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Dynamics of Bee and Wasp Populations in Maine Lowbush Blueberry (*Vaccinium angustifolium*)

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DYNAMICS OF BEE AND WASP POPULATIONS IN MAINE LOWBUSH BLUEBERRY (*Vaccinium angustifolium*)

By

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Thesis Advisor: Dr. Stephen A. Woods

An Abstract of the Thesis Presented
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Conservation of natural enemies can be an effective form of pest management. If beneficial Hymenoptera, native to the area, can be protected and encouraged to multiply, the benefits of natural insect pest control might be realized. Hymenoptera as "natural enemies" as well as "pollinators" have been studied intensively in many agroecosystems worldwide. However, lowbush blueberry is not an ecosystem where ecology of Hymenoptera has been well studied. This thesis discusses two studies conducted in lowbush blueberry fields in Washington County, Maine in 1997 and 1998.

In the first study, I investigated "towers" as a method for deploying insect traps along both a horizontal and vertical gradient. The objective was to define the spatial distribution of native bees and wasps, and interpret where these insects tend to be most abundant in and around lowbush blueberry fields. A single tower was erected near the center, along the edge, and within the surrounding forest of each blueberry field. Flight intercept traps were suspended from towers at 1, 7 and 14 m above the ground. Bees exhibited differences in both vertical and horizontal distribution. More than 85% of all bees captured were from traps 1 m above the ground, and a majority was captured at the

edge of blueberry fields. Most wasps captured in this study were tiny parasitica less than 3 mm in length. Unlike bees, no height effect was detected with wasps. However, using towers allowed me to see temporal changes in the vertical distribution of wasps from June to July. Wasps showed no difference in their overall horizontal distribution. However, categorizing them by size and antenna length (i.e. 4 categories) revealed an interaction between wasp category and tower position. Relatively large wasps were more abundant in the surrounding forests, while small wasps showed no association with any trap position.

In the second study, I investigated various field variables that might explain the abundance of wasps captured across 33 blueberry fields. A single malaise traps was placed at the field interior, along the field edge and within the surrounding forest of each field. Thirteen morphospecies were identified from wasp samples. In addition, flowering weeds were sampled at various intervals across all fields. The overall wasp population and most morphospecies were positively associated with a common flowering weed, sheep laurel (*Kalmia angustifolia*). Multiple groups of morphospecies appeared to be responding to the same flowering plants and were treated as foraging guilds. In addition, multiple morphospecies were found distributed within blueberry fields in a similar spatial pattern and were treated as communities. No two morphospecies identified in the same foraging guild were also found in the same community. This suggests wasps could belong to stable communities and maintained by different species utilizing different floral resources.

Based on the results of these studies, blueberry growers should consider integrating efforts to conserve populations of native Hymenoptera into their management

practices. In doing this, growers may also want to research methods of pesticide use that will minimize lethal effects on these beneficial bees and wasps.

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Chapter 1

SAMPLING BEES AND WASPS ALONG BOTH A VERTICAL AND HORIZONTAL GRADIENT IN MAINE LOWBUSH BLUEBERRY

Abstract

Native bee and wasp communities were sampled from 14 lowbush blueberry (*Vaccinium angustifolium*) fields in eastern Maine during the summers of 1997 and 1998. Sampling was conducted using flight intercept traps suspended at various heights (1m, 7m, 14m) from steel towers erected along a single transect within each field. The objectives of this study were to investigate the spatial distribution (vertical and horizontal) of native bees and wasps in lowbush blueberry fields and adjacent forests, and determine whether towers were an effective method for deploying insect traps in this agroecosystem. Native bees and wasps were found to exhibit very different patterns of spatial distribution which were consistent for both 1997 and 1998. Native bees were captured primarily in low traps within 1 meter of the ground. In fact, only 8.5% and 12.5% of all bees captured in 1997 and 1998, respectively, were retrieved from the middle (7m) and top traps (14m). In addition, most bees were captured along the edge of fields, and the fewest were captured in the surrounding forest. The use of towers appears unnecessary for sampling native bees along the edge or within fields since the vertical distribution of trap catch is consistent across blueberry fields. However, towers may be important when investigating bee populations in adjacent forest habitat. Similar to bees, more wasps were also captured in low traps. However, a larger proportion of wasps were

captured in the middle and top traps than seen with bees. Contrary to bees, wasps showed no association with any trap location (forest, edge, field interior). No interaction between the number of wasps captured and trap placement (i.e. height above ground and trap location along a transect from surrounding forest habitat into the blueberry field interior) was detected during either year. However, there was a noticeable increase in the number of wasps captured in the 1m trap corresponding to a decrease in the 14 m trap between June and July each year. This information would have been missed by sampling only at ground level, and may provide valuable insight to the intraseasonal dynamics of wasp communities. When considering morphological differences in size and antenna length, there was evidence that small wasps (body length < 3mm) were distributed differently along trapping transects than large wasps (body length $\geq$ 3mm). Large wasps were most common in the forest while small wasps showed no association with any specific trap location. Larger numbers of bees and wasps being captured close to the ground may be the result of these insects foraging for nectar and pollen resources. However, more wasps may have been captured in intercept traps suspended further from the ground because of parasitic host searching behavior. Based on this study, vertical sampling seems necessary to best understand the flight patterns of wasps in lowbush blueberry. Also, based on the relative abundance and spatial distribution of Hymenoptera in this study, blueberry managers should be alert to the possible negative impact insecticide applications may have around the perimeter of blueberry fields, especially on native bees.

Introduction

Numerous studies have focused on the abundance and diversity of Hymenopteran pollinators and natural enemies in different agroecosystems (Altieri & Whitcomb 1979, Banaszak 1992, Altieri et al. 1993, MacKenzie & Averill 1995). In fact, Borror et al. (1989) refers to the order Hymenoptera as "the most beneficial in the entire insect class". Many fruits and vegetables, including lowbush blueberry, could not be produced commercially without bees to pollinate plants, and recent studies continue to supply evidence of the beneficial role wasps play in reducing insect pest populations (Evans 1984, Bellamy et. al. 2004, Ceballo & Walter 2004, Garcia-Mari et. al. 2004).

These studies typically require sampling bee and wasp communities to achieve relative estimates of abundance in order to determine how these communities are distributed across different habitats. Placement of traps is critical in achieving unbiased samples that accurately represent insect populations (Disney 1986). Previous studies of aquatic, flying, and even subterranean insects have recognized the importance of sampling methods which consider the three-dimensional structure of ecosystems (Czachorowski 1993, Riis & Esbjerg 1998, Boiteau et. al. 2000). Some studies of flying insects have even shown distinct height associations in habitats where vegetation extends far above the ground (Southwood et al. 1979, Broadhead & Wolda 1985, Braverman & Linley 1993, Botero-Garces & Isaacs 2003). In fact, evidence suggests that some taxa might go undetected if sampling is restricted to the ground (Su & Woods 2001). In order to account for the three-dimensional presence of flying insects, traps may need to be arranged along a vertical as well as a horizontal gradient. However, this can increase the cost of research significantly and the need should be evaluated and carefully considered.

Multiple traps suspended from steel towers were used in 14 blueberry fields during 2 consecutive summers (1997 & 1998) Towers arranged along a single transect extending from the interior of fields into the forest border allowed me to assess any association between differences in the number of insects captured and trap field location. Since the vertical structure of vegetation varies dramatically between the surrounding forest and blueberry fields, this methodology was deemed necessary for detecting any potential interaction between differences in the vertical structure of these habitats and the distribution of bee and wasp communities. This challenge has limited most studies since other sampling methods capture species restricted to the ground with arboreal communities largely ignored. In addition, an effort of morphologically dividing wasps into subgroups based on body size and antenna length was performed. This approach allowed me to look for potential differences in spatial distributions of specific taxa within wasp communities that might be detected by trap placement.

Methods

Site Description

This study was conducted during the blooming and fruiting phase of selected blueberry fields in Washington County, Maine in 1997 and 1998. These fields have been established for the commercial production of lowbush blueberries. Lowbush blueberry production constitutes one of the largest agroecosystems in Maine. Fields are developed by clearcut harvesting of forest and applying herbicides to allow the *Vaccinium spp.* that constitute lowbush blueberry to grow with minimal competition from other native plants. Therefore, some areas where numerous fields are established next to each other give the

landscape the appearance of having enormous "gaps" (i.e. clearcuts) in the forest. Most fields used in this study were owned and managed by C&D Corporation or Cherryfield Foods, Inc. Some fields, however, were owned and managed by local resident farmers who agreed to participate in the study. All fields were used for one season only, since it is standard practice to rotate a field out of production every other year (prune cycle) by either burning or mowing it after harvest. Each blueberry field and the forest surrounding it were considered as individual study sites. The sites for this study were located in the towns of Cherryfield, Deblois, Jonesboro and Whitneyville, Washington County, Maine. Fourteen fields were selected for this study: nine in 1997 and five in 1998 (Table1.1). Fields ranged from 1.2 – 44.5 hectares, and only one occurred as an isolated parcel surrounded by forest (Table 1.1). Most fields were only partially surrounded by forest since they were situated adjacent to other lowbush blueberry fields or roads. The vertical

Table 1.1. Description of 14 blueberry field sites in Washington County, Maine.

Year Used	Field Number	Size (ha)	Field Border (% Forested)
1997	5	16.2	40
1997	6	2.4	100
1997	7	23.9	70
1997	8	13.8	40
1997	10	4.0	40
1997	11	3.2	60
1997	13	10.1	70
1997	14	6.9	60
1997	18	1.2	90
1998	3	9.5	50
1998	5	5.7	40
1998	6	2.0	80
1998	7	16.6	40
1998	8	44.5	60

structure of vegetation varied considerably between blueberry field and the surrounding forest habitat. Forests had vegetation ranging from 0.5 – 10 m above the ground, but within blueberry fields most vegetation was less the 0.5 m above the ground.

Trap Design

Flight Intercept Window-pane Trap. This trap was designed to sample the insects within the blueberry fields and within forests bordering these fields. The traps were constructed by intersecting two clear panels of plexiglass (60 cm high x 44 cm wide) perpendicular to each other forming a "+" shape when viewed from above (Jaros-Su 1999). This produces a trap with eight clear surfaces that can intercept flying insects whose flight path intersect the trap's position. In addition, a funnel with a collecting cup was placed at the top and bottom of the panels. This directs insects which hit a panel and fall down to be captured in the bottom collecting cup, or insects which hit a panel and fly upward to be guided and trapped in the top collecting cup. The bottom cup had two holes drilled into the bottom (to drain water) and was lined with nylon stocking material. A block (2.5 cm. x 2.5 cm. x 1.0 cm.) of Vapona® (2,2-Dichlorovinyl dimethylphosphate) was placed in each cup as a killing agent.

Traps were suspended in sets of three by a 15 m tower constructed of rigid steel conduit. The towers were secured upright by twelve lines, running from stakes in the ground (or the base of trees) to various points along the tower. There is a 90° bend at the top of the tower to allow the three traps to be suspended away from the tower by a trap line. The line was attached to a pulley at the top to allow the traps to be raised and lowered enabling periodic collection of insects from the traps. Traps were suspended at

1, 7 and 14 m above the ground, and designated as the Low, Mid, and Top trap of each tower, respectively.

Insect Sampling

The relative abundance of native bees and wasps in blueberry was investigated during the summers of 1997 and 1998. Towers were arranged along a single transect within each field site. Transects extended from a point 10 m into the adjacent forest, out to the interior of each field. Three trap field locations (A, B, and E) were established along transects for the placement of towers. Towers at A were 10 m beyond the field edge, into the bordering forest, towers at B were at the field edge, and towers at E were erected at approximately the center (i.e. interior) of fields. Therefore, traps were distributed horizontally, at locations A, B and E, and vertically, at 1, 7 and 14 m above the ground; forming a 3x3 matrix along each transect.

In 1997, towers were erected during the week of May 26 and their traps checked once a week while blueberry plants were in bloom until the week of June 23. Thereafter, traps were checked every other week until the week of July 21, one week before harvest. In 1998, towers were erected during the week of May 11 and their traps checked every other week until the week of July 27, one week before harvest. All insects were collected and returned to the laboratory at the University of Maine for sorting and identification.

Insect Identification

In both 1997 and 1998, all insects of the suborder Apocrita (ants, bees, parasitic and non-parasitic wasps) except those of the family Formicidae (ants), were selected

from the collection cups of all traps. These were further divided into two subgroups (bees and wasps) by separating members of the superfamily Apoidea (bees) from the suborder Apocrita (wasps). Honeybees (*Apis mellifera*), which are imported to pollinate blueberry during bloom, made up the majority of Apoidea. Since the focus of this study is on native bees, only native bees were recorded, honeybees were not used in this study. The number of native bees and wasps captured in each trap's top, and bottom, collecting cup was recorded.

Wasps were not identified beyond superfamily because most specimens were extremely small and would require expertise not available to me for proper preservation and further identification. However, I wanted to investigate whether any differences in spatial distributions could be detected by grouping wasps based on morphological features (Oliver & Beattie 1996, Jaros-Su 1999). Therefore, wasps were separated by two easily distinguishable morphological characteristics: body size (small, large) and relative antenna length (short, long). A wasp was considered small (S) if the length of its body was less than 3 mm (the smallest measurement available using the reticle in my microscope), and large (L) if it was greater than or equal to 3 mm. A wasp was considered to have short antennae (s) if they did not extend to its abdomen, and long antennae (l) if they extended to or beyond its' abdomen.

Data Analysis

Three data sets were developed for each trap to represent the following: 1) trap capture of all native bees; 2) trap capture of all wasps; and 3) trap capture of each of the 4 wasp subgroups (or morphospecies) based on body size and antenna length.

The differences in vegetation structure between the blueberry field and the adjacent forest were dramatic. Of major interest was that the vertical distribution of Hymenoptera might be related to the vertical structure of vegetation and also vary dramatically. To evaluate this, I tested for an interaction between the height and field location of traps. To focus on overall seasonal abundance and minimize problems analyzing small samples, bee and wasp samples were pooled by trap across all collection dates for each field. Initial analyses determined the existence of a trap height by field location interaction. The pooled number of bees or wasps caught in each trap was the response variable, and trap height and location were categorical variables. No transformation of data was performed. Statistical significance was assessed using a two-way log-linear model (PROC GENMOD, SAS for Windows 8.1). When no interaction was detected ($\alpha = 0.05$), trap height and location main effects were assessed using a one-way log-linear model (PROC GENMOD, SAS for Windows 8.1). If a significant height or location effect was detected, then pair-wise analyses were performed at $\alpha = 0.05$ to detect differences in relative insect abundance due to the main effect.

Additional analyses were performed using wasp samples to see whether temporal differences in relative wasp abundance occurred across trap height and/or location. Bees were not included in these specific analyses due to small sample sizes. Wasps were pooled separately by month for June and July. Pooled samples were examined for interactions between trap height, location, and month. Statistical significance was assessed using a three-way log-linear model (PROC GENMOD, SAS for Windows 8.1), as previously described. In the absence of a three-way interaction ($\alpha = 0.05$), further

analyses were performed using two-way log-linear models to determine if a trap height by month, or trap location by month, interaction existed ($\alpha = 0.05$).

To evaluate whether shifts in the community composition of wasps were occurring across trap height and location, an analysis was performed to see if an interaction existed between body-size, antenna length, trap height and location. Statistical significance was assessed using a 4-way log-linear model (PROC GENMOD, SAS for Windows 8.1). Non-significant higher order interactions were removed in a stepwise manner until the major effects of interest remained; in this case the interactions between the morphological traits and trap location and/or height.

Results

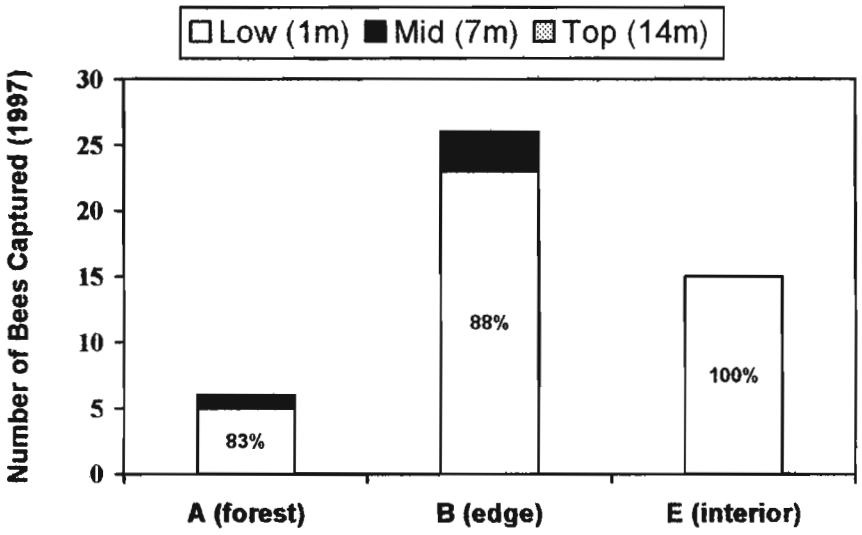
Impact of Trap Height and Location on Capture of Bees

Only 47 native bees were captured during 1997. Since pooling can mask analysis problems and the number of bees collected was relatively small, collections were examined to see if any clustering occurred that would confound analysis results. Samples of native bees were captured at each field, and the vertical pattern was consistent across the 3 trap field locations (height x location interaction term, $\chi^2 = 2.95$, d.f. = 4, $p = 0.567$). However, there was a significant and substantial trap height main effect (height term, $\chi^2 = 74.74$, d.f. = 2, $p < 0.001$). The majority of all bees (43 out of 47) captured in 1997 were recovered from the bottom traps of towers (Figure 1.1). No bees were recovered from any of the top traps, and of the remaining four insects, 3 were recovered from middle traps along the field edge and 1 in a middle trap located in the forest (Figure

1.1, Table 1.2). A trap location main effect was also detected in 1997 (location term, $\chi^2 = 13.52$, d.f. = 2, $p = 0.001$). Most bees (26 out of 47) were captured at the edge of blueberry fields and the fewest (6 out of 47) were captured in the forest (Figure 1.1). Pair-wise analyses indicated that there was a significant difference between the number of bees captured at the field edge and those captured in the forest (location term, $\chi^2 = 13.39$, d.f. = 1, $p < 0.001$), and possibly between the number of bees captured at the field edge and those captured in the field interior (location term, $\chi^2 = 2.97$, d.f. = 1, $p = 0.085$).

The number of native bees captured in 1998 was again relatively small (n = 43), but the distribution was roughly equivalent among fields. However, this year the vertical distribution was not consistent across all trap field locations and a height by location interaction was detected ($\chi^2 = 16.99$, d.f. = 4, $p = 0.002$). This interaction appears to be driven by 4 bees that were captured in the top traps of towers located in the forest (Figure 1.1). The distribution of bees captured in towers along the edge and within the interior of fields during 1998 was essentially identical to 1997 (Figure 1.1). Pair-wise analyses revealed a height by location interaction between the towers in the forest (location A) and those at the field edge (location B), and between the towers in the forest and towers in the field interior (location E), but not between those at the edge and those in the field interior (Table 1.3). Despite the significant interaction, evaluation of the main effects revealed overall patterns that were similar to 1997. Most bees (35 out of 43) were captured in bottom traps, and towers located at the interior of fields only captured bees in the low traps (Figure 1.1, Table 1.2). As a result, the overall height main effect was still significant (height term, $\chi^2 = 41.91$, d.f. = 2, $p < 0.001$). The number of bees captured along the horizontal transect was also similar to 1997 with the largest number of bees

Figure 1.1. Total number of bees captured in traps suspended at 3 different heights (1 m, 7 m, 14 m) across 3 field locations (forest, edge, interior) during 1997 and 1998. Percentages in bars represent the fraction of bees captured in Low traps at each location.



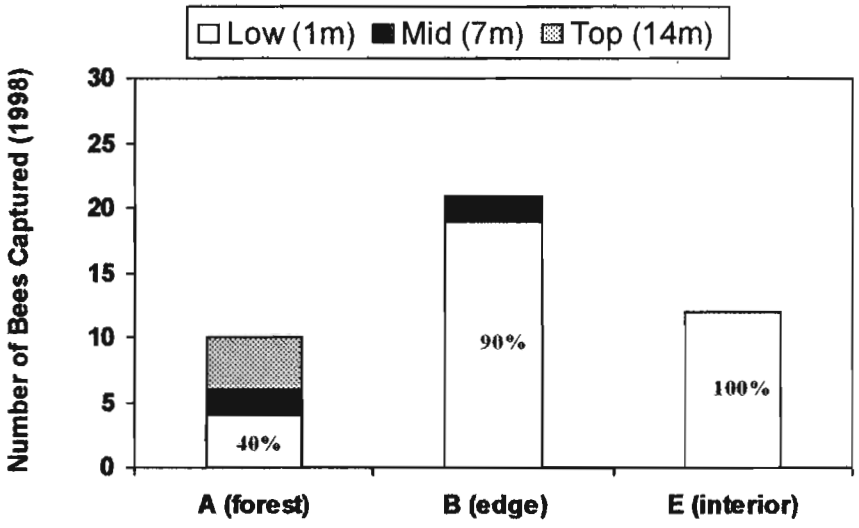


Table 1.2. Mean number of bees captured by traps (n = 9 in 1997; n = 5 in 1998) suspended at 3 different heights in blueberry. Standard error values are shown in parentheses.

Trap Height	Mean Number* of Bees Captured 1997	Mean Number* of Bees Captured 1998
Top (14 m)	0.00^{a} (0.00)	0.80^{a} (0.49)
Middle (7 m)	0.44^{b} (0.24)	0.80^{a} (0.37)
Low (1 m)	4.78^{c} (0.43)	7.00^{b} (1.81)

* Mean values having identical superscripts did not exhibit significant differences in the number of bees captured at those trap heights (pairwise linear contrasts, $\alpha = 0.05$, PROC GENMOD, SAS for Windows 8.1).

Table 1.3. Results from pair-wise analyses of bees captured in traps located in the forest, at the field edge, and in the field interior during 1998.

