more abundant and diverse pollinator communities (Kohler et al. 2008, Morandin 2007).  However, few studies have quantified the extent to which bees disperse from these high-quality habitats into intensively used agricultural landscapes (Steffan-Dewenter and Tscharntke 1999, Albrecht et al. 2007).   Given that landscape configuration (spatial arrangement of habitat) and composition (resource availability) influence bee abundance and play a role in the organization of wild bee communities, the alteration, fragmentation and deterioration of habitat associated with intensification of agricultural practices can have significant effects on wild pollinator communities and jeopardize their stabilizing effect of on pollination services at the landscape scale (Tscharntke et al. 2005, Kremen et al. 2007, Klein et al. 2006).

***Native Bees and Blueberry Pollination.***  A diverse suite of wild bees contribute to the pollination of lowbush blueberry.  As individuals, native bees such as bumble bees (*Bombus* spp.) and Digger Bees (*Andrena* spp.) can efficiently pollinate greater than six times the number of blueberry flowers per unit time than managed honey bees.  Despite these desirable pollination attributes, the contribution of native bees to lowbush blueberry production is not fully acknowledged as their numbers vary dramatically from one field to the next.

**OBJECTIVE**

**Overall Objective.**  The overall objective of this research was to develop a new lowbush blueberry land development/restoration model that increases the long term competitiveness of the industry by

incorporating landscape conservation elements specifically targeted to increase native bee abundance and, by extension, their pollination contribution.
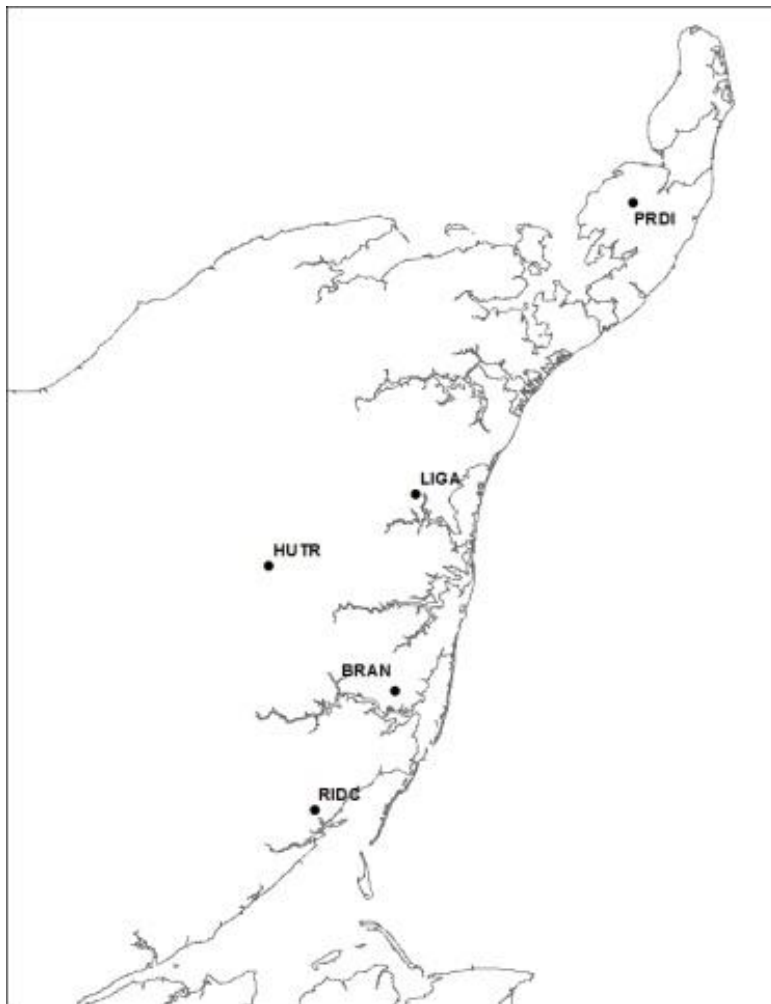
**Objective 1.** Produce complete land cover maps, incorporate environmental variables and extract landscape metrics for study areas on the Acadian Peninsula.

**Objective 2.** . Determine the variability in wild bee abundance and diversity among lowbush blueberry fields spanning a landscape gradient from structurally simple to complex.

**Objective 3.** Create habitat suitability maps (species, taxa, guilds) for bees associated with lowbush blueberry pollination.

**Objective 4.** Examine the effect of landscape pattern (composition and configuration) on wild bee abundance/diversity.

## METHODOLOGY

**Figure 1. Study sites.**

**Study Sites.** Five primary sites were used during 2011/2012 (Riviere-des-Cache (RIDC), Brantville (BRAN), Haut Tilley Road (HUTR), Little Gaspereau (LIGA) and Petite-Riviere de-l'Ile (PRDI) (**figure 1**). An additional site at Little Shippegan (LISH) was included for some analyses. Each study site consisted of a 2 × 2km area with the target blueberry field located in the centre.

**Land Cover Mapping and floral Resource Availability.** Using a combination of heads-up digitizing and automated feature extraction detailed land cover maps (10 km$^2$) were created for each study site from NB orthophotos (1m$^2$ resolution). Botanical surveys were conducted in each cover type to determine habitat-specific floral abundance during April-May, June (blueberry flowering), July / August. Floral abundance values (ranked 0-10) from each time period were then assigned to land cover polygons to create forage availability maps. Foraging resources indices (FRI) were generated (FRI=∑ (r×p); where

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r=foraging resource value and p=the proportion of the study site) at two nested spatial scales (500m and 1000m) to determine spatio-temporal forage availability at each study site.

