

AN ABSTRACT OF THE THESIS OF

Jennifer E. Bergh for the degree of Master of Science in Entomology presented on April 8, 2011.

Title: Native Bee Diversity and Floral Resource Availability in Two Willamette Valley Oregon Ecosystems.

Abstract approved:

Sujaya Rao

The importance of pollinators in native and managed landscapes is well known, and recent interest is directed towards investigating the role of native bees as providers of pollination ecosystem services. Uncertainty about bee populations at global and local scales has prompted research and general interest in conservation of bee diversity. To sustain robust populations, bees need nesting habitat and quality forage resources. This thesis describes two studies related to the relationship between bee diversity and landscape floral resource availability in two Willamette Valley ecosystems: wet prairies and blueberry agroecosystems. The wetlands are florally diverse, heterogeneous, and temporally patchy in spring and summer, whereas blueberries are florally abundant during spring crop bloom with potentially fewer floral resources after berry set; the intention of these studies was to determine if the floral resources in each ecosystem were adequate to support robust native bee communities. For each

site type, the bee fauna and associated melittophilous floral resources are described and characterized. In the studies, it was determined that bee diversity, and specifically bee abundance, was positively correlated with floral resources. This thesis presents the results of community analyses, floral resources that were identified as important forage sources, and a discussion of the relationship between landscape phenology and bee population dynamics in each ecosystem type. Implications and recommendations for landscape management to conserve and potentially enhance local native bee communities are discussed.

© Copyright by Jennifer E. Bergh

April 8, 2011

All Rights Reserved

Native Bee Diversity and Floral Resource Availability in Two Willamette Valley
Oregon Ecosystems

by
Jennifer E. Bergh

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Presented April 8, 2011
Commencement June 2011

Master of Science thesis of Jennifer E. Bergh presented on April 8, 2011.

APPROVED:

Major Professor, representing Entomology

Director of the Entomology Graduate Program

Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Jennifer E. Bergh, Author

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude and appreciation for Dr. Sujaya Rao, my major professor. Her encouragement, guidance and exacting standards have inspired me; the opportunities she has given me have, quite simply, changed my life.

I thank Dr. Andrew Moldenke for his insight and assistance in the field, at the bench, and in the office. I am extremely grateful for his guidance.

Dr. William P. Stephen was unfailingly generous with his time and expertise in bee identification, taxonomy, and field methodology. Thank you.

Thank you to my graduate committee members, Dr. John Lambrinos and Dr. Jay Pscheidt, for your time and involvement with my research and thesis. I would also like to thank Sally Villegas of the BLM-West Eugene Wetlands, Jock Beall of USFW-Finley National Wildlife Refuge, Western Sustainable Agriculture Research & Education, and Benton and Marion counties blueberry growers for research funding, knowledge, and access to the ecosystems that are the subject of this work.

To Dr. Peter McEvoy, Dr. Jeffrey Miller, Melissa Scherr, Jennifer Snyder, Danielle Lightle, Sarah Grubin, Sam Colby, Kim Skyrn, Sarah Taylor, Melissa Broussard, and Joe Kaser: thank you all for the lively and spirited discussions about research methods and ecology.

The support and friendship of Kimberly Berry were constant, invaluable, and greatly appreciated. Finally, I would like to thank my parents, Clarence and Ellen Bergh, for their love and support.

CONTRIBUTION OF AUTHORS

Dr. Sujaya Rao assisted with study design, writing, and manuscript preparation of chapters 2 and 3. Dr. Andrew Moldenke assisted with study design, data interpretation, and writing of Chapter 2.

TABLE OF CONTENTS

	<u>Page</u>
Chapter 1: Introduction	1
Chapter 2: Bee diversity and floral resource availability in three Willamette Valley wetlands.....	8
Abstract	9
Introduction	10
Methods and Materials	13
Site Descriptions	13
Bee Sampling Method.....	14
Floral Resource Scoring Method	15
Temperature Measurement Methods.....	16
Analysis.....	16
Results	18
Bee Diversity.....	18
Biodiversity Results by Wetland Site, Microhabitat and Sample Event	20
Floral Resources.....	22
Temperature Trends between Years.....	25
Effects of Multiple Factors of Bee Diversity	26
Nonparametric Community Analysis.....	28
Discussion	31
Summary	31
Seasonal Progression and Subsequent Years	32
Effect of Site and Microhabitat	33
Community Response to Floral Resource Score.....	35
Conclusion	36
Acknowledgements	38

TABLE OF CONTENTS (Continued)

	<u>Page</u>
Chapter 3: Bee diversity and floral resource availability in three Willamette Valley blueberry ecosystems	39
Abstract	40
Introduction	41
Methods and Materials	44
Site Descriptions	44
Bee Sampling Method.....	44
Floral Resource Scoring Method	45
Temperature Measurement Methods.....	46
Analysis.....	47
Results	48
Bee Diversity.....	48
Floral Resources	52
Temperature	55
Effects of Multiple Factors on Bee Diversity	57
Discussion	63
Summary	63
Effect of Time and Farm Site.....	64
Community Response to Floral Resource Score.....	66
Conclusion	67
Acknowledgements	69
Chapter 4: Discussion	70
Review of Findings	70
Study Limitations	72
Conclusion	74
Future Research.....	75
Bibliography.....	77