Field location of towers being compared	Height x Location Interaction term, χ^2	d.f.	P – value
forest vs. edge	11.77	2	0.003
forest vs. interior	11.56	2	0.003
edge vs. interior	1.56	2	0.457

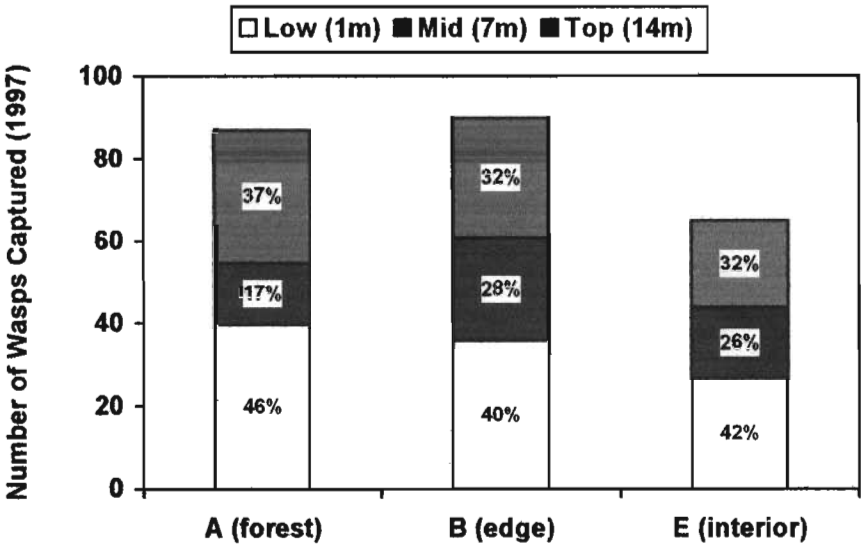
(21 out of 43) being captured at the edge and the fewest (12 out of 43) in the forest (Figure 1.1). However, the overall trap location effect was not significant in 1998 (location term, $\chi^2 = 4.56$, d.f. = 2, $p = 0.102$). Pair-wise analyses suggested that more bees were captured at the edge versus the forest in 1998 (location term, $\chi^2 = 3.98$, d.f. = 1, $p = 0.046$), but no difference was detected between the number of bees captured at the edge and those captured at the field interior (location term, $\chi^2 = 2.48$, d.f. = 1, $p = 0.115$).

Impact of Trap Height and Location on Capture of Wasps

The relative vertical distributions of wasps were similar across the three trap locations in 1997 (height x location interaction term, $\chi^2 = 2.71$, d.f. = 4, $p = 0.608$, Figure 1.2). When the non-significant interaction term was removed, an overall difference in relative wasp abundance was detected across the 3 trap heights (height term, $\chi^2 = 12.75$, d.f. = 2, $p = 0.002$). Similar to bees, more wasps were captured in the low traps at all trap locations (Figure 1.2). However, unlike bees, a substantial percentage of wasps were captured in the middle (17 – 28%) and top (32 - 37%) traps at each location (Figure 1.2). Pair-wise analyses of trap capture and trap height indicated more wasps being captured in the low trap than the middle trap, but no statistical difference was detected between the low and top trap. In addition, more wasps were captured in the top trap than the middle trap (Table 1.4).

The horizontal distribution of wasp capture also appeared more uniform than that of bees (Figure 1.2). No overall difference in wasp capture across the 3 trap locations

Figure 1.2. Total number of wasps captured in traps suspended at 3 different heights (1 m, 7 m, 14 m) across 3 field locations (forest, edge, interior) during 1997 and 1998. Percentages in bars represent the fraction of wasps captured in the corresponding traps.



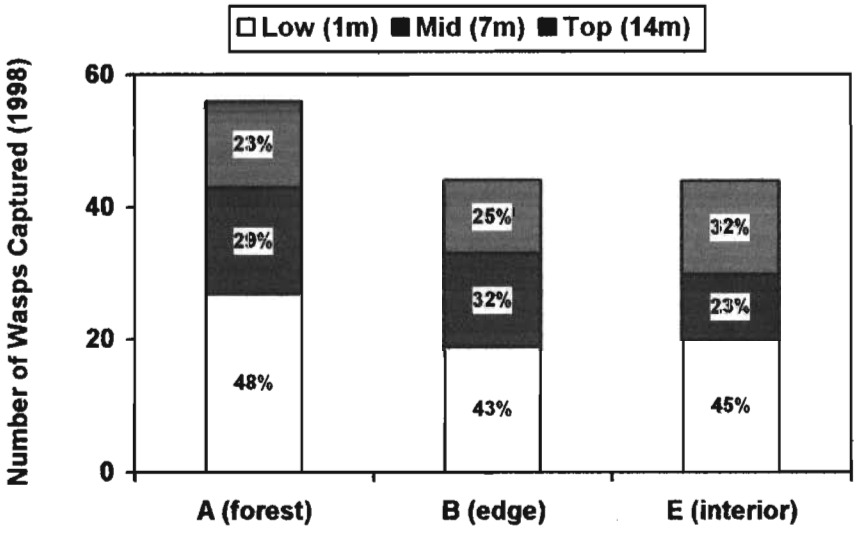


Table 1.4. Mean number of wasps captured by traps (n = 9 in 1997; n = 5 in 1998) suspended at 3 different heights in blueberry. Standard error values are shown in parentheses.

Trap Height	Mean Number* of Wasps Captured in 1997	Mean Number* of Wasps Captured in 1998
Top	9.12[a] (1.48)	7.61[a] (0.68)
Middle	6.34[b] (0.96)	8.01[a] (1.10)
Low	11.45[a] (1.78)	13.21[b] (0.66)

* Mean values having identical superscripts did not exhibit significant differences in the number of wasps captured at those trap heights (pairwise linear contrasts, $\alpha = 0.05$, PROC GENMOD, SAS for Windows 8.1).

was detected for 1997 (location term, $\chi^2 = 4.36$, d.f. = 2, $p = 0.113$). Approximately one-third (32% +/- 5%) of all wasps were captured at each of the trap field locations (Figure 1.2).

Consistent with findings from 1997, the vertical distribution of wasp capture at the three trap heights in 1998 was similar across all trap locations (height x location interaction term, $\chi^2 = 2.16$, d.f. = 4, $p = 0.707$, Figure 1.2). The main height effects indicated that a difference in the number of wasps captured was again detected across trap height in 1998 (height term, $\chi^2 = 9.58$, d.f. = 2, $p = 0.008$). Similar to the vertical distribution of wasp captured in 1997, more wasps were captured in the low traps at all locations, but a substantial percentage was also captured in the middle (23 - 32%) and top (23 - 32%) traps (Figure 1.2). Pair-wise analyses of trap height indicated significantly more wasps being captured in the low trap than the middle trap as seen in 1997. However, more wasps were also captured in low traps compared to top traps, while no difference was seen between the capture of wasps in middle versus top traps (Table 1.4).

As in 1997, the number of wasps captured in 1998 was uniform across all trap locations with approximately one-third (34% +/- 4%) of all wasps being captured at each of the three trap field locations during 1998 (location term, $\chi^2 = 1.93$, d.f. = 2, $p = 0.382$, Figure 1.2).

In an initial analysis of the changes in wasps captured from the month of June to July, no three-way interaction between trap location, height, and month was seen for 1997. However, 2-way interactions were detected in 1997 for trap location and month (location x month interaction term, $\chi^2 = 12.14$, d.f. = 2, $p = 0.002$), and trap height and month (height x month interaction term, $\chi^2 = 26.71$, d.f. = 2, $p < 0.001$) (Figure 1.3, 1.4). The analysis for wasps collected in 1998 revealed no 3-way or 2-way interactions, and the captures for trap location did not demonstrate a pattern similar to those of 1997 (Figure 1.3). However, there was a substantial increase in the numbers caught in the low trap corresponding with a slight decrease in wasps captured in the top trap as was observed in 1997 (Figure 1.4).

To investigate whether changes in trap height and location might correspond to changes in taxa, I included analyses with 4 variables (wasp size and antenna length, trap location and height). No 3-way or 4-way interactions were detected between size and/or antenna length with trap height and/or location during 1997. Even though no difference in horizontal distribution was previously detected for the overall number of wasps captured, there appear to be differences in the horizontal distributions of small wasps compared to large wasps (size x location interaction term, $\chi^2 = 11.65$, d.f. = 2, $p = 0.003$). The greatest numbers of small wasps were captured along the field edge, whereas this was where the fewest large wasps were captured (Figure 1.5). Pair-wise analyses of the

Figure 1.3. The distribution of wasps across three field locations (forest, edge, interior) during June and July of each year.

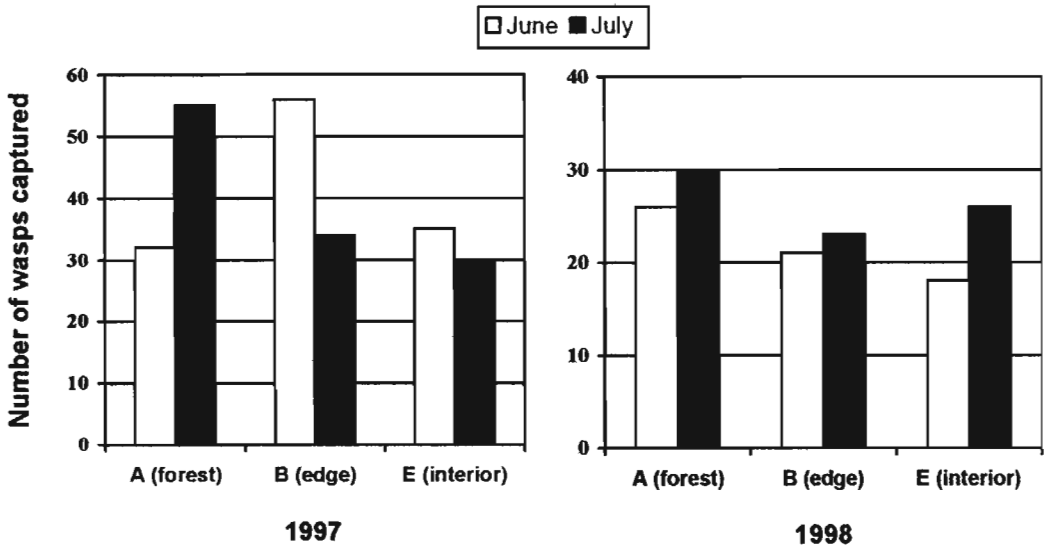
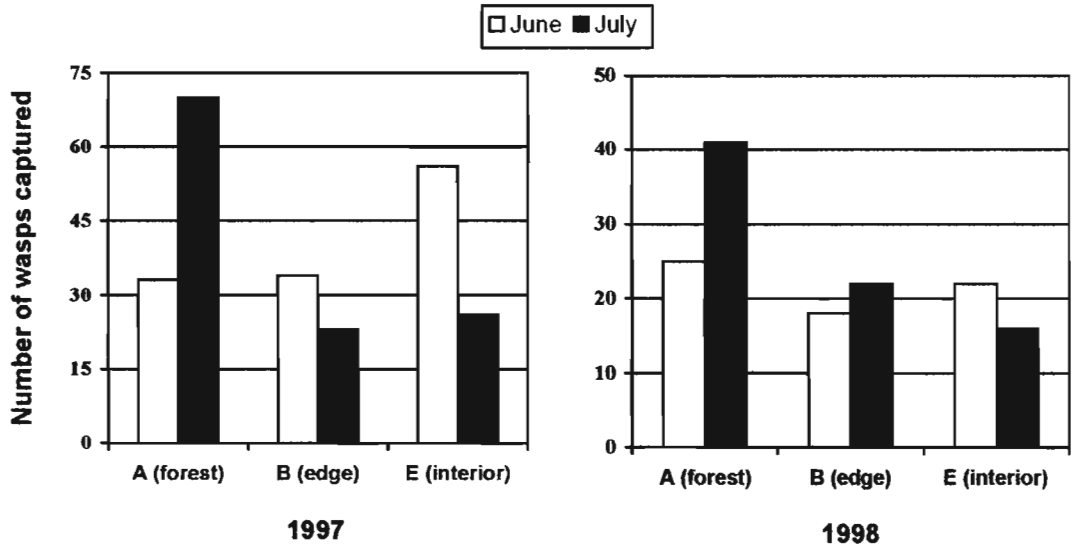


Figure 1.4. The distribution of wasps across three trap heights (1 m, 7 m, 14 m) during June and July of each year.



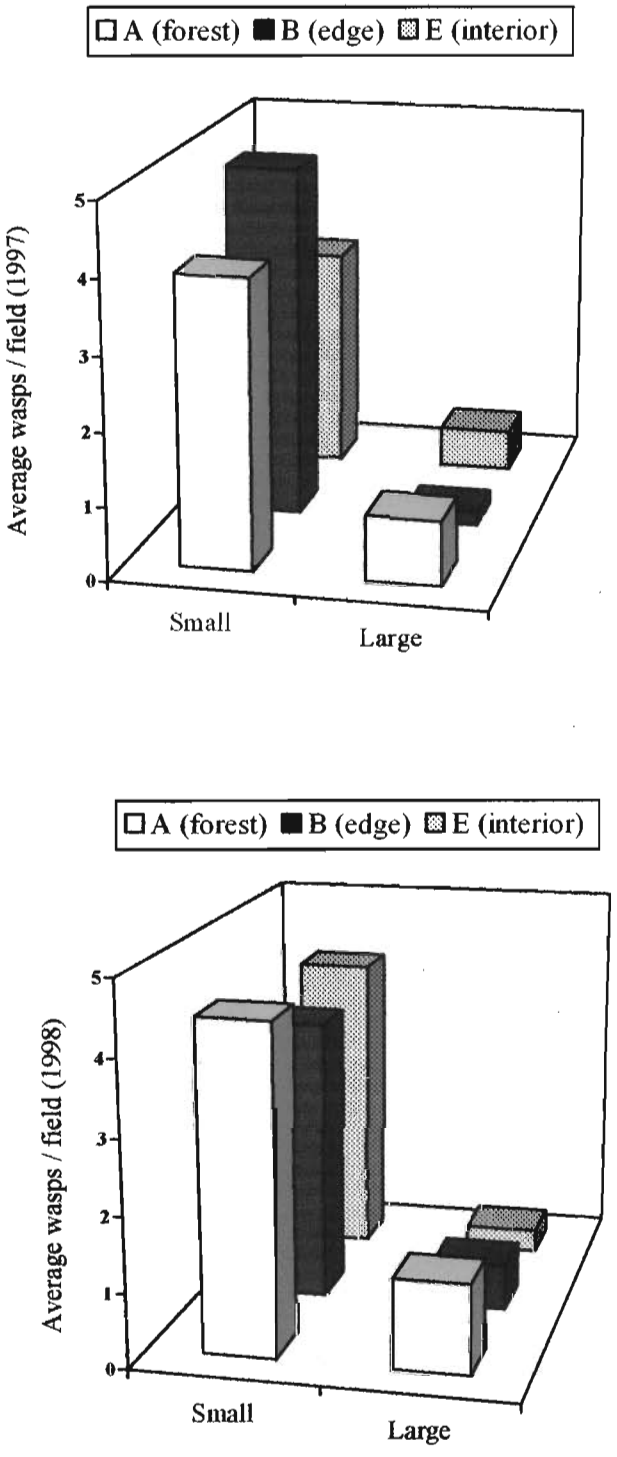
number of small wasps captured showed more being trapped at the edge of blueberry fields than in the field interior (Table 1.5). More small wasps were also captured along the edge than in the forest, but this difference was not significant. Large wasps were most often captured in the forest and least along the edge (Table 1.5). More large wasps were also captured in the forest than in the field interior, but the difference was not significant. Again, in 1998, there was some suggestion of differences in the horizontal distribution of small wasps captured compared to large wasps (size x location interaction term, $\chi^2 = 4.81$, d.f. = 2, $p = 0.090$). The numbers of small wasps captured were relatively uniform across all locations whereas the numbers of large wasps were noticeably higher in the forest and lowest in the field interior (Figure 1.5, Table 1.5). No other 2-way interactions between wasp morphology and trap placement were evident during either 1997 or 1998.

Table 1.5. Mean number of wasps captured by traps (n = 9 in 1997; n = 5 in 1998) at 3 different field locations in blueberry. Standard error values are shown in parentheses.

Trap Field Location	Mean Number* of Small Wasps Captured 1997	Mean Number* of Small Wasps Captured 1998	Mean Number* of Large Wasps Captured 1997	Mean Number* of Large Wasps Captured 1998
Forest	$3.94^{a,b}$ (1.02)	4.40^{a} (0.90)	0.89^{a} (0.38)	1.20^{a} (0.49)
Edge	4.83^{a} (0.74)	3.80^{a} (1.00)	0.17^{b} (0.09)	$0.60^{a,b}$ (0.16)
Interior	3.06^{b} (0.62)	4.10^{a} (1.03)	0.56^{a} (0.19)	0.30^{b} (0.15)

* Mean values having identical superscripts for did not exhibit significant differences in the number of wasps captured at those trap locations (pairwise linear contrasts, $\alpha = 0.05$, PROC GENMOD, SAS for Windows 8.1).

Figure 1.5. Distribution of wasps by size across three trap locations (forest, edge, interior) during 1997 and 1998.



Discussion

Since investigators have begun to acknowledge the necessity for sampling flying insects along a vertical gradient, evidence has accumulated illustrating the various vertical patterns different flying insect communities occupy within a complex vegetational canopy (Sutton et. al 1983, Devries et al. 1999, Jaros-Su 1999, Boiteau et. al. 2000, Su & Woods 2001). Some insects, such as fig wasps (Hymenoptera: Agaonidae) appear to have a greater affinity for higher altitudes proximal to the forest canopy (Kato et al. 1995). Other insects, such as crane flies, Tipulinae (Diptera: Tipulidae), and fungus gnats (Diptera: Mycetophilidae), decrease dramatically in abundance with increasing height, the vast majority (80 – 85 %) being captured near the ground (Nielson 1987). This method has also shown how insects will change flight when moving from one habitat to another. Grape berry moths, *Endopiza viteana* (Lepidoptera: Tortricidae), captured in forests surrounding vineyards were most abundant 9 m or more above the ground, but when captured within vineyards they were most abundant approximately 1.5 m above ground (Botero-Garces & Issacs 2003). In another study using towers, Su & Woods (2001) found a difference in the vertical distribution of insects across 3 forest management systems (clearcut, selection, shelterwood). They also found that some insect taxa were only captured in traps set relatively high off the ground.

In my study, no height by field location interaction in trap capture was detected consistently during the two years of study for either bees or wasps. However, using towers allowed me to detect the existence of main effects associated with both bees and wasps. Also, grouping wasps by body size and antenna length, allowed me to apply these same methods to investigate differences in the spatial distribution of subgroups that

would not be detected when looking at the overall number of wasps captured. However, using 4 wasp subgroups, based on arbitrary body size and relative antenna length, only provided superficial insights into differences in distribution within the suborder Apocrita. In addition, an interesting shift in the vertical distribution of wasps captured from June to July would not have been detected if towers had not been used. The data provided by this study clearly illustrate some distinct differences in spatial distribution between native bees and wasps in blueberry fields (Figure 1.1 and 1.2).

The relative abundance of bees in blueberry was similar between 1997 and 1998 (Figure 1.1). An overwhelming majority of bees were captured in the bottom traps of towers, and it would appear that flight patterns of bees in and around bluberry fields exist primarily within 1m of the ground. Based on these results, only a single trap seems necessary for sampling native bees at the edge and within blueberry fields. However, four bees were captured by top traps in the forest during 1998 and appear to be the reason for the interaction between trap placement (i.e. height by location) and abundance, which was not seen in 1997. Therefore, towers should still be considered for trapping bees in the forests surrounding fields until a better resolution of bee behavior is realized. So few native bees were captured in the forest (6 in 1997, 10 in 1998) that the difference of 4 insects from one year to the next caused significant statistical differences. It is unclear from this study whether the pattern in 1997 or 1998 is more typical of bee vertical distributions within forests. Additional, more intense, sampling of the native bee community in forests surrounding fields is necessary before any definitive conclusions can be made.

A more detailed explanation could be that bees are expending most of their energy foraging for nectar and pollen. This behavior would encourage them to continually fly where the blossoms of flowering plants are situated. In blueberry fields, most of the blossoms we detected were on plants less than 1m tall. For example, during bloom, there is a dramatic increase in blueberry blossoms near the ground, and after bloom, blossoms of flowering weeds are also common within and along the edge of many fields (Karem 2005). In fact, during the 1998 season I witnessed over 30 native bees foraging on a large patch of sheep laurel (*Kalmia angustifolia*) in a small blueberry field near Beddington. Additional evidence from this study shows more than 75% of all bees were captured at location B (field edge) and location E (field interior) during both years of this study (Figure 1.1). Also, bees are known to visit witherod (*Vibernum cassinoides*), a common flowering shrub along the edge of blueberry fields (Miliczky & Osgood 1979, Karem 2005). This information is particularly important since field perimeter spraying is being investigated as an alternative insecticide application technique to control blueberry maggot fly (*Rhagoletis mendax*) and avoid spraying entire fields (Collins & Drummond 2004). Managers need to realize that bees appear to congregate primarily along the edge of fields, and intense insecticide applications could be detrimental to the native bee populations (Figure 1.1). Finding an insecticide that is effective on blueberry maggot, but less toxic to bees should be a high priority.

Wasps appear to distribute themselves very differently than bees in and around blueberry fields. Wasps were somewhat evenly distributed across all trap heights for all locations in a remarkably similar pattern seen in both 1997 and 1998 (Figure 1.2). The vertical distribution of wasps captured consistently showed the largest percentage being

captured in the low trap; however, a substantial portion was also found in the middle and top traps (Figure 1.2). Even though no formal identification of each wasp specimen was performed, I believe most of the wasps captured belong to parasitic families. Many of the specimens were recognized members of the Chalcidoidea, Cynipoidea, and Proctotrupoidea superfamilies which are predominantly parasitic (Borror et. al. 1989). Therefore, these wasps may be expending energy not only in foraging for nectar and pollen, but in searching for host insects. The pursuit of host insects may cause these wasps to fly at all 3 trap heights, but foraging for nectar and pollen in addition to parasitic activity may encourage them to spend more time flying closer to the ground. This would increase the chance of a wasp being captured in a low trap as suggested previously with bees. However, since wasps would be actively searching for hosts at various heights, I wouldn't expect to see the same overwhelming majority being captured in low traps as with bees.