**Figure 2.** Blueberry field at Haut Tilley Road study site.

**Native Bee Sampling.** During the lowbush blueberry flowering period native bees were surveyed on two dates using three methods (aerial netting, pan trap and propylene glycol traps). All specimens were pinned, identified and databased.

**Analysis.** Regression analysis was used to determine the relationship between forage availability at different spatial scales and native bee abundance foraging on blueberry.

**RESULTS AND DISCUSSION**

**Native Bees Associated with Lowbush Blueberry Pollination on the Acadian Peninsula, New Brunswick**

A diverse community of native bees representing 10 genera and 69 species is associated with lowbush blueberry on the Acadian Peninsula of New Brunswick. A total of 1640 native bees were collected on blueberry in 2011/2012. The vast majority of blueberry pollinators (91%) were from three genera: *Lasioglossum* (38.8%), *Bombus* (27.2%) and *Andrena* (25.7%). The remaining 9% of the pollinator guild was composed of *Colletes* (4%), *Halictus* (<1%), *Osmia* (<1%), *Augochlorella* and *Augochlor*a (<1%) and the two cleptoparasitic genera *Sphecodes* (3%) and *Nomada* (2%). Of the bees found on blueberry 66% were solitary (*Andrena*, *Lasioglossum*, *Colletes*, *Halictus*, *Osmia*, *Augochlorella*, and *Augochlor*a), 29% social (*Bombus*) and 5% cleptoparasitic (*Sphecodes*, *Nomada* and *Psithyrus* (cleptoparasitic subgenera of *Bombus*). The following is a list of the native bees found on lowbush blueberry during this study.

**Native Bees Associated with Lowbush Blueberry on the Acadian Peninsula, New Brunswick**

**FAMILY COLLETIDAE**
Subfamily Colletidae

*Colletes*
*Colletes validus* Cresson, 1868

**FAMILY ANDRENIDAE**

*Andrena*
*Andrena (Andrena) carolina Viereck, 1909*
*Andrena (Andrena) rufosignata Cockerell, 1902*
*Andrena (Conandrena) bradleyi Viereck, 1907*
*Andrena (Larandrena) miserabilis Cresson, 1872*
*Andrena (Melandrena) carlini Cockerell, 1901*
*Andrena (Melandrena) nivalis Smith, 1853*
*Andrena (Melandrena) regularis Malloch, 1917*
*Andrena (Melandrena) vicina Smith, 1853*
*Andrena (Micrandrena) melanochroa Cockerell, 1898*
*Andrena (Simandrena) nasonii Robertson, 1895*
*Andrena (Simandrena) wheeleri Graenicher, 1904*
*Andrena (Taeniandrena) wilkella (Kirby, 1802)*
*Andrena (Thysandrena) w-scripta Viereck, 1904*
*Andrena (Trachandrena) forbesii Robertson, 1891*
*Andrena (Trachandrena) miranda Smith, 1879*

**FAMILY HALICTIDAE**

Subfamily Halictinae
Tribe Halictini

*Halictus*
*Halictus (Pachyceble) confusus confusus* Smith, 1853
*Halictus (Protohalictus) rubicundus* (Christ, 1791)
*Lasioglossum*
*Lasioglossum (Dialictus) albipenne* (Robertson, 1890)
*Lasioglossum (Dialictus) cressonii* (Robertson, 1890)
*Lasioglossum (Dialictus) laevissimum* (Smith, 1853)
*Lasioglossum (Dialictus) leucocomum* (Lovell, 1908)
*Lasioglossum (Dialictus) planatum* (Lovell, 1905)
*Lasioglossum (Dialictus) subversans* (Mitchell, 1960)
*Lasioglossum (Dialictus) tenax* (Sandhouse, 1924)
*Lasioglossum (Dialictus) timothyi* Gibbs, 2010
*Lasioglossum (Evylaeus) cinctipes* (Provancher, 1888)
*Lasioglossum (Evylaeus) comagenense* (Knerer and Atwood, 1964)
*Lasioglossum (Evylaeus) quebecense* (Crawford, 1907)
*Lasioglossum (Lasioglossum) acuminatum* McGinley, 1986
*Lasioglossum (Lasioglossum) leucozonium* (Schrank, 1781)
*Lasioglossum (Lasioglossum) zonulum* (Smith, 1848)

**Sphecodes**
*Sphecodes atlantis* Mitchell, 1956
Sphecodes autumnalis Mitchell, 1956.
Sphecodes confertus Say, 1837
Sphecodes coronus Mitchell, 1956
Sphecodes cressonii (Robertson, 1903)
Sphecodes davisii Robertson,
Sphecodes dichrous Smith, 1853
Sphecodes johnsonii Lovell, 1909
Sphecodes levis Lovell and Cockerell, 1907
Sphecodes mandibularis Cresson, 1872
Sphecodes minor Robertson, 1898
Sphecodes solonis Graenicher, 1911
Sphecodes townesi Mitchell, 1956

Tribe Augochlorini

*Augochlora*
*Augochlora pura pura* (Say, 1837)

*Augochlorella*
*Augochlorella aurata* (Smith, 1853)

**FAMILY MEGACHILIDAE**
*Tribe Osmiini*

*Osmia*
*Osmia (Acanthosmioides) kenoyeri* Cockerell, 1915
*Osmia (Melanosmia) atriventris* Cresson, 1864
*Osmia (Melanosmia) bucephala* Cresson, 1864
*Osmia (Melanosmia) inermis* (Zetterstedt, 1838)
*Osmia (Melanosmia) simillima* Smith, 1853
*Osmia (Melanosmia) tersula* Cockerell, 1912