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1.1 Finley National Wildlife Refuge wet prairie.....	4
1.2 Jackson Frazier Wetlands wet prairie	4
1.3 West Eugene Wetlands wet prairie and oak savanna.....	5
1.4 Blueberry Farm “A” (conventionally managed).....	5
1.5 Blueberry Farm “W” (certified organic)	6
1.6 Blueberry Farm “H” (transitioning to organic).....	6
1.7 Map of the Willamette Valley research sites	7
2.1 Mean bee abundance by year, wetland site, microhabitat, and sample event....	19
2.2 Mean floral resource site score by year, wetland site, and sample event.....	24
2.3 Average 48-hour temperature by sample event for study years.....	25
2.4 Bray-Curtis ordination showing sites by year in two-dimensional taxa space with environmental variables on the axes	29
3.1 Mean bee abundance by year, farm site, and sample event	51
3.2 Mean floral resource site score by year, farm site, and sample event.....	54
3.3 Average 48-hour temperature by sample event for study years.....	56
3.4 Scatter plots of all-season bee abundance and species richness by floral resource score.....	59
3.5 Scatter plots of May bee abundance and species richness by floral resource score	61

LIST OF TABLES

<u>Table</u>	<u>Page</u>
2.1 Wetland diversity measures by site and year	21
2.2 Plant species included in wetland floral resource scores more than three times per year with introduced and native species	23
2.3 Correlations and multivariate analysis of variance (MANOVA) results	27
2.4 Correlations from ordination of genera groups by floral resource score and average temperature	30
3.1 Blueberry farm diversity measures by site and year	50
3.2 Bee diversity by sample event for study years	50
3.3. Plant species providing favored resources for bees with introduced, cultivated, and native species	53
3.4 Correlations and multivariate analysis of variance (MANOVA) results	58
3.5 May bee guild on blueberry farms for study years	62

LIST OF APPENDICES

<u>Appendix</u>	<u>Page</u>
A. Bee species of three Willamette Valley wetland sites	86
B. Plant species included in floral resource scores in three Willamette Valley wetland sites	89
C. Bee species of three Willamette Valley blueberry farms	92
D. Plant species included in floral resource scores on three Willamette Valley blueberry farms	95

DEDICATION

This thesis is dedicated to Lisa Verdugo, who was there for the first field days. When I think back to where it all began, it started with her.

Native Bee Diversity and Floral Resource Availability in Two Willamette Valley Oregon Ecosystems

Chapter 1

Introduction

Native bees are important invertebrates in any ecosystem that includes flowering plants, many of which rely on insect pollinators for reproduction. Biodiversity is inherently valuable, and bees' ability to provide an ecosystem service that is critical to both plants and animals makes them an exceptionally important group of insects. In order to conserve bee populations and enhance pollination of valued plants, we need first to know the community composition and structure of the bee fauna. There are two systems in the Willamette Valley that rely heavily on bees for pollination: wet prairies with native plants and animals including rare and vulnerable populations, and agricultural ecosystems, many of which produce food crops that are directly reliant on bee pollination. The need for bees is evident and advances the question of whether these systems provide the necessary resources for the robust pollinator populations they are reliant upon.

Bees need two main landscape resources: suitable habitat for nest sites and access to continuous, quality floral resources through their reproductive season. Wet prairies are florally rich, particularly in early spring and late summer, but the resources may be patchy and temporally limited with periods of bloom shifting between

abundance and scarcity. Many agroecosystems provide a plentiful bloom in spring or early summer, but access to floral resources after crop bloom is limited to adjacent landscapes or on-farm flowering weeds, hedgerows and ornamental plantings; some farms are managed to have no other flowering plants except the crop, though this is more common in annual cropping systems. Are the bees that Oregon wetlands and agroecosystems depend on for pollination, particularly in spring, present in those systems throughout the entire growing season? What floral resources are they utilizing during periods of scarcity of bloom or after crop bloom? Is it possible to predict bee abundance in a system by quantifying the floral resources?

The objective of this research was to characterize the bee fauna and its relationship with floral resource availability in these two types of ecosystems; we hypothesized that bee diversity and floral resource levels were positively correlated. In the Willamette Valley, the footprint of wet prairies is substantially decreased from 200 years ago, and only a small fraction remains intact (WEW 2009). Much of the land conversion of wetlands has been due to agriculture, which along with urban development is now nearly as substantial in the valley as the wet prairies and oak savanna it replaced (EPA 2004).

To evaluate the relationship between native bee abundance and floral resource levels in these two systems, 3 wetland sites and 3 blueberry farms were selected for observational study. The wetland sites included the West Eugene Wetlands in Lane County, and Finley National Wildlife Refuge and Jackson Frazier Wetlands in Benton County (Figures 1.1-1.3). The blueberry farms included 2 Benton County operations,

one certified organic and the other conventionally farmed, and 1 Marion County operation, which began the transition from conventional to organic in the second year of the study (Figures 1.4-1.6). Study sites were not selected at random, but chosen based on being representative of their respective ecosystem types in the Willamette Valley and the cooperation of land managers to be included in the study (Figure 1.7). A pilot study conducted in the year before this project began informed the design.