Finding no height by location interaction with overall number of wasps captured might suggest that traps set 1m above the ground would capture an adequate sample to represent the overall population, susceptible to intercept trapping, in blueberry fields. However, changes in the number of wasps captured at different trap heights from June to July suggests that towers are necessary to capture the temporal dynamics (Figure 1.4). Traps at different heights may be sampling different parts of the overall wasp community found in blueberry. In another study, based on more formal identification of wasps, different groups of wasp morphospecies (i.e. comunities) were defined based on their horizontal distribution within blueberry fields (Karem 2005). Looking at the vertical distribution of morphospecies may be a way to further define communities of wasps

which exist in blueberry. Different morphospecies have also been found to peak in abundance during different times of the year (Karem 2005). Towers may be needed to detect the temporal dynamics of different morphospecies, in addition to capturing species which are not common near the ground (Su & Woods 2001). More detailed identification of these parasitica (i.e. down to genus) also seems necessary for investigators to decide which taxa require towers and which taxa can be adequately sampled using a single trap near the ground.

Evidence of distribution differences began to emerge when going from investigating all wasps in blueberry to subgroups (defined by size and antenna). No relationship was seen between the overall number of wasps captured and trap location, but when differences in wasp morphology were considered, I found that different size wasps exhibit varying patterns of distribution within blueberry. Larger wasps captured in intercept traps were consistantly more abundant in the forest during both years of the study, while smaller wasps showed no consistant affinity for any of the 3 trap field locations in blueberry (Figure 1.5, Table 1.5). One explanation for this association between large wasps and wooded habitat is that the group contained individuals from the family Diapriidae. Diapriids are well-known parasites of flies breeding in moist wooded areas (Borror et al. 1989). Diapriids are also very abundant in blueberry, and when large samples were recovered from malaise traps used in another study, more than 80% were captured in the forest surrounding blueberry fields. In fact, there was evidence showing distinct and varied distribution preferences for different wasp species (Karem 2005). These differences would likely be masked at the crude morphological level employed in this study.

Approximately 48 families of wasps (excluding ants) exist in the United States and Canada compared to only 6 families of bees (Michener 2000). Many of these wasp families provide an important beneficial role to the ecosystem they inhabit. Even though no interaction between trap placement (height and location) and wasp subgroup was detected in this study, the evidence is compelling that some wasp species would exhibit an association with trap placement, especially where the vertical structure of vegetation extends far beyond the ground (Sutton et al. 1983, Kato et al. 1995, Jaros-Su 1999, Su & Woods 2001). From a management perspective, it is important to know where specific groups of wasps tend to range in their respective ecosystems. Sampling along a vertical and horizontal gradient using towers in conjunction with detailed identification should provide that information. From the perspective of conservation, this method would also be more effective in locating rare individuals or communities of wasps that might never be detected by only sampling along the ground. In addition, other trap types should be considered. Light-traps and pheromone traps have been used in other studies which incorporated vertical sampling (Nielson 1987, Kato et. al. 1995, Botero-Garces & Isaacs 2003). Intercept traps appear to be most effective in capturing small parasitica, but were not effective in capturing large wasps. An additional study examining the distribution of various Hymenopteran wasp taxa in blueberry suggests that malaise traps are much more effective in trapping larger wasp species (Karem 2005). However, substantial challenges exist in trying to deploy malaise traps along a vertical gradient.

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Chapter 2

THE RELATIONSHIP BETWEEN WASP POPULATIONS AND FLOWERING WEEDS, LANDSCAPE AND MANAGEMENT PRACTICES IN MAINE LOWBUSH BLUEBERRY

Abstract

In an effort to understand the relative abundance and spatial distribution of wasps in lowbush blueberry (*Vaccinium* angustifolium) fields throughout Washington County, Maine, malaise traps were deployed to capture wasps during the late spring and summers of 1997 and 1998. Three traps were erected along a single transect in each field so that one was located in: the field interior, along the edge, and 10 meters into the surrounding forest. Samples collected from these traps were used to evaluate differences in the overall abundance of wasps both within and between blueberry fields. Abundance within fields was significantly lower toward the center than along the edge or in the surrounding forest. Evidence from both years indicates that wasps were positively associated with sheep laurel (*Kalmia angustifolia*), a flowering plant that is common in cultivated blueberry. Insecticides had a negative impact on wasp abundance. In 1997, traps deployed in fields untreated with insecticides captured approximately 25% more wasps, after the treatment period, compared to fields treated with insecticides where trap yield only increased by 5%. Contrary to 1997, both treated and untreated fields showed a reduction in the number of wasps trapped after the treatment period. However, the number of wasps captured in fields treated with insecticides declined 31% more than in untreated fields after the application period. Insecticides showed the greatest impact on

wasps belonging to Pompilidae and Braconidae. Relationships between trap capture of 13 wasp morphospecies and flowering weeds were also investigated. Most morphospecies, in 1998, were positively associated with one or more of the following flowering weeds: bunchberry (*Cornus canadensis*), bush honeysuckle (*Diervilla lonicera*), dogbane (*Apocynum androsaemifolium*), sheep laurel, and witherod (*Vibernum cassinoides*). Similar results were not evident in 1997 because the method used to sample vegetation was not as extensive as the method used in 1998. However, sheep laurel was positively associated with *Microplitis* sp. and *Phanerotoma* sp. during both years. Some morphospecies were found responding to the same plants and were grouped together as foraging guilds. Some morphospecies also showed similar spatial patterns of distribution within blueberry fields and were grouped together as communities. However, none of the morphospecies belonging to the same foraging guild were also found in the same community (i.e. morphospecies which showed similar between field distribution did not exhibit similar within field distributions). This may be evidence of niche partitioning among these particular wasp species to avoid competition in blueberry.

Introduction

Advances in agriculture have enabled large undeveloped landscapes to be transformed into single cropping systems (i.e. monocultures) in order to maximize production and yield. These large monocrops (e.g. wheat, corn, potatoes, and various fruits) are the basis for feeding the world, but unfortunately, this type of management is often the primary cause of pest problems (Cox and Atkins 1979, Pedigo 2002). This strategy is apparent in the development of the lowbush blueberry system in Maine, and likely has been a primary factor in promoting the numerous insect pests associated with

this crop (Drummond and Groden 2000). Areas of land, often greater than 40 ha., have been cleared and treated with herbicide to encourage only the existing wild blueberry plants to multiply. In fact, Maine is the largest producer of wild blueberries in the United States, with approximately 25,000 ha. dedicated to the production of wild blueberries (Yarborough 1999).

Integrated Pest Management (IPM) techniques have been adopted by many blueberry growers. However, once pest populations approach economic thresholds a more immediate method (sole use of pesticide applications) is usually employed (Yarborough and Dill 1995). Blueberry fields in this study received 1 to 3 fungicide applications, and 1 or 2 insecticide applications during each fruiting phase. This is relatively low compared to some monocultures such as cranberry which often get 3 to 4 insecticide applications each season in addition to other pesticides (Loose 2000). However, the use of pesticides in blueberry has still generated serious concerns about public health. Approximately 10 years ago, the citizens of Maine petitioned to ban the use of hexazinone when it was detected in ground water (Clancy 1994, Graettinger 1994). More recently, concerns associated with an increase in the incidence of cancer mortality triggered citizens of Addison, ME to pass an ordinance banning the aerial spraying of pesticides in blueberry (Edgecomb 2003). In addition to Addison, the Maine Board of Pesticides Control reports bans in Coplin Plantation, Lebanon, and New Sweden (ME) (Edgecomb 2003).

Ironically, the pesticides used to reduce communities of plant and insect pests have also been implicated in causing direct and indirect reductions of wasp populations, many of which are considered beneficial to crops being treated (Cox & Atkins 1979,

Wratten 1987, Tillman 1995). It is well documented that wasps are natural enemies of numerous pests in crops and forests all over the world (Quezada et al. 1976, Pisica et al. 1979, Turnock 1988, Yastrebov 1993, Babendreier 2000). In Maine lowbush blueberry, *Dusona sp.* and *Erromenus sp.* have been identified in blueberry spanworm (*Itame argillacearia*), and *Opius sp.*, *Theroscopus sp.* and *Aphidius sp.* have been identified in blueberry maggot (*Rhagoletis mendax*) (Luhman 1998, Drummond & Groden 2000). Therefore, since many species of wasp are highly sensitive to broad-spectrum insecticides, the toxic effect some insecticides have on wasp populations could make these chemicals counter-productive (Tillman 1995, Barbosa 1998, Cross et. al. 1999). Insecticides may reduce pest populations, but if the natural enemies of these pests are being killed as well, then pest populations could rebound to their original level (i.e. pest resurgence) very quickly (Cox & Atkins 1979, Pedigo 2002). Also, most non-host feeding and aculeate adult wasps visit flowers to obtain nectar and pollen to nourish themselves, as well as, their young (Gess 1996, Jacob & Evans 1998). Herbicides, designed to eradicate native flowering weeds in blueberry, may be destroying an important source of nutrition for wasps, causing an indirect negative impact on wasp populations. Declines in wasp abundance and parasitism rate when floral resources are scarce have been reported (Altieri et. al. 1993, Idris & Grafius 1995, Stapel et. al. 1997, Babendreier 2000). Blueberry plants cannot provide a season long floral resource for wasps since bloom only lasts for about 4 weeks in spring.

Considering all the scientific evidence that has accumulated about the niche beneficial wasps occupy in nature, blueberry growers should seriously consider optimizing wasp populations (i.e. maximum net production levels) as the first step in

efforts to control insect pests (Barbosa 1998, Shaw and Hochberg 2001, Pedigo 2002). In the past, methods of biological control such as: augmentation, inoculative release, and inundative release of parasitoids have been used with unpredictable and mixed results (Houseweart et al. 1984, Michaud 2002). Out of 1450 parasitoids introductions worldwide for classical biological control, it was estimated that only 17% resulted in established wasp populations that had an impact on the target pests (Mills 1994). The need for a more reliable method of controlling insect pests has triggered more interest in the conservation of natural enemies (Barbosa1998, Michaud 2002, Jacas and Urbaneja 2003). In fact, Shaw and Hochberg (2001) argue that the conservation of parasitic wasps has been seriously neglected, and that growers should "aim to conserve the trophic level occupied by parasitic Hymenoptera". Recognizing the potential value of native wasp populations and other natural enemies, numerous studies have focused on techniques for improving habitat for indigenous natural enemies of insect pests. Ideas such as wildflower planting, developing field margins with native flowering weeds, and reducing habitat fragmentation have been proposed (Altieri and Whitcomb 1979, Braman et al. 2002, Powell et. al. 2003, Steffan-Dewenter 2003).

Since most insect pests of lowbush blueberry are indigenous to Maine, it can be strongly argued that the best biological control approach would be the conservation of native wasp populations (Drummond and Groden 2000, Pedigo 2002). However, protecting and optimizing wasp populations requires knowledge about existing species, habitat association, population sizes, and identifying prey/host insects. Therefore, the primary objectives of this study were to identify some of the wasp taxa found in Maine lowbush blueberry, investigate their spatial distribution, and determine what non-

blueberry floral resources are associated with them. Initially, I looked at all wasps collectively to see what floral resources might be important, and identify how the overall population was distributed across blueberry fields and the surrounding forest border. I then examined specific wasp morphospecies to: identify some of the wasp taxa indigenous to blueberry in Maine, determine which floral resources (if any) each morphospecies is associated with, to see how these morphospecies are distributed across field and forest habitats, and to see whether multiple morphospecies make up communities within blueberry. In addition, I examined the direct effect of insecticides on these wasps.

Methods

Site Description

This study was conducted in selected lowbush blueberry fields during their fruiting cycle, within Washington County, Maine. These fields were established for the commercial production of lowbush blueberries. Lowbush blueberry production constitutes one of the largest agroecosystems in Maine. Fields are developed by clearcut harvesting of forest and applying herbicides. These herbicides selectively kill most competing native vegetation and allow the growth of lowbush blueberry plants. Therefore, some areas where numerous fields are established next to each other give the landscape the appearance of having "gaps" in the forest. The majority of blueberry fields in this study were owned and managed by C&D Corporation or Cherryfield Foods, Inc. Some fields, however, were owned and managed by local residents who agreed to participate in the study. In all fields, data collection occurred for only one season, since it

is standard commercial practice to rotate a field out of production every other year (prune cycle) by either burning or mowing it after harvesting (Drummond & Groden 2000). Each blueberry field and its bordering forest were considered as an individual study site or experimental unit.

Thirty-four sites were selected for this study: eighteen in 1997 and sixteen in 1998 (Table 2.1). Each year, field sites were identified by number, and grouped into one of three blocks representing different geographic regions of the whole study area: Block I (Beddington, Deblois), Block II (Cherryfield), Block III (Columbia Falls, Jonesboro, Jonesport, Whitneyville). Field sizes ranged from less than 1 to 71 ha. Some fields were isolated; completely surrounded by forest. Many fields were only partially surrounded by forest since they were situated immediately next to other lowbush blueberry fields. A visual estimate was conducted at each field to ascertain how much of the perimeter was forested, and how much was bordered by adjacent blueberry fields (Table 2.1).

Trap Design

In a brief preliminary study, during the fall of 1997, a number of different insect traps were used to see how effective they were in trapping bees and wasps. Results of this study led us to believe that malaise traps would be most effective for trapping wasps in blueberry. Malaise traps were used to sample insects in blueberry fields and forest stands bordering the perimeter of those fields. The trap is designed to passively intercept flying insects whose direction of travel intersects the trap's position. These traps were constructed of a vinyl mesh material (8 threads/cm.) with a pore size of 0.08 cm^2. The lower intercept panels were made by sewing two pieces of black mesh material (102 cm.

Table 2.1. Description of the 34 field sites studied in Washington County, Maine.

Year	Field Number	Block	Size (ha.)	Field Perimeter (% Forested)
1997	1	I	3.2	50
1997	2	I	14.6	70
1997	3	I	49.8	60
1997	4	I	32.4	40
1997	5	I	16.2	40
1997	6	I	2.4	100
1997	7	I	23.9	70
1997	8	II	13.8	40
1997	9	II	15.8	30
1997	10	II	4.0	40
1997	11	II	3.2	60
1997	12	III	4.0	50
1997	13	III	10.1	70
1997	14	III	6.9	60
1997	15	III	3.0	80
1997	16	III	11.3	70
1997	17	III	5.7	50
1997	18	III	1.2	90
1998	1	III	1.6	30
1998	2	III	5.9	60
1998	3	III	9.5	50
1998	4*	III	0.8	40
1998	5	II	5.7	40
1998	6	II	2.0	80
1998	7	II	16.6	40
1998	8	II	44.5	60
1998	9	I	3.2	50
1998	10	I	0.8	70
1998	11	I	68.8	50
1998	12	I	28.3	100
1998	13	I	12.1	50
1998	14	I	2.0	70
1998	15	I	70.9	70
1998	16	I	0.8	80

* Insect traps in field 4 were not setup until June 18th.

high x 91 cm. wide) together to form a "+" shape when viewed from above. The upper collecting hood was made by sewing four triangular pieces of white mesh material (50 cm. high x 66 cm. base) together to form a pyramid-shaped section that would be placed over the lower panels. A 1.52 m length of EMT steel conduit was used to support the trap. A collecting cup was seated on top of the conduit. The trap was secured to the ground using tent stakes and guy-lines. A small block of Vapona® was placed in the collecting cups of each malaise trap as a killing agent.

Insect Sampling

Wasp populations in each field site were sampled during the summers of 1997 and 1998. Three traps were deployed along a linear transect established within each field site. Transects extended from a point in the forest border, 10 m beyond the field edge, out to the interior of each field. Three field locations (A, B, E) were established along each transect for the positioning of traps. Trap A was located 10 m beyond the field border into the adjacent forest, trap B was located at the field border, and trap E was located at the field interior (near the center). In 1997, traps were set during the week of May 26 and checked once a week while blueberry plants were in bloom until the week of June 23. Thereafter, traps were checked every other week until the week of July 21, one week before harvest. In 1998, traps were set during the week of May 11 and checked every other week until the week of July 27, one week before harvest. Wasp data collected from field 4 was not used since traps were not set until June 18, 1998. All insects were collected during each field visit and returned to the University of Maine for sorting, pinning, and identification.

Insect Identification

In 1997 and 1998, all insects of the suborder Apocrita (ants, bees, parasitic and non-parasitic wasps) except those of the superfamily Formicidae (ants), were sorted from the collection cups of all traps. These insects were then further divided by removing all members of the superfamily Apoidea (bees). A reference collection of parasitic and non-parasitic wasps was then developed using these specimens. Wasp specimens were identified to superfamily, family or subfamily. Identification of all wasps to the species level was impractical due to limited taxonomic expertise. Instead, wasps from this study were placed in morphologically distinct taxa (morphs) based on external morphological characteristics. This method has been used in other studies as an alternative to formal insect species identification in order to get relative estimates of the abundance and richness of insect communities (Oliver & Beattie 1996, Jaros-Su 1999). All specimens were then sorted into morphospecies within their respective family- level taxonomic classification. All identifications were made using taxonomic keys of Borer et al. (1989) and Goulet & Huber (1993). Identification to superfamily, family, subfamily and sorting to morphospecies was performed by J. E. Karem and D. Ngollo. Some selected morphospecies were further identified to species by Dr. John Luhman of the Minnesota Department of Agriculture. As a result, some morphospecies represent a single wasp species, and some represent multiple species.

Vegetation Sampling

Two methods were used to estimate floral abundance and diversity of all flowering plants in bloom, except blueberry (*Vaccinium angustifolium*), within each field.

Quadrat sampling was used to estimate the percentage of field covered by each flowering plant species (Krebs 1989). Line transect sampling (Eberhardt 1978, Krebs 1989) was conducted in 1998 to better quantify the abundance of flowers for each flowering plant species on each sampling date. Only plants in bloom during the sampling periods were included. In 1997, two quadrat samplings were performed, once early in June and again in late July. In 1998, quadrat sampling was conducted once in late June and again in late July. In addition, line transect sampling was performed in 1998 starting 15 June and repeated every two weeks, until four samplings were completed. Identification of plant species were performed by K. Georgitis, J.E. Karem, and Dr. C. Stubbs in the field with the aid of field guides (Barnard & Yates 1998, Haines & Vining 1998, Newcomb 1977).

Quadrat Sampling. Floral sampling was performed along three transects (floral transects) which ran parallel to transects with insect traps (trapping transects). Floral transects were arbitrarily established 5 m or less from each trapping transect. Each floral transect started at the edge where blueberry becomes the dominant vegetation, usually near trap position B. Samples were taken at 5 locations randomly chosen along each floral transect using a 1 m^2 frame (quadrat). The frame was placed at a designated distance from the edge, and the identity of each flowering plant was recorded along with the percentage of space it occupied within the frame. The percentage of blueberry vegetation and barren ground within the frame was also recorded. This was repeated until five samples were completed from each of the three transects for a total of 15 samples per field.

Line Transect Sampling. Sampling was performed along a floral transect defined by a 60 m line that was laid parallel to one of the trapping transects. These floral transects were established 5 m or less on both sides of each trapping transect for a total of six floral

transects per field. The sampling line was placed on the field so that it extended 10 m into the bordering forest and 50 m into the field. All flowering weeds that touched the vertical plane, defined by the sampling line, were identified and recorded. The two-dimensional shape of the plant, the dimensions of its shape, and the number of blossoms were recorded. The plant density for species i (D_i) was calculated by the following formula:

$$\mathbf{D}_i = \sum \mathbf{A}_j / ((\mathbf{B}j/100)*\mathbf{C})) \quad j = 1 \ldots k$$

Where $\mathbf{A}_j$ = the number of plant(s) or blossoms at a specific point (j) on the floral transect (j denotes all detections of a flowering plant species along each floral transect from first to last (k)), $\mathbf{B}_j$ = diameter of the plant(s) in cm, and **C** = the total transect length in m (Georgitis 2001).

Data Analysis

Four data sets were developed to represent the following variables estimated at the site level and summed over the season: 1) the number of all wasps captured at each site; 2) the number of each morphospecies captured at each site; and 3) density and cover (%) of all flowering weeds identified at each site, and 4) the type and frequency of all pesticides applied to each site.

Abundance and Distribution of Flowering Weeds. The average percent cover of all flowering weeds in each field was estimated by way of quadrat sampling (1997 & 1998) and line transect sampling (1998 only). A Pearson correlation analysis was used to test for a positive correlation between estimates of percent cover derived from the quadrat and line transect sampling performed in 1998. The average blossom density of all

flowering weeds at each field was estimated with line transect sampling for 1998 only. The average percent cover and blossom density was estimated for each flowering weed detected at each field site across all sample dates. Estimates of plant cover and blossom density were also calculated for the area only within blueberry fields (i.e. excluding flowering weeds in the forest). In addition, estimates of flowering weed diversity were generated for each field in 1998, using both Simpson's (D_W) and Shannon's (H_W) index of diversity. These indices were used as independent variables in analyses of wasp groups. Both were used since it is suggested that Simpson's index weights common species more heavily, and Shannon's index weights rare species more (Krebs 1989).

Additional analyses of sheep laurel (*Kalmia angustifolia*) were conducted since it was abundant at field sites and strongly associated with wasps in blueberry. I examined the average percent cover of sheep laurel to see if there was a significant difference between sites. Statistical significance was assessed using a one-way log-linear model (PROC GENMOD, SAS for Windows 8.1) where the cover of sheep laurel at each site was the dependent variable and site was the independent variable. A significant site result confirms the coverage is not consistent across all field sites during that season. Sheep laurel was also examined using a Pearson correlation analysis to see if any correlation existed between sheep laurel and the cumulative abundance of all other flowering weeds detected in blueberry.