**FAMILY APIDAE**

Subfamily Nomadinae
Tribe Nomadini

*Nomada*
*Nomada cressonii* Robertson, 1893
*Nomada cuneata* (Robertson, 1903)
*Nomada depressa* Cresson, 1863
*Nomada luteoloides* Robertson, 1895
*Nomada maculata* Cresson, 1863
*Nomada vicina* Cresson, 1863
*Nomada valida* Smith, 1854

Subfamily Apinae
Tribe Bombini

***Bombus***

*Bombus (Bombus) terricola* Kirby, 1837
*Bombus (Fervidobombus) fervidus* (Fabricius, 1798)
*Bombus (Psithyrus) ashtoni* (Cresson, 1864)
*Bombus (Psithyrus) citrinus* (Smith, 1854)
*Bombus (Psithyrus) fernaldae* (Franklin, 1911)
*Bombus (Psithyrus) insularis* (Smith, 1861)
*Bombus (Pyrobombus) impatiens* Cresson, 1863
Bombus (Pyrobombus) perplexus Cresson, 1863
*Bombus (Pyrobombus) sandersoni* Franklin, 1913
*Bombus (Pyrobombus) ternarius* Say, 1837
Bombus (Pyrobombus) vagans vagans Smith, 1854
Bombus (Subterraneobombus) borealis Kirby, 1837


For the remainder of this paper we will focus on the primary pollinating genera (*Andrena*, *Lasioglossum* and *Bombus*.
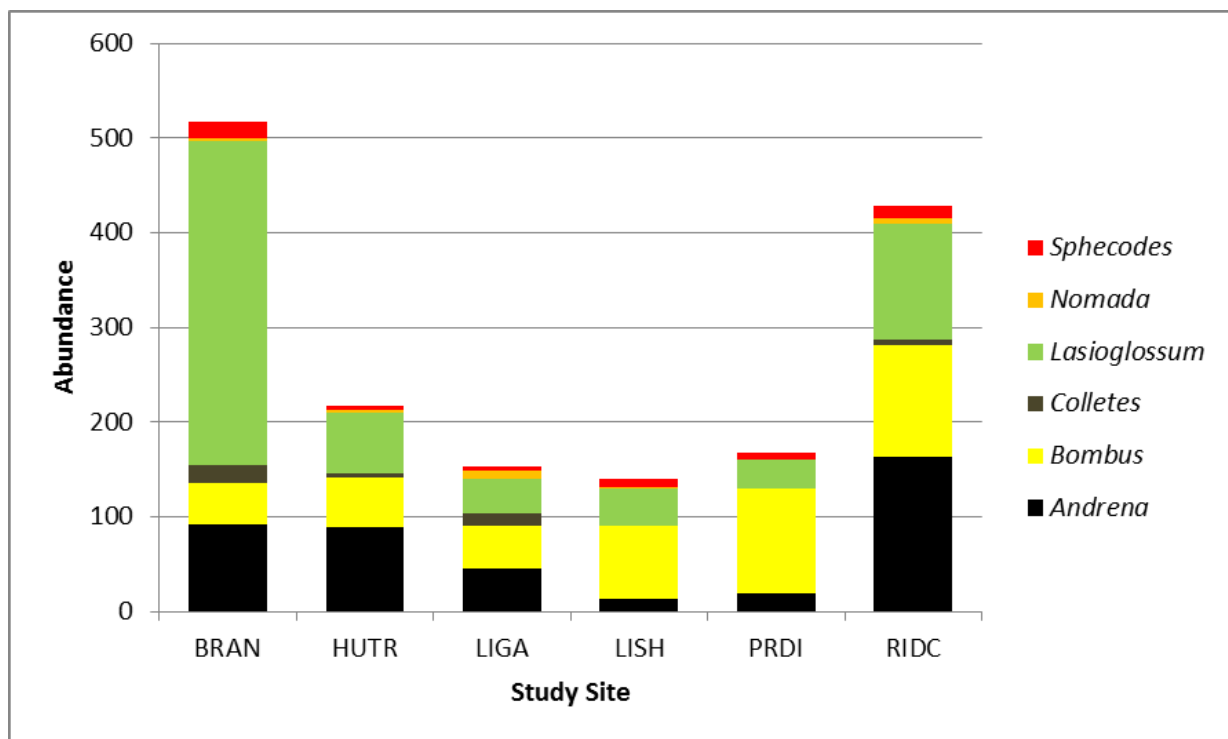


**Figure 3.** The three most important native bee genera for pollinating lowbush blueberry in New Brunswick (*Andrena*, *Lasioglossum* and *Bombus*).

**Native Bee Abundance and Diversity**

Native bee abundance and diversity varied significantly among study sites (**table 1**, **figure x**). BRAN and RIDC had the highest *overall* bee abundance among sites. However, the composition of the pollinator guild differed among these sites. *Lasioglossum* comprised the majority of bees (66%) at BRAN whereas RIDC had a more balanced representation of the major pollinating fauna (*Andrena*: 38%, *Bombus*: 29% and *Lasioglossum*: 29%). *Andrena* was well represented at RIDC, BRAN and HUTR but only a minor component of total abundance at LISH and PRDI with intermediate numbers collected at LIGA. LISH, PRDI and RIDC had the highest *Bombus* abundance among sites. At both the LISH and PRDI study sites, *Bombus* was the dominant pollinator comprising 55 and 66% of total abundance, respectively.