Chapter 2 of this thesis is the exploration of the research questions at the wetlands sites. In this study, sites were sampled over 2 years and we examined the relationship between native bee diversity and floral resource availability, as well as the effects of site, microhabitat, temperature, and time of season. We identified key forage resources for bees in these sites, and determined that some genera of bees were highly correlated with resource levels. Chapter 3 describes the study carried out in the blueberry agroecosystems following the same sampling regimen and methodology. Here we identify long-season bees that provide crop pollination in the spring and persist on the farms through the growing season. This chapter includes a discussion of the food resource needs of these bees and potential ways to enhance their populations. In Chapter 4, the major findings of both studies are reviewed as a whole and in context with other research findings to elucidate our results and inform the questions of future research in this field.



Figure 1.1 Finley National Wildlife Refuge wet prairie

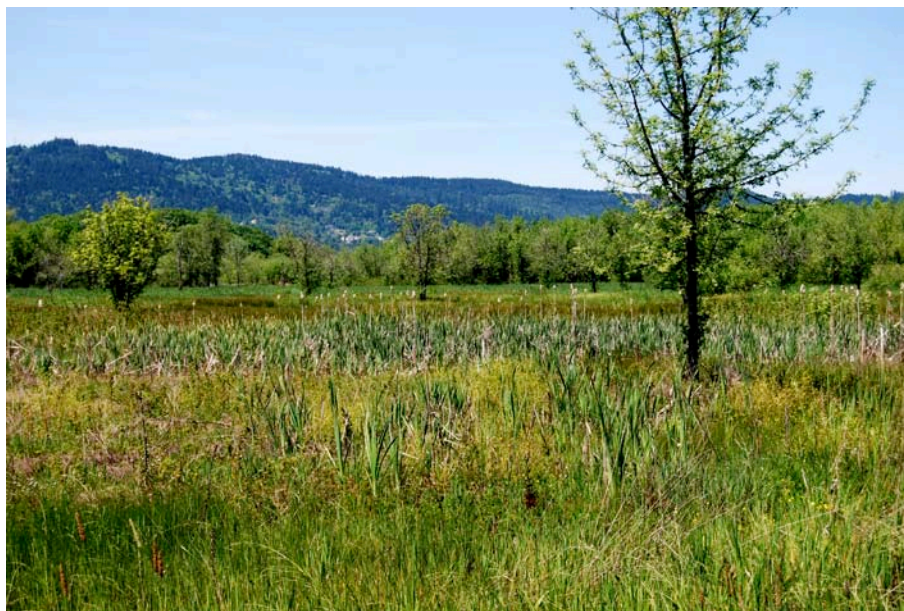


Figure 1.2 Jackson Frazier Wetlands wet prairie



Figure 1.3 West Eugene Wetlands wet prairie and oak savanna



Figure 1.4 Blueberry farm “A” (conventionally managed)



Figure 1.5 Blueberry farm “W” (certified organic)



Figure 1.6 Blueberry farm “H” (transitioning to organic)