Factors associated with differences in overall wasp capture between blueberry sites. In an initial analysis, I examined the number of all wasps captured to see if there were significant differences in the relative abundance of wasps between field sites. Wasps from each site were pooled across all collection dates. No transformation of data was

performed. Statistical significance was assessed using a one-way log-linear model (PROC GENMOD, SAS for Windows 8.1) where the total number of wasps captured at each site was the dependent variable and site was the independent variable. A significant site result indicates that the number of wasps captured is not consistent across all field sites during that season.

Upon finding a difference in abundance among sites, a multiple regression procedure (PROC GLM, SAS for Windows 8.1) was used to develop models for 1997 and 1998. These models would be used to investigate the role that flowering weeds, geographic block, and pesticide applications might have on the relative abundance of all wasps at each field site. Data for wasp abundance were logarithmically (base 10) transformed in these analyses to meet the assumptions of normality and stabilize the variance. Independent variables, representing flowering weeds, geographic block, and pesticide applications, were tested in models based on results from a stepwise procedure (PROC STEPWISE, SAS for Windows 8.1). Independent variables were included in the model if they generated an F-statistic significant at the $\alpha = 0.05$ level. Once a model was developed, residual values were expected to fall within two standard deviations of the model's predicted values. A plot of this was used to inspect the model's validity. In addition, the residuals for the model and each corresponding independent variable were plotted, and visually examined, to test the model's validity. Some independent variables were transformed to more evenly distribute values along the x-axis. Residuals were expected to fall within 2 standard deviations of values predicted by the model.

Factors associated with differences in wasp morphospecies capture between blueberry sites. For each wasp morphospecies analyzed in this study, the sum of all individuals

captured at each field was tabulated. This data set was used to see which morphospecies demonstrated, statistically, different abundance between fields. No transformations of data were necessary. Statistical significance was assessed using a two-way log-linear model (PROC GENMOD, SAS for Windows 8.1) where the total number of insects captured at each site was the dependent variable and both morphospecies and site were the independent variables. A significant morphospecies by site interaction result indicated that the relative abundance of insects between the field sites is not consistent for all wasp morphospecies entered into the analysis. To group wasp morphospecies whose relative abundance was not statistically different across fields the following method was used: 1) Two morphospecies were compared to see if a significant difference in their abundance within sites existed. If a significant result was detected then each morphospecies was placed in its own group (e.g. Group 1 and Group 2), if not, then they were placed in the same group (e.g. Group 1); 2) A third morphospecies is then compared to the existing groups for any significant site abundance differences. If the third morphospecies exhibited a significant difference in site abundance from previously defined groups then it was placed in its own group (e.g. Group 3), otherwise the morphospecies was placed with the group with which it produced the largest p-value when added; 3) Subsequently, additional morphospecies were analyzed and grouped as in step 2 until all morphospecies were analyzed. Since this method will estimate a higher p-value when a particular morphospecies exhibits more similarities in distribution to another morphospecies, or group of morphospecies, a higher significance level was used ($\alpha = 0.10$) to detect differences in distribution, thereby increasing our confidence that morphospecies grouped together based on this analysis should actually be together.

Morphospecies data was also graphed to demonstrate relative abundance between fields and substantiate these analyses.

Assuming morphospecies grouped together are responding to the same field conditions, the cumulative abundance of these groups was used for analyses. Multiple regression analyses (PROC GLM, SAS for Windows 8.1) were used to develop models explaining the relationship flowering weeds, field location, and pesticide applications might have with the relative abundance of individual or grouped morphospecies at each field site. All data for individual and grouped morphospecies abundance (except *Microplitis* and *Phanerotoma* sp.) were lognormal-transformed in these analyses to meet the assumptions of normality and stabilize the variance. The methods used were the same as those for evaluating between-field differences in overall wasp capture, previously mentioned.

Insecticides and Wasp Populations. Imidan (1.5 pints/acre), and Sniper (1 pint/acre) were the only insecticidal agents applied to fields while insects were being collected for this study (Appendix A). In 1997, 12 fields had one of these insecticides applied between the 5^{th} and 6^{th} collection (July 12 – 18), and 6 fields received no insecticide. In 1998, 9 fields had one of the insecticides applied between the 5^{th} and 6^{th} collection (July 17 – 18), and 6 fields received no insecticide. Repeated measures ANOVAs (PROC GLM, SAS for Windows 8.1) were used to examine the effect of insecticides on wasp abundance before (collection 1 – 5) and after the insecticide period (collection 6) in treated versus untreated fields. Data was logarithmically (base 10) transformed. Transformations were performed to normalize the data and stabilize the variance. A significant time by

treatment interaction indicates the number of insects captured is not consistent before and after treatment with insecticide for treated versus untreated fields.

In an effort to see whether the impact of insecticides was greater on certain wasp taxa than others, the same analysis was applied to wasp morphospecies. However, the abundance of some morphospecies was not sufficient to perform this analysis so morphospecies were grouped together by family. No analysis could be performed on morphospecies belonging to Chrysididae or Vespidae since an insufficient number of these wasps were recovered after the insecticide period. All wasp family data was lognormal-transformed except for Braconidae. No transformation of braconid data was performed for 1997, and data generated in 1998 was square-root transformed.

Spatial Distribution of Wasps in Blueberry. In an initial analysis to illustrate the horizontal distribution of all wasps in and around blueberry, I examined wasp trap counts for the 3 trap positions within field sites (i.e. forest, edge, and field). Wasp samples were pooled across all collection dates for each field by position. This yielded a seasonal total for each position within each site. Statistical significance was assessed using a one-way log-linear model (PROC GENMOD, SAS for Windows 8.1) where the total number of insects caught at each trap position was the dependent variable and position was the independent variable. A significant position term indicates that the number of insects captured is not uniform across the three trap positions. I was also interested in seeing if wasp distribution within blueberry changed between years, so I tested for a significant difference between seasons in the number of wasps captured among the 3 trap positions. Statistical significance was assessed using a two-way log linear model (PROC GENMOD, SAS for Windows 8.1) where the total of number insects caught in each trap

was the dependent variable and both year and trap position were independent variables. A significant year by position interaction indicates that the number of insects trapped across the three positions do not exhibit the same pattern of distribution for both years of the study.

Spatial Distribution of Wasp Morphospecies within Blueberry Sites. To investigate whether multiple wasp taxa utilize the same microhabitat (i.e. communities), I looked at the within-field distribution of wasp morphospecies (the same morphospecies I used for between-field analyses), and attempted to group these taxa into communities based on spatial preferences. For each morphospecies, the sum of all individuals captured within each field for each trap position was tabulated. No transformations of data were performed. Statistical significance was assessed using a two-way log-linear model (PROC GENMOD, SAS for Windows 8.1) where the total number of insects captured was the dependent variable and both morphospecies and trap field location were the independent variables. A significant morphospecies by location interaction result indicates that the distribution of insects captured between the three trap locations is not consistent for all the morphospecies entered into the analysis.

Further analyses were performed to see if multiple morphospecies display similar spatial distributions within blueberry (i.e. morphospecies communities). The same method was used to define morphospecies communities as employed in grouping morphospecies whose abundance was not statistically different across fields. Morphospecies data was also graphed to demonstrate spatial distributions and substantiate statistical analyses. A morphospecies which did not associate with any other morphospecies, statistically or graphically, was placed in its own spatial community.

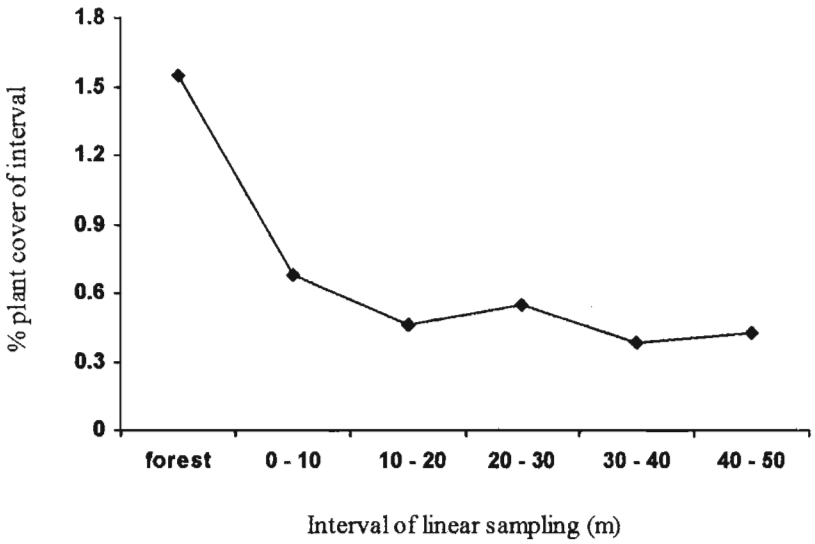
Results

Abundance and Distribution of Flowering Weeds in Blueberry

Based on estimates of percent field cover for flowering weeds detected in 15 blueberry fields sampled during 1998, the quadrat sampling method was at best, weakly correlated with the line transect sampling method ($r = 0.44, p = 0.087$). In fact, line transect sampling detected 3 - 14 different flowering weeds at each site, while quadrat sampling detected only 0 - 6 different flowering weeds at each site. Further, quadrat sampling detected a total of only 12 flowering weed species across all sites in 1998, compared to 38 detected by line transect sampling in 1998.

Numerous species of flowering weeds were identified in blueberry fields during 1997 and 1998. However, very few species were detected across a majority of sites. Species detected in at least 50% of the field sites (i.e. "common" species) in 1997 included bunchberry (*Cornus canadensis*), black chokeberry (*Aronia melanocarpa*), dogbane (*Apocynum androsaemifolium*), and sheep laurel (*Kalmia angustifolia*). In 1998, common species included bunchberry, bush honeysuckle (*Diervilla lonicera*), sheep laurel, yellow cinquefoil (*Potentilla simplex*), and witherod (*Vibernum cassinoides*). In 1997, bunchberry exhibited the highest percent cover (4.93%) when averaged across all field sites, and sheep laurel was second averaging 0.82% cover per field. However, in 1998, sheep laurel was the most abundant flowering weed, based on percent cover, averaging 0.69% cover per field. It was very abundant in the forest (Figure 2.1), and surpassed all other flowering weeds in average blossom density (1082 blossoms / ha.) by more than 50 fold during the sampling period. Bush honeysuckle and witherod may not have been commonly detected in 1997 because no vegetation sampling

Figure 2.1. Spatial distribution of sheep laurel in 15 blueberry fields in Washington County, ME, in 1998.



was done in the forest that year. These species were abundant in the forest, but extremely rare in the fields (Figures 2.2, 2.3). Based on quadrat sampling, bush honeysuckle and witherod went undetected in 1997 and occurred in only one field in 1998. Dogbane did not qualify as common in 1998 with either sampling method (as in 1997), but was identified in 6 of 15 sites that year using the line transect sampling method. It exhibits some growth in the forest, but appears to thrive proximal to the edge. In addition, a notable amount was detected in the fields of some sites (Figure 2.4).

Considering its abundance, sheep laurel could be one of the more important plants in lowbush blueberry for many wasps. It was identified in 11 of 18 fields in 1997, and 12 of 15 fields in 1998. Coverage of sheep laurel within sites ranged from 0% to 5.33% in 1997 and from 0% to 5.07% in 1998. A difference in the coverage of sheep laurel was detected between field sites during 1997 (field term, $\chi^2 = 32.12$, d.f. = 17, $p = 0.015$) and 1998 (field term, $\chi^2 = 58.19$, d.f. = 14, $P < 0.001$). While sheep laurel was

Figure 2.2. Spatial distribution of bush honeysuckle in 15 blueberry fields in Washington County, ME, in 1998.

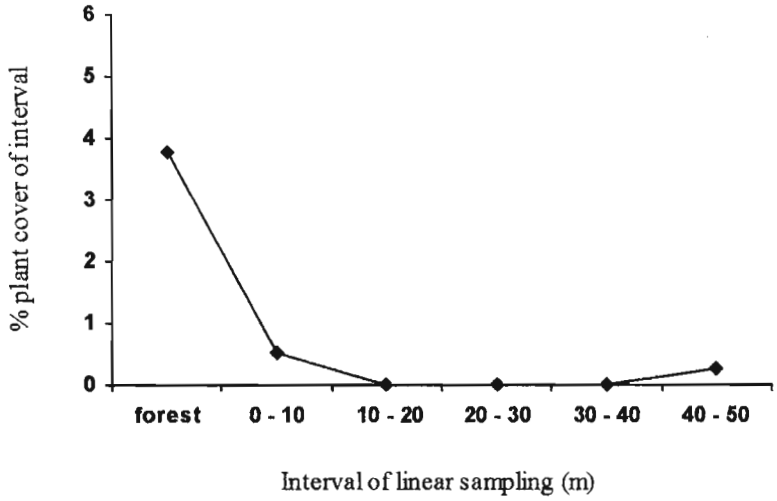
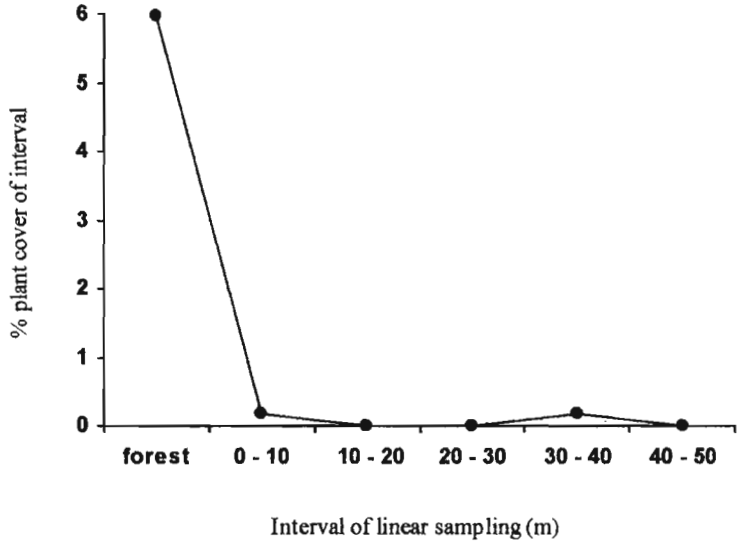
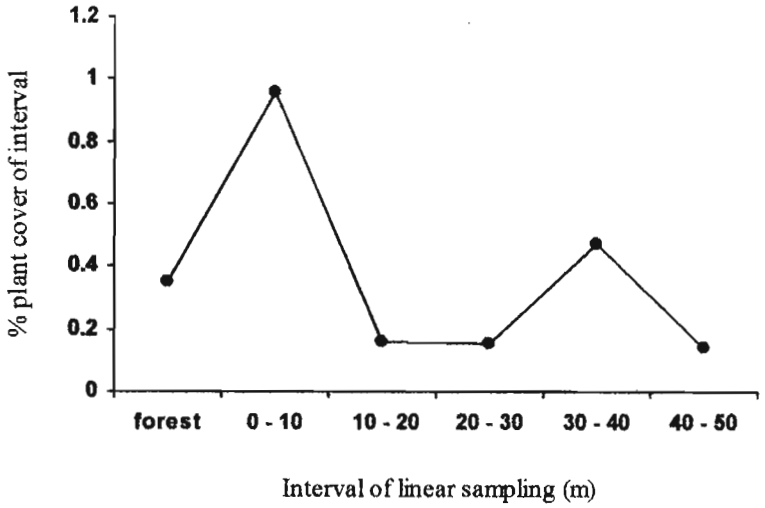


Figure 2.3. Spatial distribution of witherod in 15 blueberry fields in Washington County, ME, in 1998.



common, Pearson correlation analyses showed no relationship between the abundance of sheep laurel and the cumulative abundance of all flowering weeds in blueberry fields for 1997 or 1998 (Table 2.2). During 1998, field 9 had the highest percent cover of total flowering weeds, but sheep laurel cover was quite low. Sheep laurel also exhibited no consistent relationship with any other common flowering weed species for both years (Table 2.2). A significant correlation was found between sheep laurel and dogbane in 1997 ($r = 0.57$, $p = 0.014$), but not in 1998 ($r = -0.09$, $p = 0.730$). Based on 1998 floral data, the greatest percent cover of sheep laurel was in mid-June. By mid-July it was not in bloom.

Figure 2.4. Spatial distribution of dogbane in 15 blueberry fields in Washington County, ME, in 1998.



Factors Associated with Differences in Overall Wasp Capture between Blueberry Sites

A total of 5,056 and 4,884 wasps were captured in the malaise traps during 1997 and 1998, respectively. An initial analysis indicated that a significant and substantial differences in wasp densities existed between the field sites during both 1997 (field term, $\chi^2 = 1469$, d.f. = 17, $P < 0.001$) and 1998 (field term, $\chi^2 = 1668$, d.f. = 14, $P < 0.001$). Numbers collected in individual blueberry fields during an entire season ranged from 74 to 597 in 1997, and from 131 to 867 wasps in 1998 (Table 2.3).

No significant correlation was detected between the overall number of wasps captured at each field and percent cover of blueberry in 1997 ($r = -0.06$, $p = 0.808$) or 1998 ($r = -0.21$, $p = 0.444$) (Table 2.3). The percent of field not covered by blueberry was either bare earth or covered by weeds.

Since no association between wasps and blueberry cover was evident, I used multiple regression analyses to identify potential associations between wasps captured and various field measurements (% cover of weed species, blossom density of weed species, number of insecticide applications, field location, and % field perimeter bordered by forest) taken during each field season. Estimates of floral abundance were more limited in 1997 than 1998 because the line-transect sampling used in 1998 was more comprehensive and extended into the forest. As a result, less floral data were collected during 1997, compared to 1998, and fewer species of flowering weeds were included in the analyses relating floral resources with wasp abundance.

Based on a stepwise procedure (PROC STEPWISE, SAS for Windows 8.1), sheep

Table 2.2. Correlation coefficients for common flowering weeds. P-values are in parenthesis. BB – bunchberry BH – bush honeysuckle CB – chokeberry CINQ – cinquefoil DB – dogbane SL – sheep laurel D_W – plant diversity (Simpson's Index) TOTAL – total % coverage of all weeds in field WR – witherod.

a. Common flowering weeds detected in 18 fields (excluding forests) during 1997.

	BB	CB	DB	SL	DIV	TOTAL
BB	1.00					
CB	0.28 (0.26)	1.00				
DB	0.16 (0.54)	0.10 (0.71)	1.00			
SL	0.02 (0.95)	0.51 (0.03)	0.57 (0.01)	1.00		
D_W	0.71 (<0.01)	0.77 (<0.01)	0.14 (0.57)	0.37 (0.13)	1.00	
TOTAL	0.79 (<0.01)	0.75 (<0.01)	0.11 (0.65)	0.25 (0.33)	0.97 (<0.01)	1.00

b. Common flowering weeds detected in 15 fields during 1998.

	BB	BH	CINQ	DB	SL	WR	DIV	TOTAL
BB	1.00							
BH	-0.27 (0.30)	1.00						
CINQ	-0.01 (0.96)	0.52 (0.04)	1.00					
DB	-0.10 (0.71)	0.07 (0.79)	-0.14 (0.61)	1.00				
SL	0.03 (0.91)	-0.27 (0.30)	-0.32 (0.22)	-0.09 (0.73)	1.00			
WR	0.19 (0.48)	-0.21 (0.43)	0.16 (0.55)	-0.30 (0.26)	0.13 (0.64)	1.00		
DIV	0.36 (0.18)	-0.44 (0.10)	-0.11 (0.71)	0.12 (0.67)	0.19 (0.50)	0.05 (0.86)	1.00	
TOTAL	0.17 (0.54)	-0.17 (0.53)	0.14 (0.60)	-0.11 (0.70)	0.05 (0.86)	0.27 (0.31)	0.22 (0.44)	1.00

Table 2.3. Total wasps trapped and percent blueberry covering each field.

Field Number (1997)	Wasps Captured (1997)	% Blueberry Cover (1997)	Field Number (1998)	Wasps Captured (1998)	% Blueberry Cover (1998)
1	171	41.7	1	471	63.2
2	167	84.1	2	176	76.5
3	74	63.9	3	236	82.3
4	209	74.6	*	*	*
5	313	86.4	5	328	50.7
6	130	91.9	6	204	76.5
7	135	77.6	7	299	71.6
8	451	86.3	8	162	87.6
9	482	69.1	9	196	49.7
10	354	64.7	10	867	68.0
11	447	59.8	11	190	80.8
12	141	86.3	12	202	89.3
13	360	56.0	13	555	70.1
14	173	66.0	14	131	76.1
15	597	83.1	15	638	87.7
16	326	66.5	16	229	81.5
17	109	59.2	**	**	**
18	417	37.2	**	**	**

* field 4 data not included in study due to late setup of traps.
** only 16 fields were setup in 1998.

laurel was the only field variable associated with overall wasp capture in 1997 (Figure 2.5). However, analyses of 1998 data identified additional variables explaining total wasp distribution across fields ($r^2 = 0.68$, $F_{(3,11)} = 7.73$, d.f. = 14, $p = 0.005$),

$$\ln \mathbf{Y} = 4.08 + 1.52\mathbf{SL}^{1/3} + 1.30\mathbf{D_W}^{1/2} - 0.60\mathbf{B_2}$$

Y = all wasps captured at a site,
SL = percent cover of sheep laurel at site (partial-$r^2 = 0.34$, $P < 0.001$)
$\mathbf{D_W}$ = Simpson's diversity index for weedy flowers (partial-$r^2 = 0.17$, $p = 0.038$)
$\mathbf{B_2}$ = categorical entry for fields assigned to block 2 (partial-$r^2 = 0.17$, $p = 0.022$)

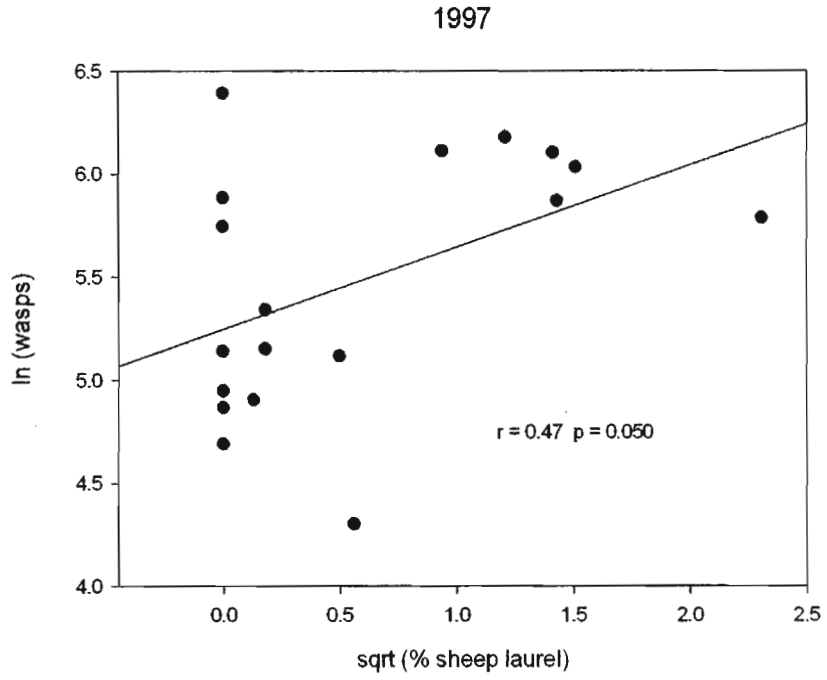
and showed a stronger association between the abundance of sheep laurel and wasp capture (Figure 2.5).