Table 1.  The relative abundance of native bee genera among sites (samples pooled to represent total captures 2011/2012).

| Study Site | Bombus | Andrena | Colletes | Lasioglossum | Nomada | Sphecodes |
|---|---|---|---|---|---|---|
| BRAN | 9% | 18% | 4% | 66% | 0% | 3% |
| HUTR | 24% | 41% | 2% | 29% | 1% | 2% |
| LIGA | 29% | 30% | 9% | 24% | 6% | 3% |
| LISH | 55% | 9% | 0% | 29% | 1% | 6% |
| PRDI | 66% | 11% | 0% | 18% | 0% | 4% |
| RIDC | 28% | 38% | 1% | 29% | 1% | 3% |



**Figure 4.**  Abundance and diversity of native bees among study sites (samples pooled to represent total captures 2011/2012).
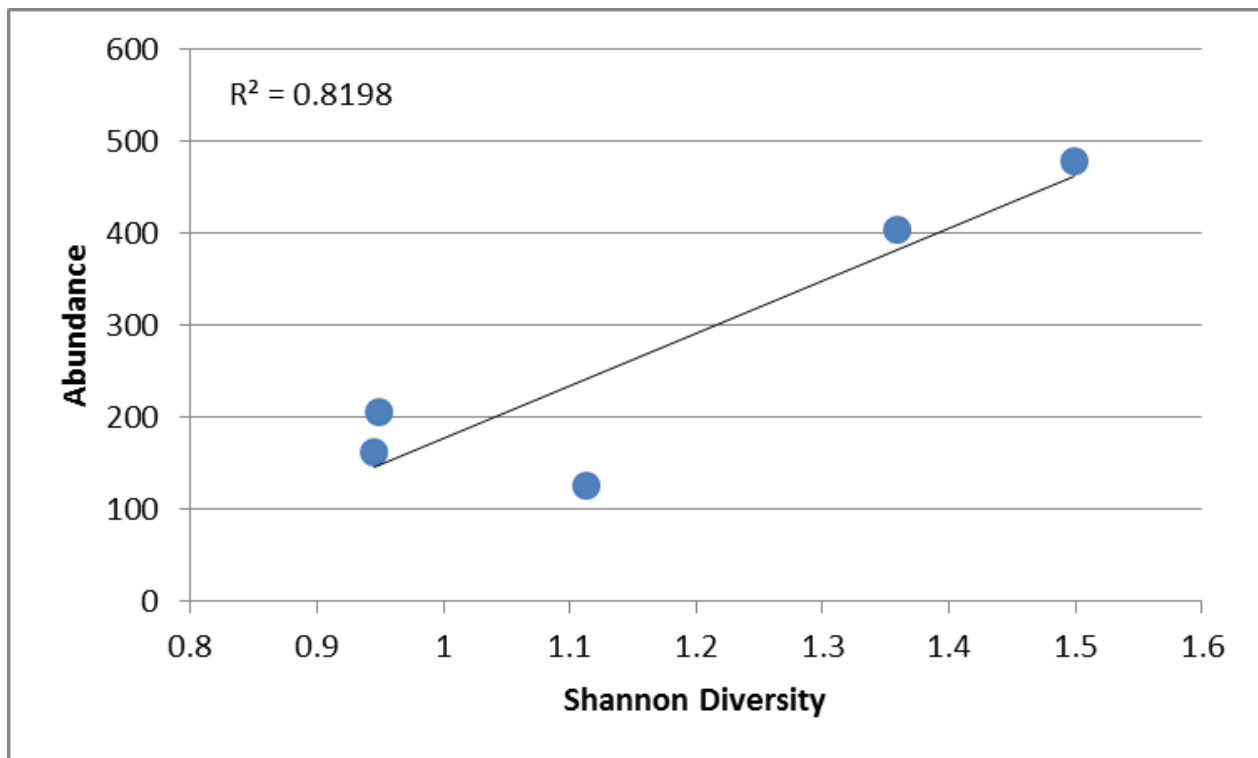
**Landscape Metrics**

Table 2 shows landscape metrics calculated for each site at 500 and 1000 metres from blueberry fields. Although metrics varied among sites, only Shannon's Diversity at 500 metres had a significant positive relationship with native bees foraging on blueberry (**figure 5**).  Interestingly, native bees did not respond to landscape heterogeneity (defined by total edge).  In the case of lowbush blueberry agroecosystems investigated during this study, increased landscape heterogeneity did not translate into greater forage availability.

**Table 2.** Landscape metric calculated for each study site.

| Site | Distance (m) | Patch Number | Total Edge | Patch Richness | Shannon Diversity | Shannon Evenness |
|------|------|------|------|------|------|------|
| BRAN | 1000 | 69 | 73,178 | 8 | 1.3702 | 0.6589 |
|      | 500 | 28 | 18,043 | 7 | 1.4984 | 0.7700 |
| HUTR | 1000 | 79 | 73,599 | 8 | 1.264 | 0.6078 |
|      | 500 | 36 | 26,706 | 6 | 0.9485 | 0.5294 |
| LIGA | 1000 | 207 | 99,307 | 15 | 1.4624 | 0.54 |
|      | 500 | 81 | 32,290 | 6 | 1.3131 | 0.7328 |
| PRDI | 1000 | 57 | 61,237 | 7 | 1.366 | 0.702 |
|      | 500 | 91 | 39,259 | 6 | 0.9456 | 0.5278 |
| RIDC | 1000 | 155 | 85,485 | 15 | 1.5178 | 0.5605 |
|      | 500 | 58 | 21,874 | 11 | 1.3584 | 0.5665 |

Patch Density=patches per 100 hectares, Total Edge=sum of the lengths (m) of all patch types.