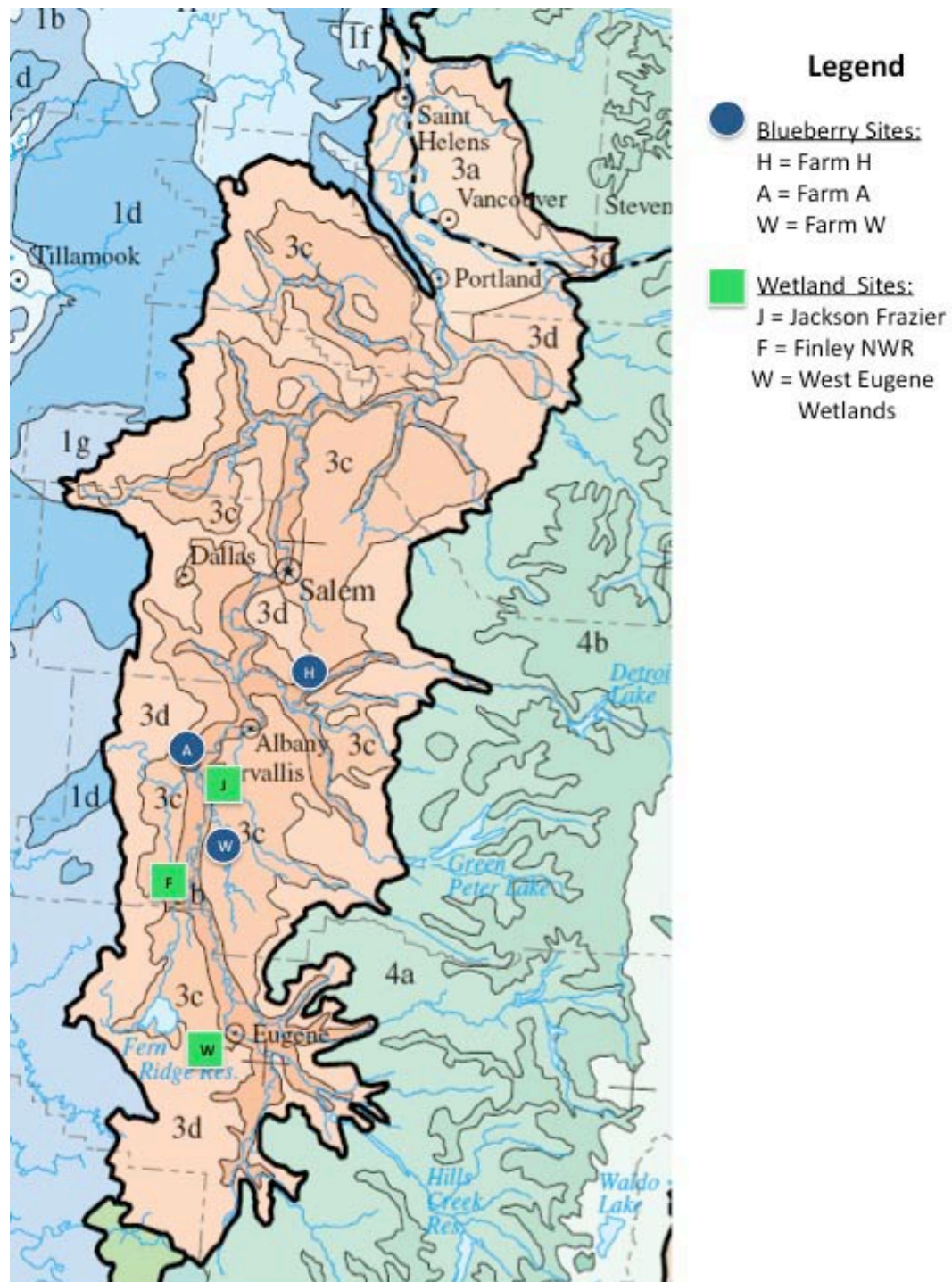


Figure 1.7 Map of the Willamette Valley ecoregion and research sites, modified from (EPA 2008).

Chapter 2

Bee Diversity and Floral Resource Availability in Three Willamette Valley Wetlands

Abstract

The positive, mutualistic association between flowers and bees is well documented, as is the importance of invertebrate biodiversity in native systems. Wet prairies are a critical reservoir of plant and animal diversity, but their footprint is decreasing under the pressures of agricultural intensification and urban development. Both preserved and restored wetlands are home to a variety of vulnerable plant and animal populations that persist based on the continued existence of mutualisms, such as that between a native plant species and its obligate specialist pollinator. As a practical matter, bee populations in these florally rich native areas may provide a reservoir of pollination services for adjacent agricultural ecosystems. The purpose of this study was to characterize the bee fauna of three Willamette Valley wet prairie systems and to determine the relationship between native bees and floral resource availability. The study showed that bee diversity is correlated with floral resource availability, and an ordination model of the bee communities in taxa space explained 71% of the variation in community composition. Additionally, 9 bee genera were found to be highly correlated with floral resource availability as well as with temperature. Identification of 11 plant species that provided a “favorite” forage resource was made and revealed that several weed species were important food sources for native bees at these 3 Willamette Valley wetlands. These findings have implications for management and conservations efforts of both wetland ecosystems as a whole and their associated native bee communities.

Keywords: native bees, biodiversity, wetlands, floral resource availability

Introduction

Widespread concern about the status of bees as pollinators has prompted research and mainstream general interest in bees and their wellbeing. Colony collapse disorder and the decreased availability of honey bees for commercial pollination have turned attention to native bees as potential alternative providers of pollination services (Kluser et al. 2010). There is already substantial research linking the pollination of native bees to indigenous native plants and agriculture (Steffan-Dewenter and Westphal 2008); their natural abundance in a variety of ecosystems carries with it potential for enhancing local crop pollination.

Wild bees need two landscape-level resources: forage and nesting habitat. Ideally, forage availability would extend from the time of the earliest bee emergences in late winter (bumble bee queens) until the last native bee enters diapause for overwintering in early fall (mated bumble bee females). Because of the short flight range of most native bees, many of which are small-bodied or are behaviorally doorstep foragers, the forage must also be available locally (Stephen et al. 1969, Cane 2001). Habitat fragmentation is therefore a primary threat to native bee diversity as it removes floral resources and confines the bees to ever-smaller patches (Potts et al. 2003, Harris and Johnson 2004). Other threats include urban and industrial development, agricultural intensification, pathogens and parasites, and off-target pesticide effects (Goulson 2008, Freitas et al. 2009).

High bee abundance is required to provide adequate pollination to crops. In order to achieve populations capable of delivering this service, quality food and

nesting habitat are needed to build and sustain robust native bee communities (Greer 1999). Wild and managed native areas are thought to be a reservoir for bee diversity and, in turn, the ecosystem service of pollination (Kremen et al. 2002). Pollination services are critical to a variety of agricultural crops and also to many native plants.