Factors Associated with Differences in Wasp Morphospecies Capture Between Blueberry Sites

A total of 13 wasp morphospecies were selected for analysis from all wasps captured during this study (Table 2.4). These morphospecies were selected because of distinct morphological features that made them easy to recognize and, in some cases, because of abundance. Four of these morphospecies were identified to family, 3 were identified to genus, and 6 to species (Table 2.4).

In previous analyses, the total number of wasps captured was correlated with the abundance of sheep laurel and diversity of weeds in general. However, these relationships represent only a general picture of how wasps respond to floral communities in and around blueberry fields. Another investigation was performed to evaluate whether individual taxa might respond differently to differences in weed communities represented in this study.

Figure 2.5. Overall abundance of wasps in relation to the percent cover of sheep laurel at each blueberry site in Washington County, ME, in 1997 and 1998.



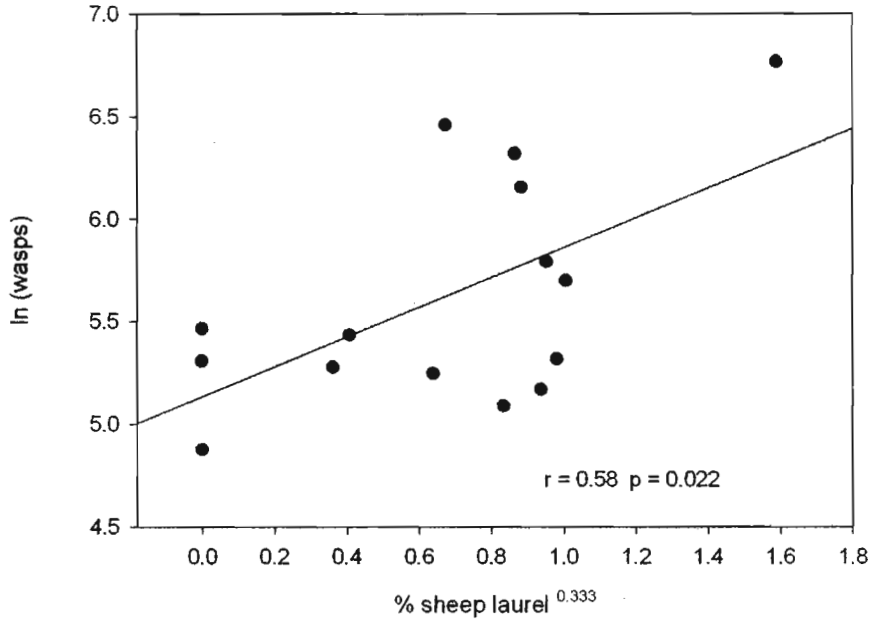


Table 2.4. Thirteen morphospecies of parasitic and non-parasitic wasps identified from all wasps captured in malaise traps.

Morphospecies I.D.	Family	Subfamily	Genus	Species
BM2	Diapriidae	N/A	N/A	N/A
BM3	Chrysididae	N/A	N/A	N/A
BM5	Vespidae	Vespinae	N/A	N/A
BM6	Pompilidae	N/A	N/A	N/A
BM7	Ichneumonidae	Ophioninae	*Ophion*	N/A
BM8	Ichneumonidae	Tryphoninae	*Netelia*	*chloris, blantoni, tarsata*
BM9	Ichneumonidae	Campopleginae	*Dusona*	*laminata, montrealensis, variabilis*
BM11	Braconidae	Microgastrinae	*Microplitis*	*N/A*
BM12	Braconidae	Cheloninae	*Phanerotoma*	*N/A*
BM13	Ichneumonidae	Banchinae	*Banchus*	*flavescens*
BM14	Ichneumonidae	Cryptinae	*Aptesis*	*incompta*
BM16	Ichneumonidae	Ichneumoninae	*Cratichneumon*	*pteridis, rubricoides, flavipectus*
			Barichneumon	*soror, excesior*
BM17	Ichneumonidae	Banchinae	*Exetastes*	*abdominalis*

Initial analyses were performed to identify morphospecies with similar responses to floral communities by examining the relative abundance of taxa across all fields. The between-field capture of some morphospecies was positively associated with the capture of others during both field seasons (Table 2.5). Three groups, containing multiple taxa with similar between-field distribution, were identified: 1) *Microplitis sp.* and *Phanerotoma sp.* 2) *B. flavescens, Barichneumon spp.* and *Cratichneumon spp.* and 3) Chrysididae, Vespinae, and *Dusona spp.* (Table 2.5). The remaining taxa were distributed differently from all other groups and individual taxa.

Multiple regression analyses were performed on the 3 groups and the 6 individual (i.e. ungrouped) taxa for 1997 and 1998 (i.e. a total of 9 separate analyses for each season). In 1997, only groups 1 and 3 were positively associated with any flowering weed species, sheep laurel and aster, respectively (Table 2.6). In 1998, all 3 groups and

Table 2.5. Morphospecies, which did not exhibit significant differences in abundance between blueberry sites, placed in the same group. Chi-squared values represent the site x morphospecies interaction term ($\alpha = 0.10$, PROC GENMOD, SAS for Windows 8.1).

Group	Wasp Morphospecies	Year	χ^2	d.f.	p-value
1	*Microplitis sp.*	1997	23.10	17	0.128
	Phanerotoma sp.	1998	10.83	14	0.699
2	*B. flavescens*				
	Barichneumon spp.	1997	22.86	17	0.154
	Cratichneumon spp.	1998	4.11	14	0.995
3	Chrysididae				
	Dusona spp.	1997	26.26	34	0.826
	Vespinae	1998	19.51	28	0.882

all individual morphospecies, except *Ophion sp.*, were positively associated with one or more of the following five species of flowering weeds: bunchberry, bush honeysuckle, dogbane, sheep laurel, witherod. Similar to the previous analyses on overall wasp capture, sheep laurel was positively associated with more wasp taxa than any other plant species, and often contributed more to the model (i.e. highest partial-r^2) than any other variable (Table 2.6). The importance of plant diversity in total wasps captured may reflect the contributions of these other weeds at the grouped and ungrouped taxa levels.

Examination of the phenology of floral resources and wasp capture may also provide insights into the associations between wasp morphospecies and native flowering weeds (Figure 2.6). Most of these important floral species bloomed shortly after blueberry and provided a potential resource for wasps after blueberry blossoms had fallen. Peak bloom of sheep laurel and other flowering weeds coincided with high trap yields of most morphospecies associated with them (Figure 2.6). However, some morphospecies were trapped in relatively large numbers prior to bloom of these weeds (i.e. during blueberry bloom) such as Vespidae and *Ophion* sp. (Figure 2.6).

Table 2.6. Flowering weeds and other field variables associated with each of the 13 wasp morphospecies.
AST = aster BB = bunchberry BF = bracken fern BH = bush honeysuckle DB = dogbane SL = sheep laurel RASP = raspberry WR = withered WRICH = weed richness ACRE = field size B1 = block 1 sites B2 = block 2 sites B3 = block 3 sites BORD = % of field border forested D_W = Diversity Index for flowers INS = insecticide applications PEST = all pesticide applications.

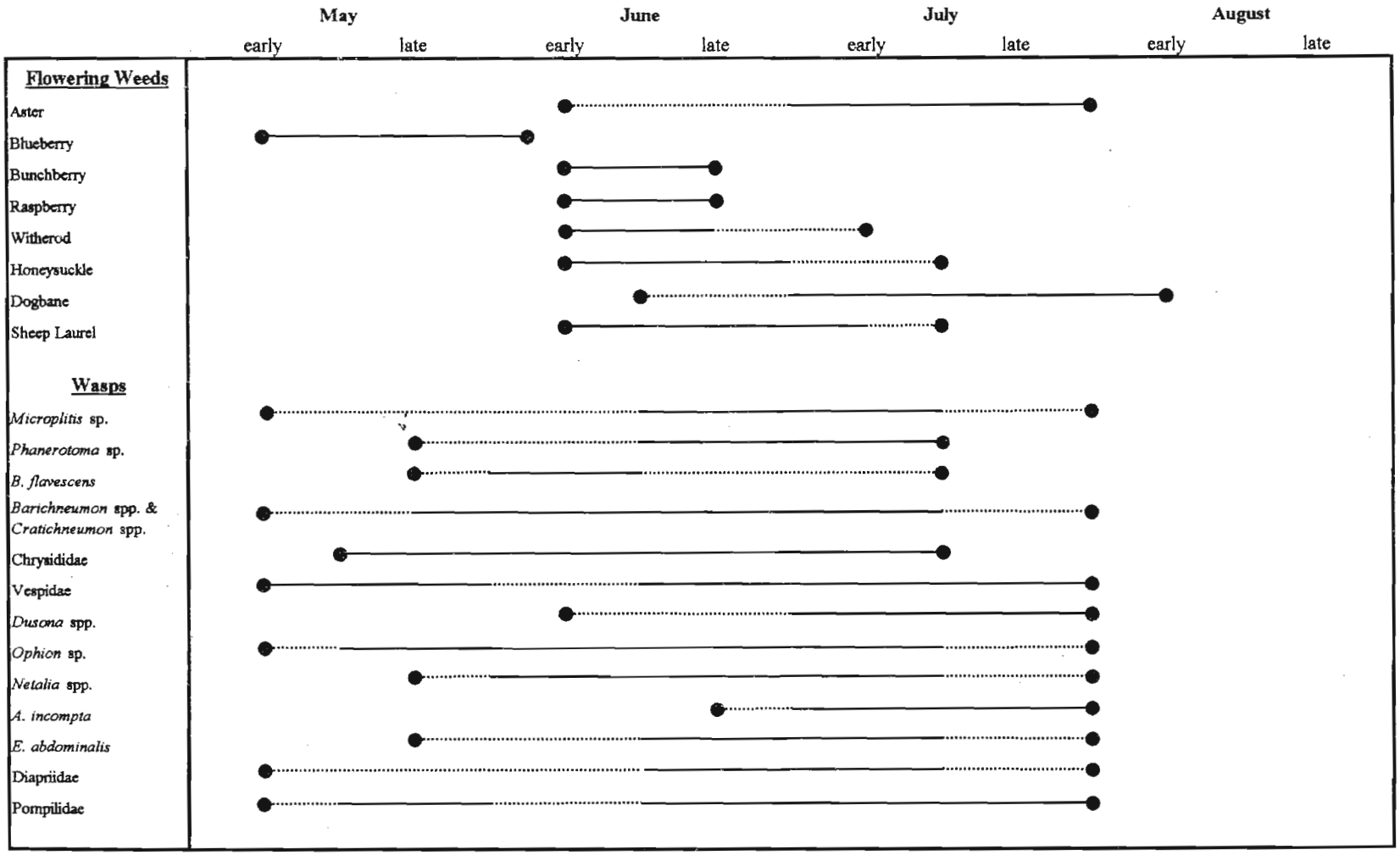
Scientific Name (Morph I.D.)	Group*	Year	Associated Flowering Weeds (partial R^2, *p-value*)	Other Associated Variables (partial R^2, *p-value*)
Ichneumonidae:				
Ophion sp. (BM7)		1997	-BF (0.21, *0.019*)	B2 (0.35, *0.003*)
		1998	-WRICH(0.13, *0.050*)	-BORD(0.13, *0.037*), B1(0.47, *0.013*)
Netelia spp. (BM8)		1997	N/S	N/S
		1998	BH(0.15, *0.004*), WR(0.13, *0.017*), -RASP(0.10, *0.010*)	-B3(0.20, *0.025*), ACRE(0.18, *0.003*)
Dusona spp. (BM9)	3	1997	AST (0.26, *0.031*)	N/S
		1998	SL(0.60, <*0.001*), WR(0.12, *0.012*), BB(0.10, *0.033*)	N/S
B flavescens (BM13)	2	1997	N/S	N/S
		1998	DB(0.38, <*0.001*), BH(0.15, *0.004*), SL(0.09, *0.002*)	-B2 (0.18, *0.013*)
A incompta (BM14)		1997	N/S	N/S
		1998	DB(0.29, *0.002*), WR(0.19, *0.028*)	-INS (0.15, *0.050*)
Barichneumon spp. & Cratichneumon spp. (BM16)	2	1997	N/S	N/S
		1998	DB(0.38, <*0.001*), BH(0.15, *0.004*), SL(0.09, *0.002*)	-B2 (0.18, *0.013*)
E. abdominalis (BM17)		1997	N/S	N/S
		1998	SL(0.31, <*0.001*), BH(0.18, <*0.001*), BB(0.12, *0.003*)	B1 (0.22, *0.005*)

Table 2.6 (cont).

Scientific Name (Morph I.D.)	Group	Year	Associated Flowering Weeds in 1997, 1998 (partial R^2, *p-value*)	Other Variables Associated in 1997, 1998 (partial R^2, *p-value*)
Braconidae:				
Microplitis sp. (BM11)	1	1997	SL (0.21, *0.055*)	N/S
		1998	SL(0.46, *0.005*), DB(0.12, *0.040*)	B1 (0.18, *0.033*)
Phanerotoma sp. (BM12)	1	1997	SL (0.21, 0.055)	N/S
		1998	SL(0.46, *0.005*), DB(0.12, *0.040*)	B1 (0.18, *0.033*)
Vespidae:				
Vespinae (BM5)	3	1997	AST (0.26, *0.031*)	N/S
		1998	SL(0.60, <*0.001*), WR(0.12, *0.012*), BB(0.10, *0.033*)	N/S
Diapriidae (BM2)		1997	N/S	-ACRE (0.29, *0.022*)
		1998	SL(0.27, <*0.001*), DB(0.14, *0.010*), BH(0.09, *0.029*)	D_w (0.21, *0.003*), -B2 (0.18, <*0.001*)
Chrysididae (BM3)	3	1997	AST (0.26, *0.031*)	N/S
		1998	SL(0.60, <*0.001*), WR(0.12, *0.012*), BB(0.10, *0.033*)	N/S
Pompilidae (BM6)		1997	N/S	N/S
		1998	N/S	-PEST (0.40, *0.011*)

* Morphospecies having the same group number were positively correlated in abundance between sites during both years of the study.

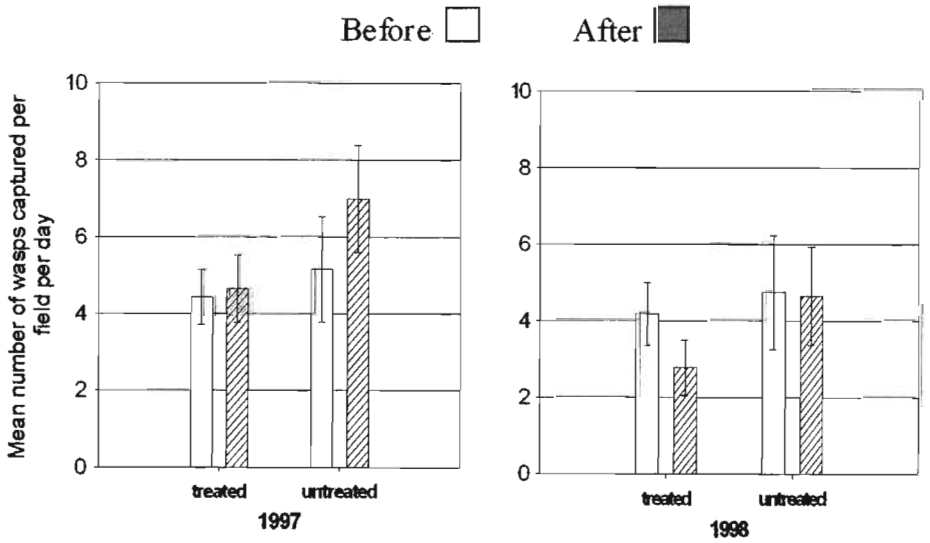
Figure 2.6. Phenology of wasp morphospecies and the primary flowering weeds associated with them. Solid bars indicate relatively high abundance, and broken bars indicate relatively low abundance, for the corresponding plant or wasp morphospecies.



Insecticides and Wasp Populations

Imidan (1.5 pints/acre), and Sniper (1 pint/acre) were the only insecticides used to treat fields in this study (Appendix A). Suspicious that the impact of these organophosphate insecticides on overall wasp capture was being masked by other variables (i.e. block) in previous analyses, a repeated-measures analysis enabled me to compare changes in wasp capture, before and after insecticide applications in treated and untreated fields. There was a significant time (before and after) by insecticide treatment interaction in 1998 ($F_{1,88} = 6.50$, $p = 0.017$). Results from 1997 were not significant ($F_{1,106} = 3.14$, $p = 0.086$), but are consistent with 1998 and would be significant using a higher rejection value of $p \leq 0.10$. In 1997, untreated fields showed large increases in trap yields, ranging from 18 – 53%, after the treatment period, compared to fields treated with insecticides which showed minimal increases in trap yields (Figure 2.7). A very

Figure 2.7. The mean number of wasps captured daily before and after the insecticide application period in treated (n = 12 in 1997; n = 9 in 1998) and untreated fields (n = 6 in 1997; n = 6 in 1998). Bars represent the standard error of the mean (S.E.).

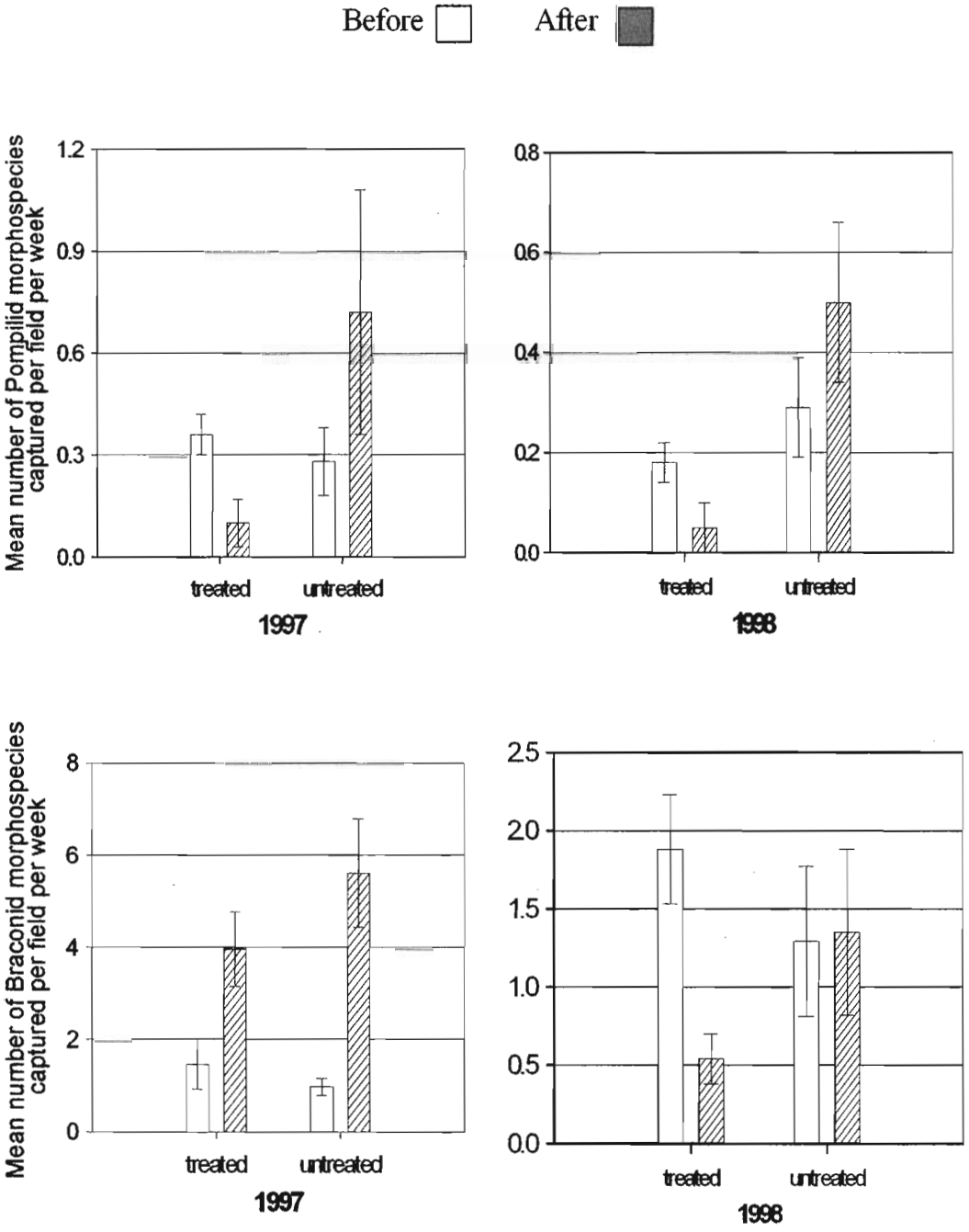


different result was seen in 1998, the number of wasps decreased in both treated and untreated fields, but the decrease was substantially greater in insecticide treated fields. Fields treated with insecticide exhibited decreases in trap yield ranging from –31% to –42%, but untreated fields showed minimal change (Figure 2.7).