**Figure 5.** The relationship between native bee abundance foraging on blueberry and habitat diversity (Shannon's Diversity) within 500 metres of blueberry fields (F=13.65, p=0.0344).
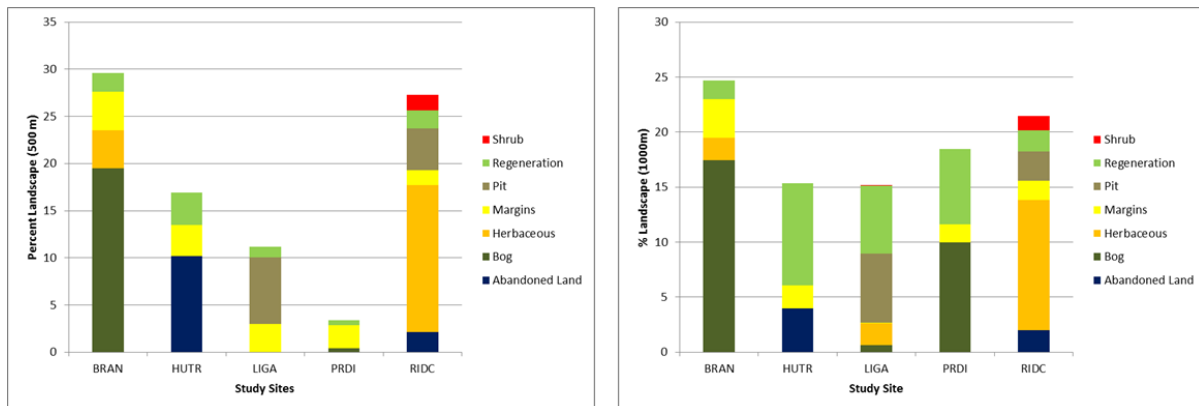
**Table 3.** Results of regression analysis showing relationships of native bee abundance on blueberry and foraging resource Index values at 500 and 1000 metres surrounding blueberry fields at different times of the year (significant p values shown).

| Genera | Time Period | Distance (m) | |
| --- | --- | --- | --- |
| | | 500 | 1000 |
| *Andrena* | Season[†] | **p=0.037** | p=0.080 |
| | Pre-Bloom | **p=0.042** | p=0.066 |
| | Bloom | **p=0.046** | p=0.060 |
| | Summer | NA | NA |
| *Bombus* | Season[‡] | p=0.968 | p=0.749 |
| | Pre-Bloom | p=0.785 | p=0.918 |
| | Bloom | P=0.735 | p=0.822 |
| | Summer | p=0.184 | P=0.821 |
| *Lasioglossum* | Season[‡] | p=0.164 | p=0.393 |
| | Pre-Bloom | p=0.139 | p=0.199 |
| | Bloom | p=0.219 | p=0.338 |
| | Summer | p=0.608 | p=0.926 |

Season=April-September, Pre-Bloom=April/May, Bloom=June, Summer=July/August, [†]April-July, [‡]April-September, NS= not significant, NA=not applicable.
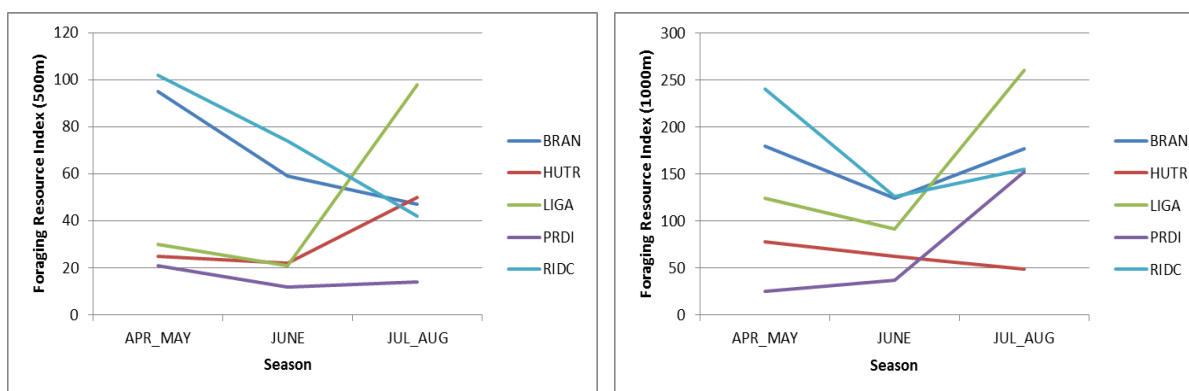
## Flowering Habitat

Non-blueberry flowering habitat was placed in seven categories: Shrub (*Prunus*, *Salix*, *Viburnum*), Regeneration (succession following forest clearing - *Epilobium*, *Solidago*, *Aster*), Pit (floral communities surrounding pits - *Vicia*, *Trifolium*, *Solidago*, *Lotus*), Margins (roadside, field, forest margins), Herbaceous (meadows), Bog (bogs-*Chamedaphne*, *Kalmia*, *Rhodora*), Abandoned Land (agricultural/cleared land not under production). The amount and composition of flowering habitat (excluding blueberry) differed among study sites at both 500 and 1000 metres surrounding blueberry fields (**figure 6**). BRAN and RCDI had the highest proportion of flowering habitat at both 500 (30 and 27%, respectively) and 1000 metres (25 and 21%, respectively) from blueberry fields. However, RCDI had a greater diversity of flowering habitat than BRAN and the other study sites.



**Figure 6.** A comparison among study sites of the percentage of total and habitat-specific flowering habitat at 500 and 1000 metres around blueberry fields.