In the Willamette Valley of Oregon, forest, savanna, prairie and wetland ecosystems make up the native landscape, some of which is directly adjacent to agriculture. Relict fragmented prairie and native restoration projects create a mosaic of florally rich, low-disturbance habitat throughout the valley. Bordered by agriculture and development, these transitional ecosystems provide permeable habitat matrix where native plants and wildlife live (Kearns et al. 1998, Moron et al. 2008). Characterized by annual wet-dry cycles, seasonal inundation from natural water sources and hydrophilic plant communities, wetlands are rapidly disappearing ecosystems with less than 1% of their original acreage intact (Mitsch and Gosselink 2000, WEW 2009). Though highly diverse in plant species, it was not known if the heterogeneous composition and patchiness of bloom in these stable wetland fragments was adequate to support a robust native bee community.

Phenological studies evaluating bees, pollen, and nectar sources have been conducted, but there is little published baseline data about bee diversity and floral resource availability in wet prairie systems with much of the published research focused on a particular plant guild or a single species or genus (Moron et al. 2008, Potts et al. 2009).

Three wet prairie systems in the Willamette Valley of Oregon provided the

experimental setting for a study of bee populations in managed native settings. The objectives of this study were to describe the biodiversity of the bee fauna in each of the sites and to determine if either bee abundance or richness was correlated with the availability of floral resources for forage. We hypothesized that bee diversity, specifically bee abundance, and floral resource availability would be positively correlated.

Methods and Materials

Site Descriptions

Three Willamette Valley managed wetland systems were selected for the study: Finley National Wildlife Refuge (44.42N, 123.30W) and Jackson Frazier Wetlands (44.60N, 123.23W) in Benton County, OR, and West Eugene Wetlands (44.07N, 123.25W) in Lane County, OR. Finley National Wildlife Refuge (Finley NWR) is the largest relict Willamette Valley prairie system, characterized by wet prairie, upland oak savanna, and lowland ash forest (EPA 2008). The refuge itself is bordered by mixed forest, fields planted to wildlife forage, and agriculture. A 72-ha subsite of wet prairie bordered by ash forest was surveyed. Jackson Frazier Wetlands (Jackson Frazier) is a 58-ha urban fragment of previously disturbed, restored prairie with mixed wetland communities including emergent and shrub-scrub wetlands and lowland ash forest. This site is managed by the city of Corvallis and is bordered by highway, agriculture, and residential urban development. The West Eugene Wetlands (WEW) is a mosaic of fragmented wetland sites under restoration with interagency and community involvement (WEW 2009). The 57-ha subsite surveyed for this study is characterized by wet and upland prairie, emergent wetland, and oak savanna. WEW shares boundaries with Fern Ridge Reservoir, agriculture, and residential and industrial urban development.

Bee Sampling Method

Bees were collected using unscented blue vane traps which consist of two plastic vanes (10 x15cm) which fit together perpendicularly and snap into a lid which screws onto a 950-mL clear plastic collecting jar (Stephen and Rao 2005). The entire assembly is hung from a stake at a level of 1m above the ground. Bees are visually drawn to the trap, fly into the vanes, and drop into the collection jars. Some hand collecting was also performed via either direct catch or sweep net to ensure that all bee taxa present locally were being collected in the traps.

Prior to sampling initiation, 3 fixed trap locations in the shape of a triangle were selected at each site. Traps were placed at each of the corners with one trap on the apex in the center of the wet prairie (Trap 1), one trap along the fenceline or hedgerow of the site margin to adjacent agriculture or in the case of the WEW site, another managed system (Trap 2), and the third trap at the transition to oak or ash forest (Trap 3). The trap locations were approximately 500-m apart and located to facilitate comparisons between microhabitats; their exact locations were static between sampling periods and years.

Sites were monitored from May to September in 2009 and 2010 at approximately 3-week intervals for a total of 6 sampling events per year (May 29, June 30, July 23, August 13, August 27, September 18 in 2009, and May 15, June 9, July 1, July 23, August 6, September 2 in 2010). Sampling dates were shifted as necessary to ensure nominally favorable weather and to avoid any effects from large-

scale, local field disturbances such as storms, burns, and pesticide applications in adjacent areas.

For each sampling event, the traps were hung for a 48-hour period, then collected and transported to the laboratory where bee specimens were frozen, pinned, sorted and identified. Identifications were made using Hurd and Michener (1955), Stephen (1957), Stephen and Bohart et al. (1969), Roberts (1973*a* and 1973*b*), Michener (2007), and the Oregon State Arthropod Collection. In the absence of regionally reliable keys for some groups, they were sorted to morphospecies. Specimens are vouchered in the Rao Native Bee Collection at Oregon State University.