Based on the morphospecies used in this study, response to insecticide applications varied among four wasp families (Diapriidae, Braconidae, Ichneumonidae and Pompilidae). Pompilidae appear to suffer (based upon trap capture) the greatest negative impact from insecticides applied to blueberry fields. A highly significant time by treatment effect was seen with pompilids in 1997 ($F_{1,34} = 10.56$, $p = 0.005$) and 1998 ($F_{1,28} = 11.43$, $p = 0.005$). The number of pompilid wasps trapped in treated fields consistently decreased after the application of insecticides while the number of Pompilids trapped in untreated fields increased more than 100% for both years after the application (Figure 2.8).

Braconid wasps also appear to decrease after insecticide applications. In 1997, a significant time by treatment effect was not detected at a 0.05 rejection level ($F_{1,34} = 3.39$, $p = 0.084$), but the difference between the number of Braconid wasps captured in untreated versus treated fields was substantial. After the application period, the number of Braconid wasps captured in untreated fields increased approximately 3 times that of treated fields (Figure 2.8). In 1998, a time by treatment effect was detected ($F_{1,28} = 9.82$, $p = 0.008$), and fields treated with insecticides showed about a 71% decrease in the number of Braconid wasps recovered from traps following application while untreated fields exhibited a 14% increase (Figure 2.8).

Figure 2.8. The mean number of pompilid and braconid morphospecies captured daily before and after the insecticide application period in treated (n = 12 in 1997; n = 9 in 1998) and untreated fields (n = 6 in 1997; n = 6 in 1998). Bars represent the standard error of the mean (S.E.).



No time by treatment effect was detected for Diapriids in 1997 ($F_{1,34} = 2.64$, $p = 0.124$) or 1998 ($F_{1,28} = 1.59$, $p = 0.229$). However, evidence from 1997 suggests insecticides may have had a negative impact on Diapriid populations that year (Figure 2.9). No time by treatment effect was detected with Ichneumonids in 1997 ($F_{1,34} = 1.04$, $p = 0.323$) or 1998 ($F_{1,28} = 2.57$, $p = 0.133$) (Figure 2.9).

Spatial Distribution of All Wasps within Blueberry Sites

Malaise traps were set in 3 different positions (forests, edge, and field center) in an effort to determine how wasps are distributed across the 2 habitats within blueberry agroecosystems: fields and surrounding forests. Wasps as a group were primarily captured in the forest and along the edge, with relatively few being trapped in the interior of blueberry fields (Figure 2.10). A significant difference in the number of wasps captured at the 3 different trap positions was detected in both 1997 (position term, $\chi^2 = 1168$, d.f. = 2, $p < 0.001$) and 1998 (position term, $\chi^2 = 2000$, d.f. = 2, $p < 0.001$). Consistently, the largest number of wasps was captured in the forest during both years. These patterns are noticeably consistent during and after blueberry bloom both years (Figure 2.10). However, there is a noticeable decrease in the percentage of wasps captured along the edge from 1997 to 1998, coinciding with an increase in the number of wasps trapped in the forest during 1998 (Table 2.7). In fact, a significant difference was detected between 1997 and 1998 in the distribution of wasps within blueberry sites (year x position interaction term, $\chi^2 = 103.13$, d.f. = 2, $p < 0.001$).

Figure 2.9. The mean number of Diapriid and Ichneumonid morphospecies captured daily before and after the insecticide application period in treated (n = 12 in 1997; n = 9 in 1998) and untreated fields (n = 6 in 1997; n = 6 in 1998). Bars represent the standard error of the mean (S.E.).

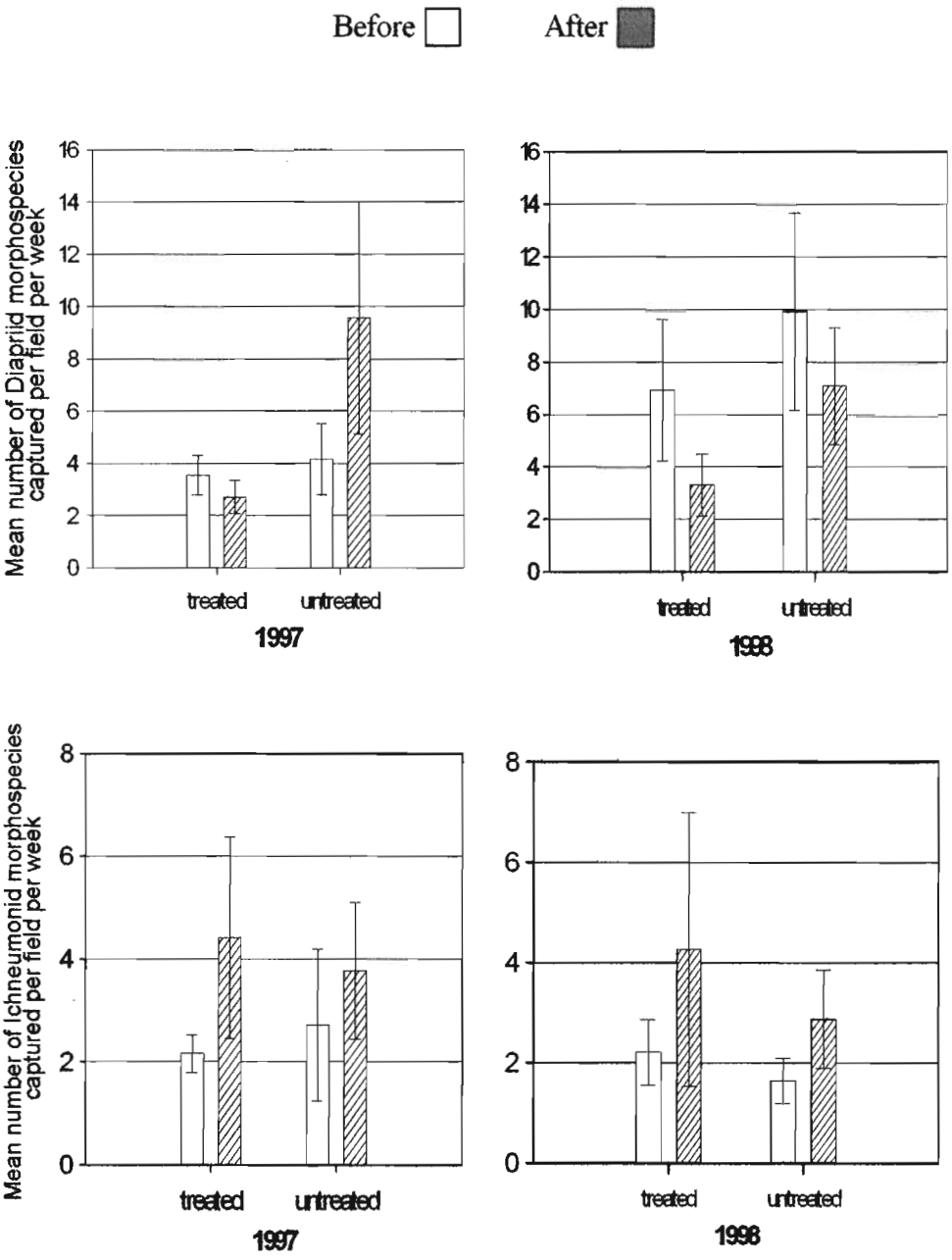
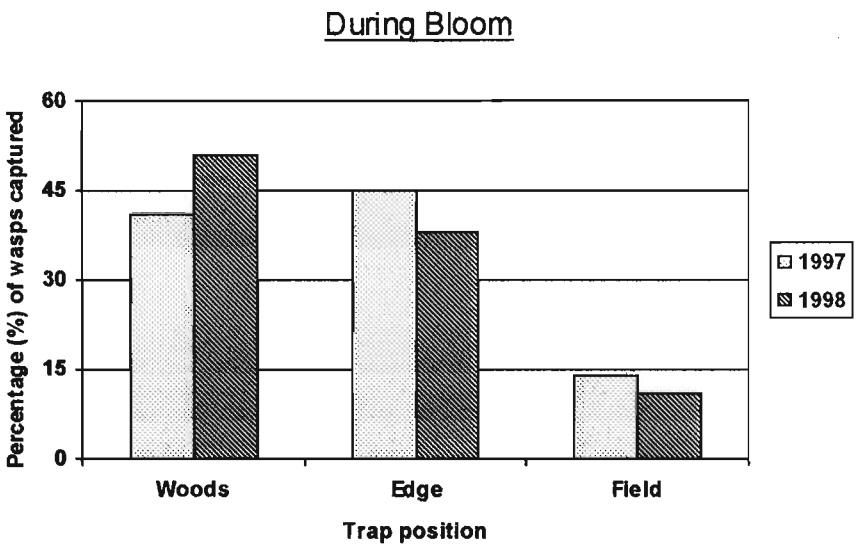


Figure 2.10. The percentage of wasps captured, at each trap position, during and after blueberry bloom.



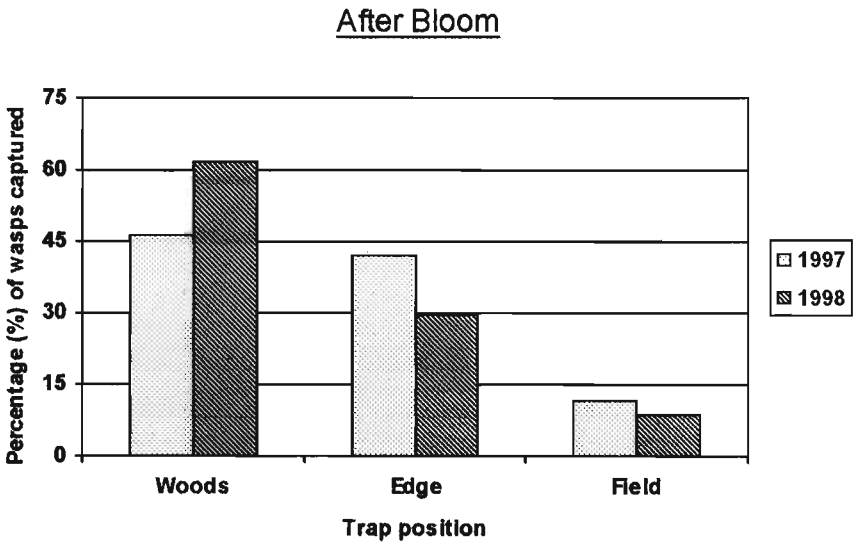


Table 2.7. Mean number of wasps ±SE captured at 3 different field locations across 15 blueberry fields in Washington County, ME.

Trap Position	Mean Number* of Wasps Captured 1997	Mean Number* of Wasps Captured 1998
Forest	122.4±19.1a	197.3±42.0a
Edge	117.3±22.0a	106.3±20.1b
Center	33.4±3.2b	31.3±3.0c

* Mean values having identical letters within a column did not exhibit significant differences in the number of wasps captured at those trap positions (pairwise linear contrasts, $\alpha = 0.05$, PROC GENMOD, SAS for Wndows 8.1).

Spatial Distribution of Wasp Morphospecies within Blueberry Sites

To investigate wasp distribution beyond suborder, the same 13 morphspecies previously examined were pooled together as communities based on their spatial distribution across the 3 trap positions within blueberry. Six communities (C1 – C6) were identified from these taxa (Table 2.8). Community distribution varied dramatically from wasps captured almost exclusively in the surrounding forests to those captured primarily in the field center.

C1 includes 2 morphospecies (Diapriidae & *A. incompta*) that varied significantly and substantially in abundance between the forest and the field during both 1997 and 1998 (Table 2.8). Wasps in this community were very abundant in the bordering forest, and extremely rare within the field (Figure 2.11). Not one individual from *A. incompta* was captured in the field interior during either year.

C2 was made up of a single morphospecies (*Cratichneumon* spp. and *Barichneumon* spp.) which did not associate with any of the other 5 communities

Table 2.8. Wasp communities derived from the spatial distribution of morphospecies across the 3 trap field locations (forest, edge, interior).

Community Identity	Composition (Morphospecies I.D.)	Year	Individuals Captured	Community Distribution (%)*			d. f.	χ^2	P-value
				Forest	Edge	Interior			
C1	Diapriidae (BM2) Ichneumonidae: *A. incompta* (BM14)	1997 1998	697 1450	73a 80a	26b 19b	1c 1c	2 2	0.36 1.12	0.834 0.571
C2	**Ichneumonidae:** *Barichneumon* spp. & *Cratichneumon* spp. (BM16)	1997 1998	134 87	52a 67a	43a 27b	5b 6c	n/a	n/a	n/a
C3	**Vespinae** (BM5) **Pompilidae** (BM6) **Ichneumonidae:** *Netelia* spp. (BM8) **Braconidae:** *Microplitis* sp. (BM11)	1997 1998	227 334	48a 45a	38a 42a	14b 13b	6 6	7.28 7.80	0.296 0.253
C4	**Ichneumonidae:** *Dusona* spp. (BM9) *B. flavescens* (BM13) **Braconidae:** *Phanerotoma* sp. (BM12)	1997 1998	256 55	31a 24a	61b 72b	8c 4c	4 4	5.84 0.72	0.212 0.949
C5	**Chrysididae** (BM3) **Ichneumonidae:** *E. abdominalis* (BM17)	1997 1998	34 46	27a 43a	27a 32a	46a 25a	2 2	2.65 0.27	0.265 0.875
C6	**Ichneumonidae:** *Ophion* sp. (BM7)	1997 1998	49 62	18a 5a	33b 29b	49b 66c	n/a	n/a	n/a

*Communities having identical superscripts for different habitats did not exhibit significant differences in abundance between those areas of blueberry sites.

consistently during both years of the study. The distribution of C2 (Figure 2.12) was intermediate between C1 and C3 (Figure 2.11, 2.13). C2 did associate with C3 in 1997 (morphospecies x position interaction term, $\chi^2 = 10.87$, d.f. = 8, $p = 0.209$), but not in 1998 (morphospecies x position interaction term, $\chi^2 = 24.74$, d.f. = 8, $p = 0.002$). From 1997 to 1998, there is a noticeable increase in the proportion of C2 being caught in the forest coinciding with fewer being captured at the edge, becoming more like C1, but still statistically different from C1 (Figure 2.12). The shift was substantial enough to regard this morphospecies as being distinct from C3.

Community 3 included 4 morphospecies (Vespinae, Pompilidae, *Netelia* spp. & *Microplitis* sp.) that were comparable in abundance between the forest border and the field edge, but substantially declined in numbers near the center of fields (Figure 2.13).

Figure 2.11. The proportion of Diapriidae and *A. incompta* (C1) captured at each trap position. Bars with different letters are significantly different (χ^2, $\alpha = 0.05$).

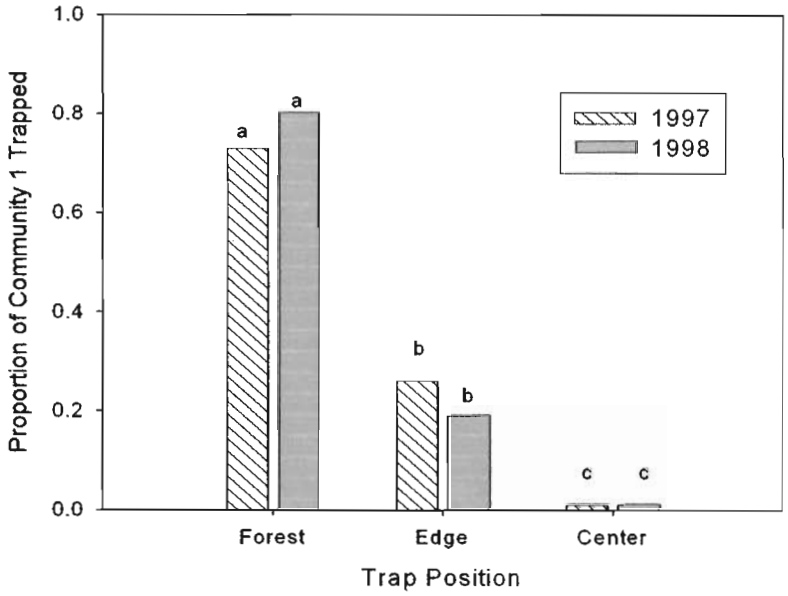


Figure 2.12. The proportion of *Cratichneumon* spp. and *Barichneumon* spp. (C2) captured at each trap position. Bars with different letters are significantly different (χ^2, $\alpha = 0.05$).

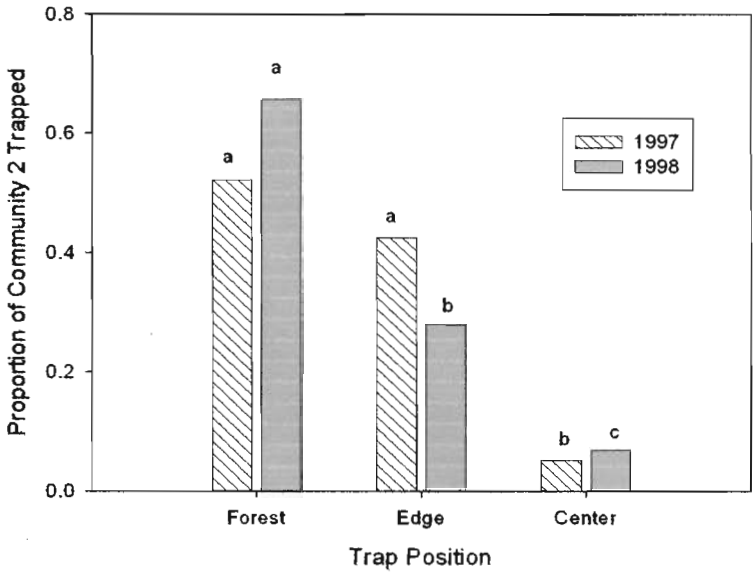
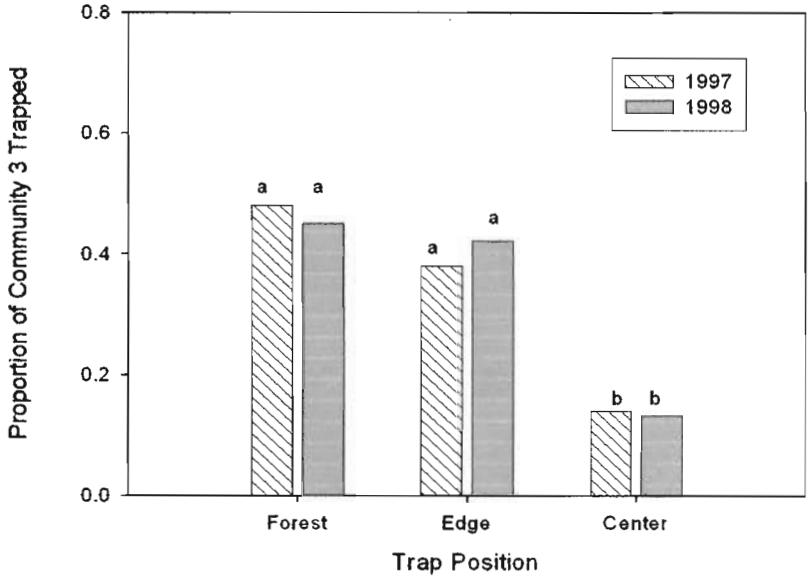


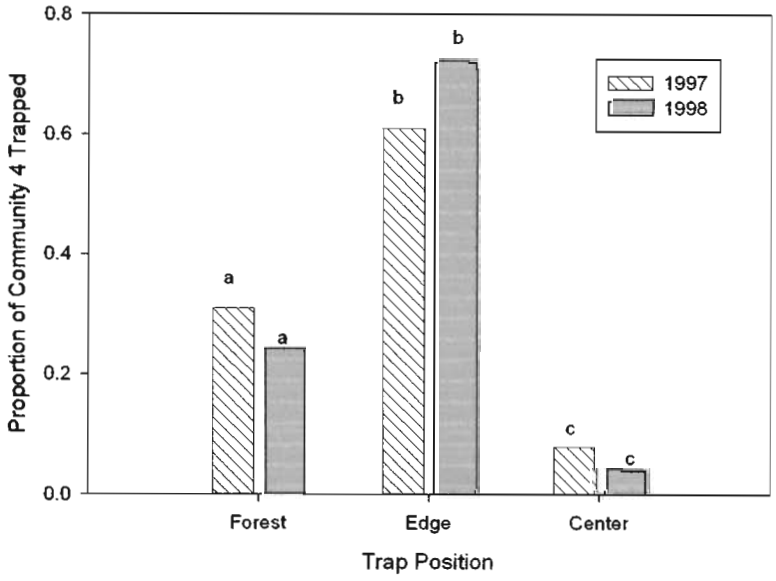
Figure 2.13. The proportion of Vespinae, Pompilidae, *Netelia spp.*, and *Microplitis sp.* (C3) captured at each trap position. Bars with different letters are significantly different (χ^2, $\alpha = 0.05$).



Community 4 includes 3 morphospecies (*Dusona* spp., *B. flavescens*, & *Phanerotoma* sp.) that were most abundant along the edge and relatively rare in the interior of blueberry fields. An intermediate number of these wasps were also captured in the forest (Figure 2.14). Significant differences in the abundance of this community were detected between all 3 habitats (Table 2.8).

Community 5 includes 2 morphospecies (Chrysididae & *E. abdominalis*) that seem to be evenly distributed within blueberry (Figure 2.15). In fact, no significant difference in trap capture was detected across any of the 3 trap positions for 1997 or 1998 (Table 2.8).

Figure 2.14. The proportion of *B. flavescens*, *Dusona* spp., and *Phanerotoma* sp. (C4) captured at each trap position. Bars with different letters are significantly different (χ^2, $\alpha = 0.05$).