**Seasonal Foraging Resources**

As a result of the differing proportions and diversity of flowering habitat seasonal Foraging Resource Index values had different profiles among sites at 500 and 1000 metres surrounding blueberry fields (**figure 7**). At 500 metres, BRAN and RIDC were characterized by relatively abundant early season forage that declined over the remainder of the season. In contrast, LIGA and HUTR had relatively low floral availability during the pre-bloom and bloom stage but moderate (HUTR) and high (LIGA) during the summer. PRDI had relatively low floral availability throughout the spring and summer. Expanding the spatial scale from 500 to 1000 metres changes the seasonal FRI profiles. BRAN and RIDC have similar FRI profiles characterized by relatively high early season forage that declined during the blueberry flowering period (blueberry excluded from analysis) then climbed to moderate levels compared to other sites during the summer. At 1000 metres, moderate early season FRI values at LIGA climbed to be the highest among sites during the summer. At this distance HUTR saw a gradual decline in the amount of forage available over the season. At this expanded spatial scale PRDI still had relatively low early season floral availability, however, this expanded to moderate levels during the summer.
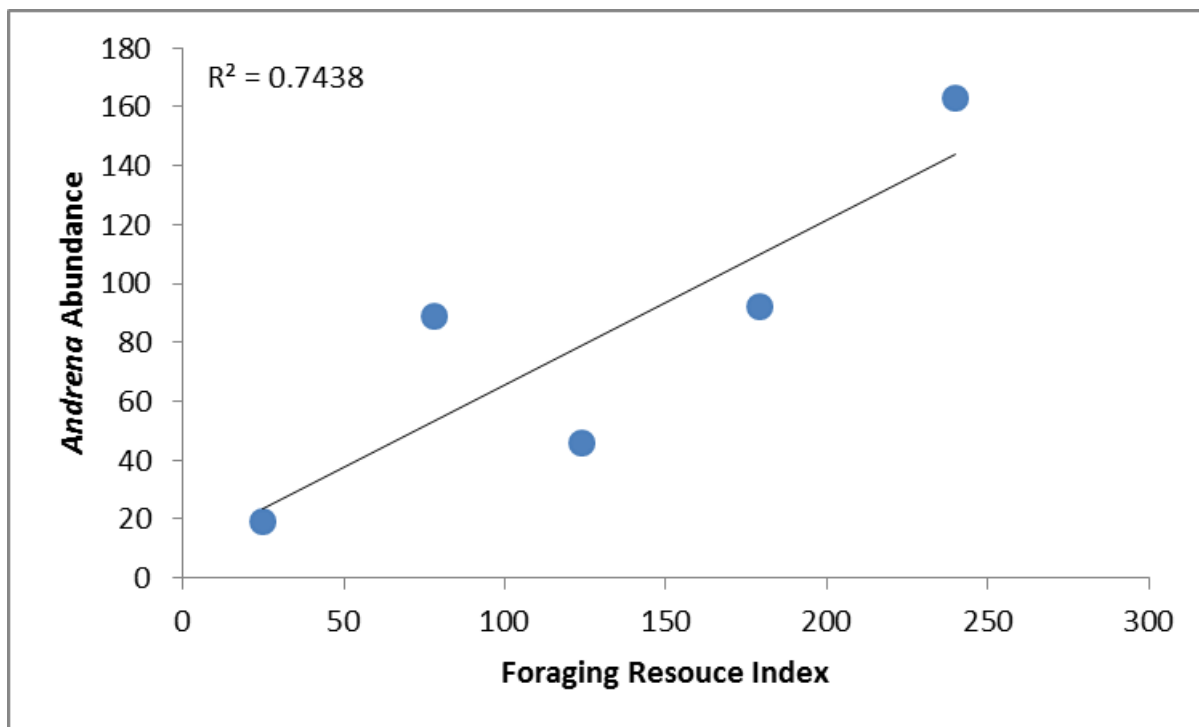