Floral Resource Scoring Method

Prior to beginning the study, each site map was overlaid with a grid of numbered 100-m² plots. A list of random numbers, with replacement, was generated for each site to provide randomized plot selections for each of the 12 sampling events (6 in each year). At each sampling event, three plots were selected, separated into quadrants, and marked with flags. Each quadrant was walked in a serpentine pattern and the melittophilous, or bee foragable, plant species in bloom were recorded. Plants were identified using Kozloff (2005) and Burrill et al. (1996). The quadrants were scored for percentage of area with plants in bloom that could provide forage for bees. Bare ground and plants that were either not in bloom or were in bloom but are not utilized by bees (grasses, sedges, and microflora that were not observed to be visited by bees,

e.g., *Microsotis*) were not included in the score. The floral resource scores were simple percentages of cover in bloom within each quadrant. The scores for all 4 quadrants of each plot were averaged into a single plot score, then the three scores per site were averaged to a site-level floral resource score. This single site floral resource score was the measure used for all analyses. Based on the random selection of plots at each sample event, the floral resource score is treated as representative of site-level floral resource availability.

Temperature Measurement Methods

Temperature measurements in the field reflected a single point in time and were not representative of the entire sampling period; therefore, the average temperature over each 48-hour sampling period was calculated from each site's local weather station data (IPPC 2011). The mean temperature was obtained by taking the highs and lows from the 3 calendar dates in which the sample event fell and averaging them into a mean temperature for the event.

Analysis

Bee biodiversity was calculated utilizing the Shannon Diversity Index. Chao1 species richness estimations were calculated for comparison to observed richness to measure theoretical sampling performance, which is the number of species observed versus the number of species expected. Analyses of the relationships between bee abundance, species richness, floral resource availability, and average temperature were performed

using correlations and multivariate analysis of variance (MANOVA) in SPSS (2010). Ecological community analyses by Sorensen distance were performed in PC-ORD using multi-response permutation procedures (MRPP) and Bray-Curtis ordination with variance-regression endpoint selection as recommended by McCune (2002).

Seven sampling events were removed from the data set prior to analysis. Two of these events were missed at Finley NWR pending permits from land management. The other 5 events were removed due to inclement weather with wind speeds greater than $10\text{-m}\cdot\text{s}^{-1}$ (Finley NWR 2010 sample event #6, WEW 2010 sample event #6, Jackson Frazier 2009 sample event #2 and 2010 sample event #1 and 6). Additionally, individual specimens collected via direct methods to ensure inclusion of their taxa in the traps were not included in the analyses.

Results

Bee Diversity

A total of 1,708 bees in 5 families, 17 genera and 69 species were collected from all wetland sites between 2009 and 2010 (Appendix A). Total abundance and species richness were two times higher in 2009 with 1,176 individuals belonging to 69 species collected compared to 532 individuals in 33 species collected in 2010. Mean number of bees per trap was significantly different ($P=0.02$) between years (Figure 2.1a).

Halictidae was the richest family with 31 species, followed by Apidae with 24 species. *Lasioglossum* (*Dialictus*) spp. was the most diverse genus with 14 morphospecies. *Agapostemon* Guérin-Méneville was the most abundant genus accounting for 36% of all the halictids. In Apidae, there were 7 species of *Melissodes*, including the rare *Melissodes pullatella* LaBerge, a specialist on *Grindelia* (Severns and Moldenke 2010). There were also 7 species of *Bombus* Latreille which accounted for 46% of all collected Apidae and 21% of the total collected bee specimens for all years. *Apis mellifera* L., the European honey bee, accounted for <20% of the total collected specimens.

In 2009 and 2010, all taxa that were observed or caught by hand also appeared in the blue vane traps.