Community 6 was made up of a single morphospecies (*Ophion* sp.) that did not associate, statistically or graphically, with any of the other 5 communities consistently during both years of the study. C6 was unique because most individuals were captured in the center of fields during both seasons, and few were captured in the forest (Figure 2.16). Community 6 did associate with C5 in 1997 (morphospecies x position interaction term, $\chi^2 = 0.22$, d.f. = 4, $p = 0.377$), but not in 1998 (morphospecies x position interaction term, $\chi^2 = 18.35$, d.f. = 4, $p = 0.001$). From1997 to 1998, there is a noticeable increase in the proportion of this population being caught at the field center coinciding with a decrease in the forest (Figure 2.16).

No two morphospecies which were similarly distributed within blueberry sites were also similarly distributed between sites (Tables 2.5 & 2.8).

Figure 2.15. The proportion of Chrysididae, and *E. abdominalis* (C5) captured at each trap position. Bars with different letters are significantly different (χ^2, $\alpha = 0.05$).

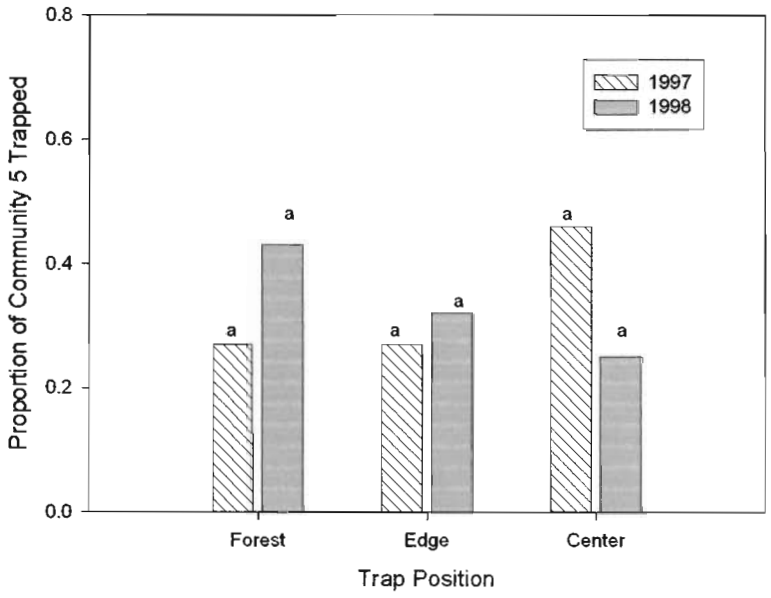
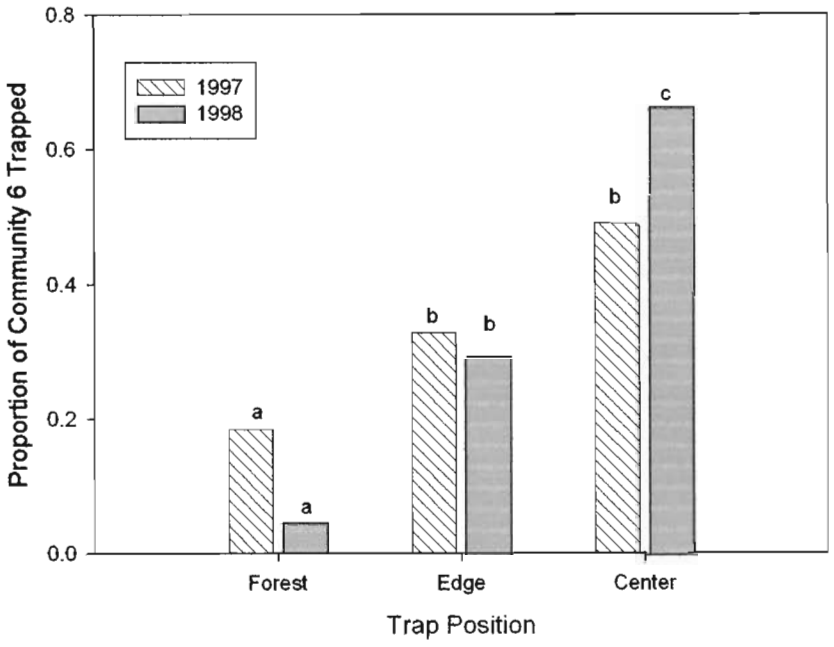


Figure 2.16. The proportion of *Ophion* sp. (C6) captured at each trap position. Bars with different letters are significantly different (χ^2, $\alpha = 0.05$).



Discussion

Wasps trapped during 1997 and 1998, varied between sites as much as 6 fold across fields (Table 2.3). Since flowering plants have been documented as a vital resource for adult wasps (van Emden 1990, Hunt et al. 1991, Altieri 1994, Idris & Grafius 1995, Shukla et al. 1997), the abundance of floral resources in blueberry fields was targeted as a primary factor affecting wasp populations. However, blueberry, by far the most abundant floral resource, was not associated with wasp densities during either season (Table 2.3). Sheep laurel was the only plant to which wasps, as a group, appeared to consistently respond. The abundance of sheep laurel was an important variable in developing models to explain differences in overall wasp abundance, and that of many wasp morphospecies, between sites. The impact of this plant was probably

underestimated in 1997 because no vegetation sampling was conducted in the surrounding forests that year. This flowering weed has a nectar resource comparable to lowbush blueberry (Loose 2000), and enters bloom soon after blueberry blossoms have disappeared (Figure 2.6). In fact, when line transect sampling was performed in 1998, blueberry fields averaged far more sheep laurel blossoms (1082 blossoms / ha.) than any other flowering weeds (3 – 16 blossoms / ha.), making it a more abundant food source during the summer. However, sheep laurel is not the only resource available to wasps in and around blueberry fields (Appendix B). In fact, the 1998 model of overall wasp abundance includes weed diversity as a significant independent variable. Since plant diversity was not associated with sheep laurel, other flowering weeds, in addition to sheep laurel, may be important resources for wasps (Table 2.2). Plant diversity may also reflect the other plant species that were associated with specific groups or individual taxa (Table 2.6).

To identify other flowering weeds associated with wasps, it was necessary to look at wasp morphospecies. Based on ease of identification and relative abundance, 13 morphospecies were chosen for these analyses (Table 2.6). These morphospecies represented 27.5% and 41.5% of all wasps captured in 1997 and 1998, respectively. Results of stepwise analyses revealed five flowering weeds (aster, bunchberry, bush honeysuckle, dogbane, and witherod), in addition to sheep laurel, which were positively associated with 11 of the 13 morphospecies (Table 2.6). However, aster was only associated with morphospecies in 1997 and the other 4 plants (bunchberry, bush honeysuckle, dogbane, and witherod) were only associated with morphospecies in 1998. This inconsistency may be the result of not sampling vegetation in the forest adjacent to

the fields in 1997. Since insufficient samples of bunchberry, bush honeysuckle, dogbane, or witherod were detected in 1997, these plants could not be included in wasp models for that year. In fact, bush honeysuckle and witherod were found almost exclusively along the edge and in the forest in 1998. Therefore, the existence of these species bordering fields in 1997 would have been unaccounted for using only the quadrat method (Figure 2.2). The 2 morphospecies showing no positive response to flowering weeds in blueberry were Pompilidae and *Ophion* sp. Pompilid wasps are commonly referred to as "spider wasps" because larvae primarily feed on spiders which adults have captured, paralyzed, and stored in cells (Borror et al. 1989). The availability of floral resources in Maine lowbush blueberry may not influence Pompilid abundance, but adults are known to utilize nectar and pollinate flowers (Vieira & Shepherd 1999). Possibly, no association was detected because pompilids are responding primarily to spider populations. Curiously, *Ophion* sp. was the only morphospecies to show a negative response to floral densities. *Ophion* sp. seem to be associated with the field interior and may be primarily limited by the abundance of blueberry pests and not floral resources (Table 2.6). However, based on the analyses of these 13 morphospecies, it appears the abundance of most wasp species is positively influenced by various flowering weeds, and by sheep laurel in particular (Table 2.6). Multiple morphospecies (i.e. groups) even seem to respond to the same floral resources and could be considered members of foraging guilds (Root 1967, Morrison et al. 1992).

Spatial "communities" of wasps also appear to exist in blueberry. Multiple wasp morphospecies showed no differences in distribution within blueberry sites (Table 2.8). These wasp communities are likely subsets of larger terrestrial communities in which

wasps are secondary consumers (Evans 1984). Therefore, it might be reasoned that in order to coexist within the same spatial community, wasp species need to exhibit some foraging differences (e.g. food, prey or host selection) or severe interspecific competition would occur (Evans 1984). Evidence of this principle might be provided by the wasp communities in this study, since no two morphospecies within the same spatial community (Table 2.8) also belonged to the same floral foraging guild (Table 2.6).

Community 1 was composed of all wasps belonging to the family Diapriidae, and those of the species *Aptesis incompta* (Hymenoptera: Ichneumonidae). They appear to avoid the field interior and confine themselves primarily to the forest; with lower numbers at the edge possibly because half the trap is exposed to the field (Table 2.8). Information about the biology of these morphospecies, strongly support these findings. Most North American species of Diapriidae belong to two subfamilies: Belytinae and Diapriinae, of which all individuals captured in this study appear to belong (Borror et al. 1989). Belytinae are commonly found in moist wooded areas since they are well-known for parasitizing flies which breed in fungi (e.g. Mycetophilidae). Likewise, Diapriinae are also known to inhabit moist wooded habitat; occupying a similar niche as Belytinae (Borror et al. 1989).

Studies of *Aptesis* sp. reveal they are very effective biocontrol agents, acting as parasites of apple sawfly (*Hoplocampa testudinae*) in Switzerland, pine sawfly (*Deprion pini*) in Russia, gooseberry sawfly (*Pristiphora pallipes*) in the United Kingdom, and winter moth (*Operophtera brumata*) in Germany (Sechser 1970, Sharov 1983, Rahoo & Luff 1988, Babendreier 2000). Similar forest pests such as cankerworm (Lepidoptera: Geometridae), hemlock looper (Lepidoptera: Geometridae), and birch leafminer

(Hymenoptera: Tenthredinidae) are common in the northeast United States, and may be hosts to the *Aptesis incompta* found in forests around blueberry (Borror et al. 1989). This could explain why *A. incompta* restricts its activity to the wooded areas. In addition, adult females showed diminished longevity and fecundity when deprived of food (e.g. nectar), so nutritional requirements could encourage wasps to remain in wooded areas where blossoms are more abundant (Babendreier 2000). *A. incompta* showed a positive response to witherod, which occurs exclusively in the forest, and dogbane, which was most abundant along the field edges (Figure 2.3, 2.4).

Community 2 was a single morphospecies containing 3 species of *Cratichneumon* and 2 species of *Barichneumon* with a spatial distribution similar to that of Community 1. However, enough individuals from this morphospecies were captured in the fields so that the distribution was significantly different. *Cratichneumon* and *Barichneumon* are members of the subfamily Ichneumoninae, which are considered specialized parasites of Lepidoptera. They are strong fliers and can roam long distances in their flight, but their activity is strongly dictated by weather. They avoid direct sunlight, preferring shade and areas with high humidity (Heinrich 1977). This would explain why most are captured in the forest and along the edge where shade is abundant. They may avoid blueberry fields in the summer during clear sunny days where conditions can get very hot and dry. However, during periods of overcast and rain, they may venture out into the fields looking for hosts. They are also known to visit flowers, which tend to grow in shaded areas (Heinrich 1977), and in this study were associated with 3 flowering weeds common along the edge and in the forest of blueberry fields (Table 2.6). These wasps are considered extremely beneficial in forest ecosystems, and *Cratichneumon sublatus* have

even been recognized for their ability to control populations of saddled prominent (*Heterocampa guttivitta*), a forest pest in hardwood stands throughout Maine (Allen 1972).

Community 3 was comprised of all wasps belonging to the family Pompilidae, the subfamily Vespinae (Hymenoptera: Vespidae), the genus *Microplitis* (Hymenoptera: Braconidae), and 3 species of the genus *Netelia* (Hymenoptera: Ichneumonidae) (Table 2.8). This community was most abundant along the field edge and in the forest with a smaller fraction (~14%) being captured near the center of fields. The distribution of this community was remarkably consistent for both years of this study. The spatial distribution also appears consistent with published information about the biology of these morphospecies. Vespine wasps are generalists, which tend to utilize both plants (i.e. nectar and pollen) and insects (e.g. lepidoptera larvae) for nutritional resources (Matsuura & Yamane 1990, Hunt et al. 1991, Maingay et al. 1991, Reid et al. 1995). They may even be utilizing nectar from blueberry in addition to whatever insect larvae are available during the spring. This could explain why a substantial number were trapped prior to bloom of the flowering weeds that were associated with them (Figure 2.6). They are known to be strong-flying insect predators that likely use a relatively large territory for hunting (Matsuura & Yamane 1990). This may allow them to reach all areas of the blueberry landscape, but frequent areas around the forest and field edge where preferred floral resources are more abundant (Table 2.6). Vespinae are known to forage on mushrooms, tree sap, and even pollen, but probably have a difficult time getting nectar from plants because of the size of their head and mouthparts (Matsuura & Yamane 1990, Hunt et al. 1991). In addition, wasps from this morphospecies typically construct their

nests in the forest since wood pulp, from dead trees, is often mixed with saliva to form the nest (Evans & Eberhard 1970).

The spatial distribution of Pompilidae (spider wasps), and to a lesser extent community 3, is probably linked to spider populations (e.g. Lycosidae) (Kurczewski 1981), since these wasps showed no response to floral resources in this study (Table 2.6). Similar to spider wasps, Maloney (2002) found fewer wolf spiders (Lycosidae), the most common spider family in Maine blueberry, were captured in traps placed toward the center of blueberry fields. Approximately 40 – 60% more wolf spiders were captured at the field edge compared to the number captured 30m into blueberry fields in her study. No trapping of spiders was conducted in the forest. In addition, other studies show that spider wasps often build nests in hollow woody stems, high vegetation, sandy soil, or under loose bark which are features found primarily along the field edge and in wooded areas surrounding Maine blueberry fields (Kurczewski 1981, Veenendaal 1984, Evans & Shimizu 1996). These nests are composed of a single cell, and are used by the female to deposit a paralyzed host upon which she will lay a single egg. She will continue this, often creating a series of nest cells, never to return to the previous one (Evans & Shimizu 1996).

Microplitis sp. may be utilizing floral resources (i.e. nectar) and a large number of noctuid and geometrid species as hosts for their eggs (Arthur & Mason 1986, Stapel et al 1997). So, these wasps may be more abundant along the field edge and in the forest since that is where the floral resources that they respond to are most abundant (Table 2.6). However, species of *Microplitis* are also a documented natural enemy of numerous crop pests, such as bertha armyworm (*Mamestra configurata*) (Arthur & Mason 1986, Eller et

al. 1990, Stapel et al 1997, De Moraes & Lewis 1999). It stands to reason that it could be a natural enemy of some blueberry pests, such as black armyworm (Lepidoptera: Noctuidae) and blueberry spanworm (Lepidoptera: Geometridae), and probably journeys into the blueberry fields in pursuit of these hosts.

The last morphospecies of this community (3 species of *Netelia*) is a collection of nocturnal ectoparasites that are natural enemies of some Lepidopteran pests (Shaw 2001). Adult females are known to feed on the hemolymph of host larvae and occassionally from non-host larvae (Zhumanov 1987, Shaw 2001). Previous literature indicates that *Netelia* sp. frequently parasitize larvae of the genus *Heliothis* and is known to be a natural enemy of tobacco budworm (*H. virescens*) (Arnett 1993, Broadley 1984, Tingle et al. 1994). Although, *H. virescens* is found in Maine and feeds on various Solanaceae (Arnett 1993), it is not known as a crop pest in this region. However, *Netelia* may be a natural enemy of a serious Maine pest known as corn earworm (*H. zea*) since these larvae are very similar to tobacco budworm (Neunzig 1964). Similar to *Microplitis, Netelia* sp. also utilizes carbohydrate resources (Zhumanov 1987, Shaw 2001). In fact, laboratory studies showed that adult females feeding on both hemolymph and carbohydrates (e.g. honey) lived almost twice as long as females feeding strictly on hemolymph (Zhumanov 1987). However, *Netelia* sp. was not associated with any of the same plants as *Microplitis* in this study (Table 2.6). Bush honeysuckle and witherod appear to be important resources for *Netelia* sp., and these wasps are probably more common in the forest and edge because this is where these flowers are primarily found in blueberry (Figure 2.2, 2.3). Another reason *Netelia* sp., as well as *Microplitis*, are common in and near the forest is adult females are suspected of responding to green leaf volatiles emitted

by plants damaged by caterpillars (Whitman and Eller 1990). A small fraction of *Netelia* specimens were captured in the fields. These insects may be coming out at night to attack blueberry pests and/or they may be attracted to moonlight reflected by malaise traps. Blueberry spanworm may be a host species since another member of the same subfamily, *Erromenus* sp., has been identified from spanworm collected in various blueberry fields around Washington County during 1997 (Luhman 1998).

Community 4 consisted of 3 morphospecies that were very abundant along the edge of blueberry fields while being somewhat less abundant in the forest and rare in the field center (Table 2.8). The most abundant of these morphospecies was *Phanerotoma* sp. (Hymenoptera: Braconidae). Members of this genus are generalist egg-larval parasites well known for attacking a wide variety of lepidopteran crop pests such as: pink bollworm (*Pectinophora gossypiella*), potato tuberworm (*Phthorimaea operculella*), beet armyworm (*Spodoptera exigua*), and tobacco budworm (Chiri & Legner 1986, Jones 1996). These wasps are also known to use some of their time foraging on plants (Sisterson & Averill 2002). Populations of *Phaneratoma* sp. were strongly associated with sheep laurel and dogbane in this study (Table 2.6). Dogbane was typically more abundant along the edge of fields than in anywhere else in blueberry, and may offer one explanation as to why these insects are most abundant along the edge (Figure 2.4). It seems odd that a parasite of crop pests would be scarce within fields (Table 2.6). However, if they are not strong fliers, and need to stay in close vicinity of their food sources, they may roam along the edge of fields in search of hosts nearby. A few were captured in the interior of fields, but there could have been patches of sheep laurel or dogbane in those fields.

The other morphospecies (*Dusona* spp. and *B. flavescens*) in this community are both Ichneumonids (Table 2.8). Both are parasitic of Lepidoptera, usually of early larval instars. The 3 *Dusona* species are considered generalists, and have been recorded most often from Geometridae in addition to Lasiocampidae, Tortricidae, Noctuidae, and other macro-Lepidoptera. In fact, *Dusona* sp. has been identified from blueberry spanworm collected from blueberry fields in Jonesboro, ME. (Luhman unpublished data1998). Being generalists in blueberry may explain why few *Dusona spp* are captured toward the center of fields. An abundance of insect hosts are likely to be found along the field edge and in the forest. *B. flavescens*, on the other hand, is considered more of a specialist known for attacking Bertha armyworm (*Mamestra configurata*) in Canada (Arthur & Mason 1986). However, it has also been recorded from larvae of spotted cutworm moth (*Xestia adela*), a known pest in the northeast United States, which feeds on a wide variety of plants (Wylie & Ayre 1979, Arnett 1993). Since armyworm is a pest in blueberry, *B. flavescens* has probably developed a role in its control. However, armyworm is not a primary pest of blueberry, occurring infrequently (Drummond and Groden 2000), and low field abundance of these wasps may be due to a lack of alternate hosts. In this study, these 2 morphospecies exhibited very strong responses to a number of flowering weeds in blueberry. Since these plants have minimal temporal overlap, *Dusona* spp. and *B. flavescens* may be adjusting to changes in resource availability throughout the season. However, *Dusona* spp. associated more with sheep laurel while *B. flavescens* associated more with dogbane, which may suggest some level of resource partitioning (Table 2.6).

Community 5 consisted of two morphospecies that displayed a relatively even distribution throughout blueberry (Table 2.8). One member of this community,

Chrysididae, is a parasitic wasp with a wide range of hosts: walking sticks, sawflies, moths, and even dead insects (Kimsey & Bohart 1990). However, they are probably most well known for parasitizing the nests of bees and wasps (earning them the name of cuckoo wasps), which alleviates them from having to build nests of their own. They have a very thick integument, which enables them to repel the stings of adult bees and wasps while depositing their eggs into the cells of their hosts' nests (Evans & Eberhard 1970). Chrysidid wasps are also known to visit flowers (Gess 1996), and were associated with sheep laurel, witherod, and bunchberry in this study (Table 2.6). They may utilize blueberry plants as a nectar source and then switch to flowering weeds when blueberry is out of bloom. As with Vespinae, the utilization of blueberry might explain why a substantial number of them were captured prior to bloom of the flowering weeds associated with them (Figure 2.6). Utilizing a number of plant species and having a wide range of host insects may explain there uniform distribution throughout blueberry.

Exetastes abdominalis (Hymenoptera: Ichnuemonidae) was the other morphospecies included in community 4 (Table 2.8). *Exetastes* species are solitary endoparasitoids known for their ability to parasitize cabbage moth, *Mamestra brassicae* (Lepidoptera: Noctuidae) in Eastern Europe and Russia, and *Heliothis* spp. in Texas (Eger et al. 1982, Slovak 1986, Napiorkowska-Kowalik 1997, Buleza 2002). A special feature of experienced adult females, which allows them to minimize search time, is their ability to find larvae by using host-specific volatiles (Buleza 2002). Evidence also suggests that floral resources play an important role in the fecundity and longevity of adults (Slovak 1986). In fact, Yastrebov 1992 found that the distance from nectar plants and rate of parasitism were inversely related. He suggests that surrounding fields with

nectar producing plants actually increases parasitism by *Exetastes atrator* and reduces the need for chemical treatments (Yastrebov 1993). In our study, *E. abdominalis* was significantly associated with 3 flowering weeds: sheep laurel, bush honeysuckle, and bunchberry (Table 2.6). Again, these flowers primarily occur in and near the forest, which may explain why *E. abdominalis* occurs there. In addition, if *E. abdominalis* is as effective at parasitizing noctuid moths in blueberry as is *E. artator* at parasitizing cabbage moth, then this might explain why *E. abdominalis* is so common toward the center of blueberry fields as well (Table 2.6).