**Figure 7.** Seasonal Foraging Resource values for study sites at 500 and 1000 metres surrounding blueberry fields.

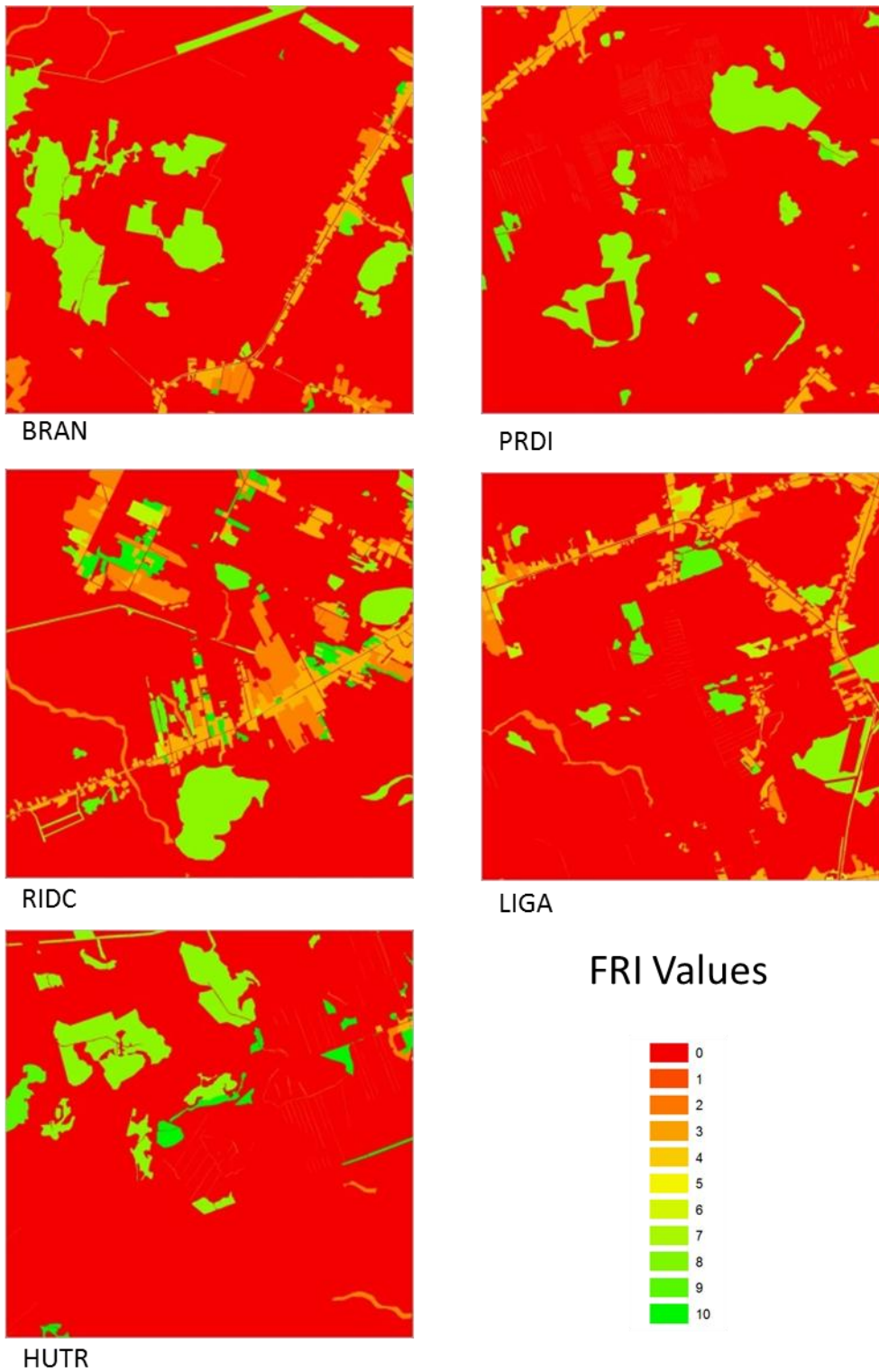**Relationship between Native Bees and Foraging Resources**

The distribution of non-blueberry foraging resources surrounding blueberry fields is shown in **figure 8**. There was no significant relationship between *total* native bee abundance and Foraging Resource Index (FRI) values at 500 ($r^2$=0.833, p=0.027) and 1000 metres ($r^2$=0.852, p=0.0254). However, when individual genera were assessed, *Andrena* had a significant relationship with FRI at 500 metres ($r^2$=0.711, p=0.042) over its entire April to late-June life span (**table 3**). Of the three major blueberry pollinating genera only *Andrena* has a life span that does not involve the entire season. Both *Bombus* and *Lasioglossum* require foraging resources from early spring to late summer. For *Andrena*, there is a strong relationship between abundance and FRI during pre-bloom and bloom at 500 metres ($r^2$=0.744, p=0.040 and $r^2$=0.782, p=0.046, respectively). Although the majority of *Andrena* found on blueberry were large and capable of foraging ranges of an estimated 1,100 metres, no relationship was detected with their abundance on blueberry and FRI to that distance. This suggests that alternative foraging resources proximal to blueberry fields are important to *Andrena*. When *Andrena* are emerging from

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overwintering (often nesting within the blueberry field) they will only initiate new nests if there is a sufficient source of food close by. Therefore, early season forage determines if and where *Andrena* will establish nests. **Figure 9** shows the significant positive relationship between *Andrena* foraging abundance on blueberry and forage availability prior to the blueberry flowering period. Since blueberry fields offer excellent nesting substrate for *Andrena* early season forage availability will encourage bees to nest within fields and surrounding habitats and be available for blueberry pollination. Early season forage is just as important for other native bee genera, however, the longer flight periods of these bees means that food must be available throughout the season.

Bombus and *Lasioglossum* abundance on blueberry did not show a significant relationship between foraging resources present at different times of the year (**table 3**). Temporal floral resources, particularly at the 500 metre distance, were not stable at study sites (**figure 7**). Sites with relatively high spring FRIs (BRAN and RIDC) were characterized by declines in summer floral availability. In contrast, sites with relatively low spring FRIs (LIGA and HUTR) had increases in floral availability over the summer. For genera requiring foraging resources from spring to late summer (*Bombus* and *Lasioglossum*) gaps in floral availability or insufficient food sources undoubtedly impacted bee abundance. It is the seasonal fluctuation of floral resources that most likely impact *Bombus* and *Lasioglossum* abundance foraging on blueberry. Given the strong response of *Andrena* to local forage availability, it is expected that *Bombus* and *Lasioglossum* would show similar responses in areas with stable floral resources over the entire flight season of these genera. Unfortunately, the agroecosystems used in this study did not satisfy these criteria. Whether this is an artifact of low sample size or the general condition on the Acadian Peninsula needs further investigation.
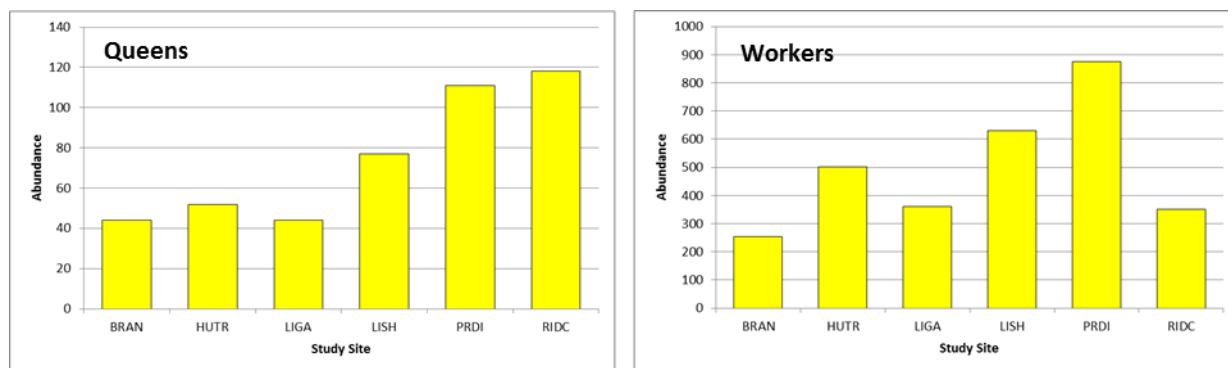