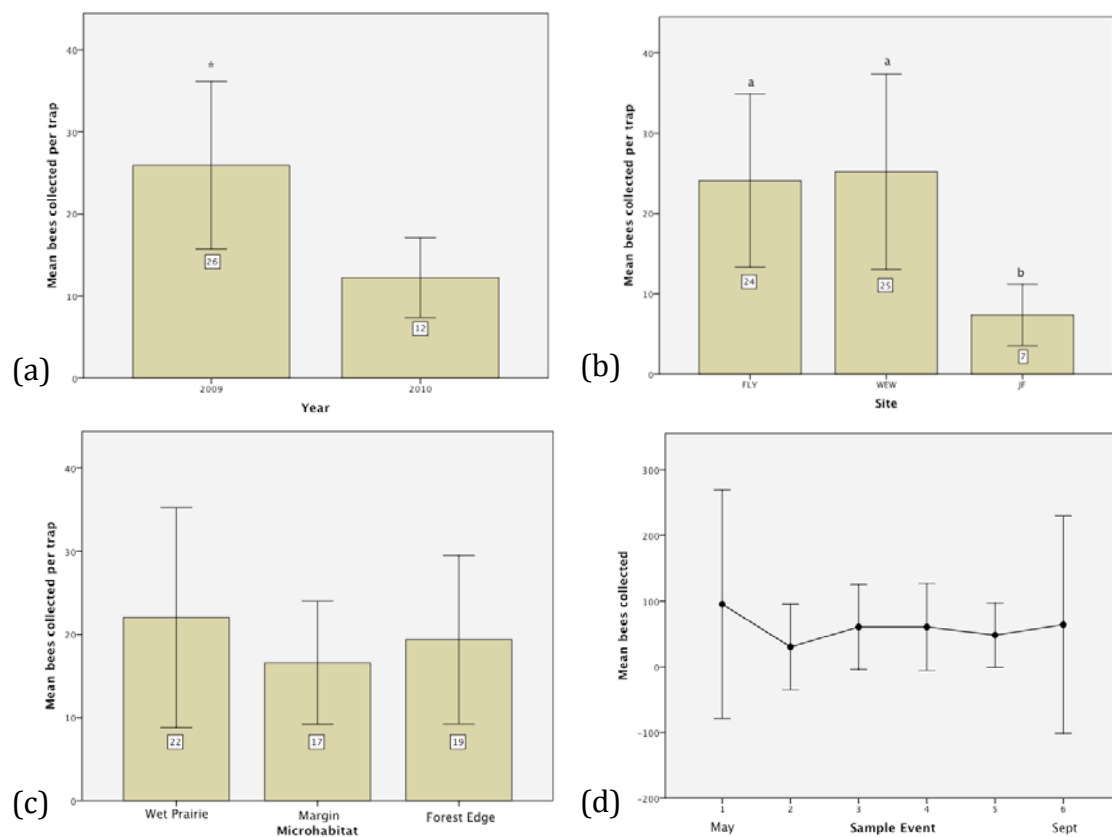


Figure 2.1. Mean bee abundance between (a) 2009 and 2010 ($n=87$, $P=0.02$); (b) wetland sites ($n=87$, $P=0.02$); (c) microhabitat/trap locations ($n=87$, $P=0.76$); and (d) sampling events ($n=29$, $P=0.51$)

Biodiversity results by wetland site, microhabitat and sample event

West Eugene Wetlands had the highest total abundance and overall Shannon diversity, whereas Finley NWR had the highest species richness (Table 2.1). Chao1 estimates of total species richness were calculated for each site by year and for both years.

Observed species richness at Finley NWR was estimated to be 96% of the Chao1 estimate, or theoretical species richness, WEW 48%, and Jackson Frazier 75%. WEW had the lowest estimated-to-observed ratio despite the highest total abundance because of a high proportion of singleton species: 23 of 62 total species.

At WEW, the most common native bee species were *Agapostemon virescens* Fabricius, *Halictus farinosus* Smith, and *Lasioglossum pacificum* (Cockerell). The most common native species at Finley NWR were *Bombus griseocollis* (Degeer), *B. vosnesenskii* Radoszkowski, *H. farinosus* and *Melissodes metenuea* Cockerell. Jackson Frazier's most common native bees were *B. vosnesenskii*, *B. appositus* Cresson, *B. californicus* Smith, *M. metenuea*, and *M. rivalis* Cresson.

The WEW site had the highest mean number of bees per trap with 25.2 (n=33), followed by Finley NWR with a mean of 24.1 (n=27), and Jackson Frazier with the lowest mean of 7.4 (n=27) (P=0.02, Figure 2.1b). There was no significant difference between mean bees collected by microhabitat trap location within the sites (Figure 2.1c). There was also no difference in mean number of bees collected by sampling event (Figure 2.1d).

Table 2.1. Bee diversity measures of three wetland sites by sampling year and all years

	Finley NWR		West Eugene Wetlands		Jackson Frazier	
	<u>2009</u>	<u>2010</u>	<u>2009</u>	<u>2010</u>	<u>2009</u>	<u>2010</u>
Total Abundance	493	174	533	302	150	56
Species Richness	45	39	56	41	32	19
Chao1 Richness Estimate	78	57	144	51	53	21
Shannon Diversity	2.65	2.92	3.03	2.68	2.62	2.73
			<u>All Years</u>			
Total Abundance	667		835		206	
Species Richness	66		62		39	
Chao1 Richness Estimate	69		128		52	
Shannon Diversity	2.86		3.02		2.85	

Floral Resources

A total of 42 melittophilous plant species in 13 families and 39 genera were observed in the randomized plots and included in floral resource scores and analyses (Appendix B). The 15 most common plants included in floral resource scores, defined as present in greater than 3 sampling events at each site in each year, are shown in Table 2.2.

Plant species that had relatively short bloom periods (approximately 2-3 three weeks) but provided an observed heavily foraged and “favorite” resource for native bees included 11 species: *Achillea millefolium*, *Cirsium vulgare*, *Crataegus douglasii*, *Dipsacus fullonum*, *Grindelia integrifolia*, *Hypochaeris radicata*, *Mentha pulegium*, *Rubus armeniacus*, *Sidalcea campestris*, *Spiraea douglasii*, and *Trifolium repens*.

Floral resources were significantly greater in 2009 than in 2010 (Figure 2.2a), and were significantly different between sites (Figure 2.2b). Floral resources also varied by 3-week sampling event (Figure 2.2c).