Community 6 consisted of a single morphospecies containing all specimens of *Ophion* sp. trapped in this study. *Ophion* sp. was unique in its distribution, which was primarily within blueberry fields (Table 2.6). These wasps are solitary nocturnal hunters, which tend to parasitize larger lepidopteran larvae in later instar stages (Varkonyi et. al. 2002). They are known to be specialists in utilizing moths of the genus *Xestia* (Lepidoptera: Noctuidae) in Europe and more specifically fall armyworm (*S. frugiperda*) in the southeastern United States (Mitchell et. al. 1983, Varkonyi et. al. 2002). It seems likely that here in Maine they are utilizing Bertha armyworm and possibly other large lepidopteran larvae of blueberry pests such as blueberry spanworm. This morphospecies may be extremely valuable as a natural enemy of blueberry pests in Maine, emerging during the evening to patrol fields in search of noctuid larvae to attack only to return to cover during the day. I was unable to find any information suggesting that they utilize plants, and it is therefore not surprising they were not positively associated with any plants in this study (Table 2.6). As adults, they may not utilize plants but simply feed on the hemolymph of host insects for nutritional needs.

The insecticides used during this study, Imidan (1.5 pints/acre), and Sniper (1 pint/acre), appear to have substantial negative impacts on overall wasp populations in blueberry (Figure 2.7). Further, pompilid and braconid wasps appear to be far more sensitive to the toxic effects of these two insecticides than diapriids and ichneumonids (Figure 2.8, 2.9). Noticeable decreases in pompilid populations in treated fields (while untreated fields showed substantial population increases) during both years may be the result of both direct and indirect toxic affects on these wasps. Spider populations may also be reduced which would impact pompilids in treated fields. Studies of braconid wasps and insecticides seem to be more common. A number of researchers have found braconids to be very sensitive to a variety of insecticides used in agriculture (Raposa et. al. 2003, Tillman 1995). Tillman (1995) examined a number of insecticides and found all except Thiodicarb were extremely toxic to a species of *Microplitis* (*Microplitis croceipes*). Imidan (1.5 pints/acre), and Sniper (1 pint/acre) may not have the lethal effects on diapriids it seems to have on braconids and pompilids, however, diapriids were mostly captured within the forest border and may be spared the lethal impact of these chemicals because they were applied primarily to the fields. It does seem odd that ichneumonid populations did not suffer from insecticides. Again, ichneumonids may not be as sensitive to these types of insecticides as braconids and pompilids. However, the importance of looking at wasps beyond the family level becomes evident here. Some ichneumonids (i.e. *A. incompta*) may be sheltered from insecticides because they primarily inhabit the forest border just like diapriids, while others may be suffering from insecticides because they are primarily found in the blueberry fields (i.e. *Ophion sp.*).

Considering past research that has identified the important role of natural enemies in agriculture (Pedigo 2002, Barbosa 1998, Altieri et. al. 1993, Wratten 1987), conserving and promoting populations of native wasps which utilize blueberry pests as protein sources should be an integral part of pest management. This study has gathered information necessary to further this idea by generating an initial inventory of known and suspected beneficial wasps in Maine lowbush blueberry. It has also provided evidence about their spatial distribution across different habitats and association with some of the native floral resources in blueberry. This information could be useful for managers considering previously proposed ideas of planting wildflowers and developing field margins with native flowering weeds in order to promote populations of wasps which are natural enemies to blueberry pests (Altieri and Whitcomb1979, Braman et al. 2002, Powell et al. 2003, Steffan-Dewenter 2003). Based on information from other studies (Arthur & Mason 1986, Chiri & Legner 1986, Jones 1996, Stapel et al. 1997, Luhman unpublished data 1998), five of the wasp morphospecies in this study, *Microplitis* sp., *Phanerotoma* sp., *Dusona* sp., *B. flavescens*, and *Ophion* sp. are likely to be integral in suppressing insect pest populations in blueberry. Further research is likely to produce more concrete evidence about each of these wasp species with regard to: which blueberry pests they impact the most, which native flowering weeds are essential resources, and what management strategies are most effective in promoting and maintaining populations of these wasp species. Also, considering the negative impact insecticides had on Braconid morphospecies (*Microplitis* sp., *Phanerotoma* sp.) in this study (Figure 2.8), growers should consider other chemicals that have been found less toxic to wasps such as thiocarb and acephate (Tillman 1995). Biological controls such as *Bacillus thuringiensis*

and *Beauveria bassiana* could also be effective in reducing particular insect pests without harming beneficial wasp populations (Drummond & Groden 2000).

Published research of two other morphospecies in this study, *E. abdominalis* and *Netelia* sp. indicate they are also effective natural enemies of crop pests in areas outside the northeast United States (Eger et al. 1982, Broadley 1984, Shaw 2001, Buleza 2002). This information may justify emphasizing their roles as "potential biocontrol agents" which need to be investigated further to establish whether blueberry managers would want to undertake specific efforts to conserve and promote populations of these insects.

This study also looked at other wasp species, such as, *Barichneumon* sp., *Cratichneumon* sp., and *A. incompta*, which are known to suppress forest insect pests (Allen 1972, Rahoo & Luff 1988, Babendreier 2000). An inventory of these wasps and information about their behavior in blueberry may be useful to managers who may want to suppress forest pests along the perimeter of blueberry fields. Additional studies like this one may also provide an inventory of wasp species that are not beneficial to blueberry growers. For example, vespid wasps in various parts of the world (e.g. Argentina and New Zealand) are considered pests because of their impact on invertebrate populations and even birds (Beggs et al. 1998, Beggs 2001, Sackman et al. 2001). It may be important to determine if they have the same negative impacts in blueberry. Finally, an additional list of wasp species that are relatively rare in blueberry could also be generated from continued research of this type. For example, only three individuals of the genus *Spilochalcis* (Hymenoptera: Chalcididae) were identified from all the insects captured during both years. Because Chalcid wasps are known to be extremely effective enemies of crop pests (Borer et al. 1989, Arnett 1993), it might be found that

management efforts to conserve and increase populations of rare species belonging to this family would be well rewarded.

Based on the wasps captured in this study, there appears to be numerous beneficial taxa in Maine lowbush blueberry. This research, in an effort to better understand the ecology of these wasps, has also generated a number of important results that should be considered, particularly by growers and scientists. Sheep laurel is strongly associated with wasp taxa in blueberry, but other flowering weeds (e.g. dogbane) may also be important. The majority of wasp taxa were found in forests and along the edge. However, one wasp morphospecies (*Ophion sp.*) was strongly associated with the field interior and may be an important natural enemy of blueberry pests. Since, some taxa appear to have similar spatial distribution it appears that wasp communities exist in blueberry. Also, some level of niche-partitioning may exist since wasps that were associated with the same flowering weeds were not found in the same community. Finally, it appears that some wasp taxa respond differently to insecticides. This information could be especially important when managing taxa associated with the field interior.

Conservation biological control is likely the most environmentally friendly and inexpensive pest control method available to blueberry managers. Ironically, the concept of conserving natural enemies has been possible since the start of blueberry cultivation, but is relatively new compared to using chemicals and classical biological control techniques. The degree of its success, however, depends on the amount of reliable and useful information generated from studies like this one that focus on the biology of native natural enemies.

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APPENDICES

Appendix A

PESTICIDE RECORDS

Table A.1. Pesticides applied to blueberry fields in this study during the spring and summer of 1997.

Field Number - Name (1997)	Application Date	Pesticide Type	Pesticide Brand	Rate/Acre	Method
1 - Varin's	None	None	None	None	None
2 - Pork Brook VI	5/5/97	Fungicide	Funginex	24 oz.	Air
	5/19/97	Insecticide	Biobit XL	2 pints	Air
	6/2/97	Fungicide	Benlate	1 lb.	Air
	7/12/97	Insecticide	Sniper	1 pint	Air
3 - Pork Brook I	5/5/97	Fungicide	Funginex	24 oz.	Air
	5/19/97	Insecticide	Biobit XL	2 pints	Air
	6/2/97	Fungicide	Benlate	1 lb.	Air
	7/12/97	Insecticide	Sniper	1 pint	Air
4 - Pork Brook III	5/5/97	Fungicide	Funginex	24 oz.	Air
	5/19/97	Insecticide	Biobit XL	2 pints	Air
	6/2/97	Fungicide	Benlate	1 lb.	Air
	7/12/97	Insecticide	Sniper	1 pint	Air
5 - Burnt Camp	5/5/97	Fungicide	Funginex	24 oz.	Air
	5/19/97	Insecticide	Biobit XL	2 pints	Air
	6/2/97	Fungicide	Benlate	1 lb.	Air
	7/12/97	Insecticide	Sniper	1 pint	Air
6 - Gravel Pit	5/5/97	Fungicide	Funginex	24 oz.	Ground
	5/19/97	Insecticide	Biobit XL	2 pints	Ground
	6/2/97	Fungicide	Benlate	1 lb.	Ground
	7/12/97	Insecticide	Sniper	1 pint	Ground
7 - McCoy North	5/5/97	Fungicide	Funginex	24 oz.	Air
	5/19/97	Insecticide	Biobit XL	2 pints	Air
	6/2/97	Fungicide	Benlate	1 lb.	Air
	7/12/97	Insecticide	Sniper	1 pint	Air

Table A.1. (cont.)

Field Number - Name (1997)	Application Date	Pesticide Type	Pesticide Brand	Rate/Acre	Method
8 - SLD	5/7/97	Fungicide	Funginex	24 oz.	Ground
	5/21/97	Fungicide	Funginex	24 oz.	Ground
	6/5/97	Fungicide	Benlate	1 lb.	Ground
	7/16/97	Insecticide	Imidan	1.5 pints	Ground
9 - SL9	5/7/97	Fungicide	Funginex	24 oz.	Ground
	5/21/97	Fungicide	Funginex	24 oz.	Ground
	6/5/97	Fungicide	Benlate	1 lb.	Ground
	7/16/97	Insecticide	Imidan	1.5 pints	Ground
10 - NLOG	5/7/97	Fungicide	Funginex	24 oz.	Ground
	5/21/97	Fungicide	Funginex	24 oz.	Ground
	6/5/97	Fungicide	Benlate	1 lb.	Ground
	7/18/97	Insecticide	Imidan	1.5 pints	Ground
11 - SLK	5/7/97	Fungicide	Funginex	24 oz.	Ground
	5/21/97	Fungicide	Funginex	24 oz.	Ground
	6/5/97	Fungicide	Benlate	1 lb.	Ground
	7/18/97	Insecticide	Imidan	1.5 pints	Ground
12 - Wass Pineo	5/9/97	Fungicide	Funginex	24 oz.	Ground
	7/17/97	Insecticide	Sniper	1 pint	Ground
13 - Blueberry Hill	5/9/97	Fungicide	Funginex	24 oz.	Ground
	5/27/97	Fungicide	Funginex	24 oz.	Ground
14 - Farnsworth	5/12/97	Fungicide	Funginex	24 oz.	Ground
	5/21/97	Herbicide	Velpar	1.25 lbs	Ground
	7/16/97	Insecticide	Sniper	1 pint	Ground
15 - Annie Whitelaw	5/6/97	Fungicide	Funginex	24 oz.	Ground
16 - Musoko	5/6/97	Fungicide	Funginex	24 oz.	Ground
	5/21/97	Fungicide	Funginex	24 oz.	Ground
17 - Sprague	5/5/97	Fungicide	Funginex	24 oz.	Ground
18 - Crowley	None	None	None	None	None

Table A.2. Pesticides applied to blueberry fields in this study during the spring and summer of 1998.

Field Number - Name (1998)	Application Date	Pesticide Type	Pesticide Brand	Rate/Acre	Method
1 - Musoko	5/4/98	Fungicide	Funginex	24 oz.	Ground
	5/20/98	Fungicide	Orbit	4 oz.	Ground
2 - Farnsworth	5/11/98	Fungicide	Funginex	24 oz.	Ground
	5/21/98	Herbicide	Velpar	1.25 lbs.	Ground
	7/17/98	Insecticide	Sniper	1 pint	Ground
3 - Blueberry Hill	None	None	None	None	None
4 - Jordan's	None	None	None	None	None
5 - SL-14	5/4/98	Fungicide	Funginex	24 oz.	Ground
	5/19/98	Fungicide	Orbit	4 oz.	Ground
	6/4/98	Fungicide	Benlate	1 lb.	Ground
	7/17/98	Insecticide	Imidan	1.5 pints	Ground
6 - SG-4	5/4/98	Fungicide	Funginex	24 oz.	Ground
	5/19/98	Fungicide	Orbit	4 oz.	Ground
	6/4/98	Fungicide	Benlate	1 lb.	Ground
	7/17/98	Insecticide	Imidan	1.5 pints	Ground
7 - SG-3	5/4/98	Fungicide	Funginex	24 oz.	Ground
	5/19/98	Fungicide	Orbit	4 oz.	Ground
	6/4/98	Fungicide	Benlate	1 lb.	Ground
	7/17/98	Insecticide	Imidan	1.5 pints	Ground
8 - SL-1	5/4/98	Fungicide	Funginex	24 oz.	Ground
	5/19/98	Fungicide	Orbit	4 oz.	Ground
	6/4/98	Fungicide	Benlate	1 lb.	Ground
	7/17/98	Insecticide	Imidan	1.5 pints	Ground
9 - Varin's	None	None	None	None	None
10 - Pork Brook I	None	None	None	None	None

Table A.2. (cont.)

Field Number - Name (1998)	Application Date	Pesticide Type	Pesticide Brand	Rate/Acre	Method
11 - Pork Brook II	4/30/98	Fungicide	Orbit	4 oz.	Air
	5/25/98	Fungicide	Benlate	1 lb.	Air
	8/3/98	Insecticide	Sniper	1 pint	Air
12 - Pork Brook IV	4/30/98	Fungicide	Orbit	4 oz.	Air
	5/25/98	Fungicide	Benlate	1 lb.	Air
	8/3/98	Insecticide	Sniper	1 pint	Air
13 - McCoy Brook S1	4/30/98	Fungicide	Orbit	4 oz.	Air
	5/25/98	Fungicide	Benlate	1 lb.	Air
	7/18/98	Insecticide	Imidan	1.5 pints	Air
14 - McCoy Brook S2	4/30/98	Fungicide	Orbit	4 oz.	Air
	5/25/98	Fungicide	Benlate	1 lb.	Air
	7/18/98	Insecticide	Imidan	1.5 pints	Air
15 - Junior Grant IIA	4/30/98	Fungicide	Orbit	4 oz.	Air
	5/25/98	Fungicide	Benlate	1 lb.	Air
	7/18/98	Insecticide	Imidan	1.5 pints	Air
16 - Junior Grant IIB	4/30/98	Fungicide	Orbit	4 oz.	Air
	5/25/98	Fungicide	Benlate	1 lb.	Air
	7/18/98	Insecticide	Imidan	1.5 pints	Air

Appendix B

FLOWERING WEED SPECIES IN MAINE LOWBUSH BLUEBERRY

Table B.1. A list of flowering weed species detected in blueberry fields used in this study. Numbers not in parentheses represent the number of fields a specific weed was detected in for the corresponding year and sampling method.

Weed Species (Common Name)	1997 Quadrat Sampling (% cover)	1998 Quadrat Sampling (% cover)	1998 Line Transect Sampling (% cover)	1998 Line Transect Sampling (flowers/100m^2)
Apocynum androsaemifolium L. (dogbane)	10 (0.26)	3 (0.05)	6 (0.27)	6 (38)
Aronia melanocarpa Michx. (chokeberry)	12 (0.36)	0	0	0
Aster sp. (aster)	4 (0.08)	0	1 (0.02)	1 (5)
Comptonia peregrine Coult. (sweet fern)	8 (1.73)	0	0	0
Cornus canadensis L. (bunchberry)	9 (4.93)	0	10 (0.21)	10 (61)
Diervilla lonicera P. Mill. (bush honeysuckle)	5 (0.20)	1 (<0.01)	13 (0.66)	13 (149)
Drosera rotundifolia L. (sundew)	0	0	1 (<0.01)	1 (<1)
Epilobium angustifolium L. (fireweed)	1 (<0.01)	0	2 (0.02)	2 (2)
Fragaria sp. (strawberry)	2 (0.02)	1 (0.01)	1 (<0.01)	1 (<1)
Galium trifidum L. (small bedstraw)	2 (0.02)	0	0	0
Geranium maculatum L. (wild geranium)	0	0	1 (<0.01)	1 (1)
Hedyotis sp. (bluets)	2 (0.01)	0	0	0
Hieracium aurantiacum L. (orange hawkweed)	2 (0.06)	0	2 (0.01)	2 (4)
Hieracium caespitosum Dumort. (yellow hawkweed)	0	0	3 (<0.01)	3 (12)
Hieracium pilosella L. (mouse-ear hawkweed)	1 (<0.01)	0	1 (<0.01)	1 (5)

Table B.1. (cont.)

Weed Species (Common Name)	1997 Quadrat Sampling (% cover)	1998 Quadrat Sampling (% cover)	1998 Line Transect Sampling (% cover)	1998 Line Transect Sampling (flowers/100m^2)
Hieracium scabrum Michx. (rough hawkweed)	1 (0.05)	0	0	0
Hypericum canadense L. (Canada St. John's-wort)	1 (0.03)	0	1 (0.03)	1 (11)
Hypericum mutilim L. (dwarf St. John's-wort)	0	3 (0.06)	4 (0.13)	4 (397)
Kalmia angustifolia L. (sheep laurel)	11 (0.82)	3 (0.37)	12 (0.69)	12 (10,130)
Ledum groenlandicum Oeder (labrador tea)	0	0	1 (0.02)	1 (19)
Linaria canadensis Chaz. (toadflax)	2 (0.07)	2 (0.11)	4 (0.06)	4 (457)
Lysimachia quadrifolia L. (whorled loosestrife)	0	1 (0.13)	1 (0.64)	1 (3359)
Lysimachia terrestris B.S.P. (yellow loosestrife)	2 (0.04)	0	1 (0.01)	1 (30)
Maianthemum canadense Desf. (Canada mayflower)	3 (<0.01)	0	0	0
Melampyrum lineare Desr. (cowwheat)	3 (<0.01)	2 (0.06)	5 (0.25)	5 (171)
Menyanthes trifoliate L. (wild bean)	1 (<0.01)	0	0	0
Polygala sanginae L. (field milkwort)	0	0	1 (<0.01)	1 (3)
Polygonum sp. (smartweed)	0	0	1 (<0.01)	1 (33)
Potentilla simplex Michx. (yellow cinquefoil)	2 (0.14)	2 (<0.01)	7 (0.04)	7 (31)
Potentilla tridentate Ait. (three-toothed cinquefoil)	0	0	1 (0.15)	1 (541)
Prenanthes trifoliolata Fern. (tall rattlesnake-root)	3 (0.03)	0	2 (<0.01)	2 (1)
Pteridium aqualinum Kuhn (bracken fern)	7 (0.06)	0	0	0
Pyrola sp. (wintergreen)	0	0	1 (<0.01)	1 (2)
Ranunculus acris L. (common buttercup)	0	0	1 (0.04)	1 (5)

Table B.1. (cont.)

Weed Species (Common Name)	1997 Quadrat Sampling (% cover)	1998 Quadrat Sampling (% cover)	1998 Line Transect Sampling (% cover)	1998 Line Transect Sampling (flowers/100m^2)
Rosa sp. (pasture rose)	1 (<0.01)	1 (<0.01)	0	0
Rubus allegheniensis Porter (blackberry)	3 (0.02)	0	1 (<0.01)	1 (3)
Rubus hispidus L. (swamp dewberry)	0	0	2 (0.05)	2 (15)
Rubus idaeus L. (red raspberry)	0	0	8 (0.12)	8 (45)
Rudbeckia hirta L. (black-eyed susan)	0	1 (0.05)	1 (0.19)	1 (31)
Rumex acetosella L. (sheep sorrel)	3 (0.01)	0	2 (0.02)	2 (22,175)
Sisyrinchium angustifolium P. Mill. (pointed blue-eyed grass)	0	0	1 (0.04)	1 (354)
Solidago sp. (goldenrod)	2 (0.03)	0	3 (0.02)	3 (43)
Spiraea latifolia Dippel (meadowsweet)	3 (0.47)	0	1 (<0.01)	1 (3)
Trientalis borealis Raf. (starflower)	2 (0.02)	0	0	0
Trifolium procumbens L. (hop clover)	0	0	1 (0.11)	1 (39)
Unidentified species (unknown name)	2 (0.04)	0	1 (0.01)	1 (423)
Vaccinium macrocarpa Ait. (cranberry)	2 (0.03)	0	0	0
Viburnum cassinoides Torr. & Gray (witherod)	0	0	7 (0.60)	7 (28)
Vicia sp. (vetch)	2 (<0.01)	1 (0.07)	1 (0.04)	1 (41)
Viola sp. (violet)	2 (<0.01)	0	0	0

BIOGRAPHY OF THE AUTHOR

Joseph E. Karem was born in Beverly, Massachusetts and graduated from Nauset Regional High School in North Eastham. Accepting an athletic scholarship from the University of Massachusetts, he moved to Lowell where he earned a Bachelor of Science degree in both Biology and Mathematics. Shortly after graduating in 1988, Joseph worked at Corning Laboratories as a Toxicology Technologist. While working at Corning, he returned to the University of Massachusetts to pursue a Master of Science degree in Clinical Laboratory Sciences. He graduated in 1995 and received the Dean's Award for Outstanding Graduate Student. Deciding on a career in Environmental Science, he began the Master of Science program in Ecology and Environmental Sciences at the University of Maine in Orono. However, after 2 years of graduate work, he was offered a full-time position as an adjunct professor in the department of Science and Humanities at Husson College. After 4 years at Husson, he returned to finish his graduate thesis, and accepted a position with Dr. Ivan Fernandez in the department of Plant, Soil and Environmental Sciences. Joseph is a candidate for the Master of Science degree in Ecology and Environmental Sciences from The University of Maine in August 2005.