**Figure 9.** Significant positive relationship between *Andrena* foraging on blueberry and the Foraging Resource Index value with 500 metres of blueberry fields during pre-bloom (F=10.79, p=0.0463).

**Figure 8.** Foraging Resource Index (FRI) values of habitats surrounding blueberry fields (centroids of maps). The blueberry land cover class has been omitted from maps in order to show clearly the distribution and FRI values of alternative foraging habitats within a 2 × 2km area.

Some of the study sites investigated had high spring abundance of queens foraging on the crop but few colonies persisting to the summer (**figure 10**).  This lack of correlation indicates that spring *Bombus* abundance is based, in part, on dispersing queens and not entirely on resident populations.  Considering dispersal as an important factor further explains the weak relationship observed between local floral availability in summer and *Bombus* foraging abundance (queens) on blueberry.  Dispersing queens enter the system and initiate nests if pre-bloom forage is available and continue to provision during the blueberry flowering period when resources are abundant.  In sites with scarce forage availability during the summer fledgling colonies collapse.  Therefore, some blueberry agroecosystems are acting as ecological sinks drawing their bumble bees from (and depending on) areas of suitable habitat in the broader landscape.  As such, the broader landscape and bumblebee metapopulation dynamics at a regional scale may be an important component of lowbush blueberry pollination.  Also, there was no significant relationship between the number of *Bombus* workers in the summer and (1) the amount of forage at that time of year ($r^2$=0.444, p=0.219) and (2) the amount of forage during the spring ($r^2$=0.011, p=0.866).  For taxa such as *Bombus* and *Lasioglossum*, the lack of local forage abundance over their life spans appears to be a main driver of reduced abundance foraging on blueberry. Even though sites may have high floral abundance at different times of the year, stabilizing food sources over the entire season may be a critical component of enhancing native bee pollination of lowbush blueberry on the Acadian Peninsula.



**Figure 10.**  The abundance of *Bombus* queens and workers captured among study sites.

**Summary**

We see that the abundance of native bees on blueberry can related to the amount of foraging resources available as in the case of *Andrena*.  Using *Andrena* as a model, it is apparent that food availability proximal to fields (within 500 metres) is key to the maintenance of a strong local pollinator force even though estimated foraging flight ranges extend well beyond this distance for many bees.

The relationship revealed between native bee abundance and habitat diversity is likely related to sites with higher habitat diversity having a wider range of plant communities flowering at different time of the season.  Also, it should be considered that greater habitat diversity may provide increased nesting opportunities for a diverse community of native bees with differing nesting criteria.

From this study, it is evident that many of the lowbush blueberry agro-ecosystems on the Acadian Peninsula lack continuous foraging resources from early spring to late summer.  Gaps in floral availability for critical pollinating genera such as *Bombus* and *Lasioglossum* with extended flight periods (April-September) is most likely contributing to reduced populations in the vicinity of many blueberry fields.  The lack of correlation with spring *Bombus* queens to local floral availability indicates that dispersal from higher quality habitats into blueberry agroecosystems is contributing to abundance on blueberry.  Many lowbush blueberry agroecosystems are acting as biological sinks as local conditions fail to provide continuous foraging resources required for natural colony cycles.

**Recommendations**

The abundance of the important pollinating genera, *Andrena*, was related to higher floral availability within 500 metres of the field during the early part of the season prior to blueberry flowering.  The provision of forage at this time of the year will also be beneficial for *Bombus* and *Lasioglossum*.

- **Recommendation:**  Maintain or establish early season forage (example: willow) with 500 metres of blueberry fields.



**Figure 11.**  *Bombus* on willow

The lack of continuous forage (spring/summer) at some site resulted in the failure of *Bombus* colonies to survive and produce reproductives (i.e. queens required for pollination the following year).

- **Recommendation:**  Establish foraging habitat for *Bombus* within 500 metres of blueberry fields that flowers during July and August (**figures 12 and 13**).  Removal of small areas of woodland will allow for native plant communities flourish (fireweed, goldenrod, asters) and provide needed forage for bees during the summer.  This in combination with the establishment of early season forage such as willow will stabilize foraging resource throughout the season and allow for higher *Bombus* and *Lasioglossum* abundance to be maintained within the agroecosystem.

It is important for producers to become familiar with the spatial and temporal distribution of flowering plant populations in relation to their blueberry fields.

- **Recommendation:** Visiting fields four times over the season will identify site-specific gaps in foraging resources.  Visits should be conducted in May (pre-bloom), during bloom (especially for sites that do not have both crop and sprout fields), early to mid-July and early to mid-August.  Site visits need not identify plant species but rather get a sense if there are habitats within the local landscape (500m) that have flowering plant populations at the four specified times of the year.  This will identify critical foraging gaps and allow for focused foraging habitat restoration.

**Figure 12.** Summer foraging habitat on margin of blueberry field, Little Gaspereau, NB.



**Figure 13.** Summer foraging habitat on abandoned land, Brantville, NB.

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