Table 2.2. Plant species included in wetland floral resource scores greater than three times per year (equivalent to approximately 2 months of bloom); [I] introduced species, [N] native species

Family	Species	Common Name	Bloom
Apiaceae	<i>Daucus carota</i> L. ^[I]	Queen Anne's lace	Jul-Sep
Asteraceae	<i>Cirsium vulgare</i> (Savi) Ten. ^[I]	Bull thistle	Jun-Aug
	<i>Grindelia integrifolia</i> DC. ^[N]	Gumweed	Jun-Aug
	<i>Hypochaeris radicata</i> L. ^[I]	Hairy cat's ear	May-Sep
	<i>Leucanthemum vulgare</i> Lam. ^[I]	Oxeye daisy	May-Aug
	<i>Tanacetum vulgare</i> L. ^[I]	Common tansy	Jul-Sep
Fabaceae	<i>Lathyrus latifolius</i> L. ^[I]	Perennial pea	Jul-Sep
	<i>Lotus corniculatus</i> L. ^[I]	Bird's-foot trefoil	May-Jul
	<i>Lotus formosissimus</i> Greene ^[N]	Seaside bird's-foot trefoil	May-July
	<i>Trifolium repens</i> L. ^[I]	White clover	May-Jun; Aug-Sep
	<i>Vicia sativa</i> L. ^[I]	Garden vetch	Jun-Aug
Lamiaceae	<i>Mentha pulegium</i> L. ^[I]	Pennyroyal	Jun-Aug
	<i>Prunella vulgaris</i> L. ^[N & I]	Common selfheal	Jun-Sep
Rosaceae	<i>Rosa woodsii</i> Lindl. ^[N]	Wood's rose	May-Aug
Scrophulariaceae	<i>Parentucellia viscosa</i> (L.) Caruel ^[I]	Yellow glandweed	Jun-Sep

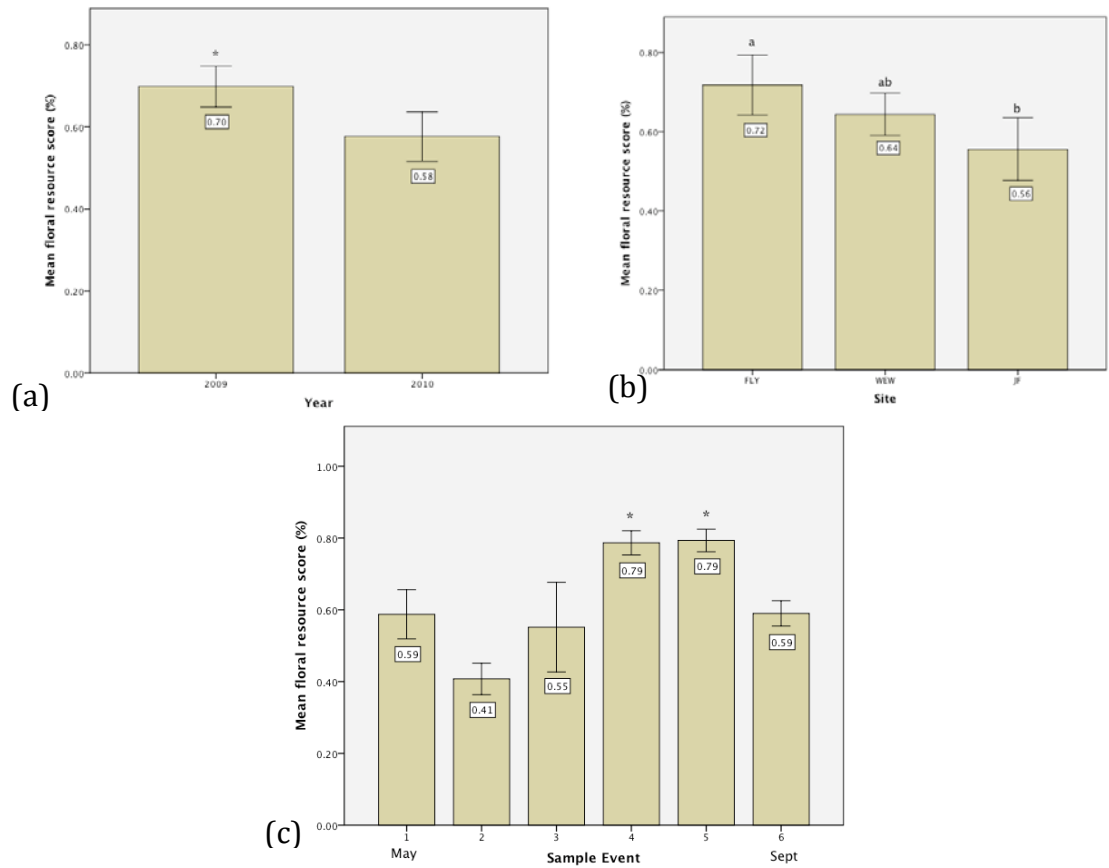


Figure 2.2. Mean floral resource site score by (a) years 2009 and 2010 ($n=29$, $P=0.002$); (b) wetland sites ($n=29$, $P=0.006$); and (c) sample events ($n=29$, $P=0.0001$)

Temperature Trends between Years

Average temperatures were similar between years with the trends across sample events presented in Figure 2.3. There were no significant differences in average temperature by sample event between study years.

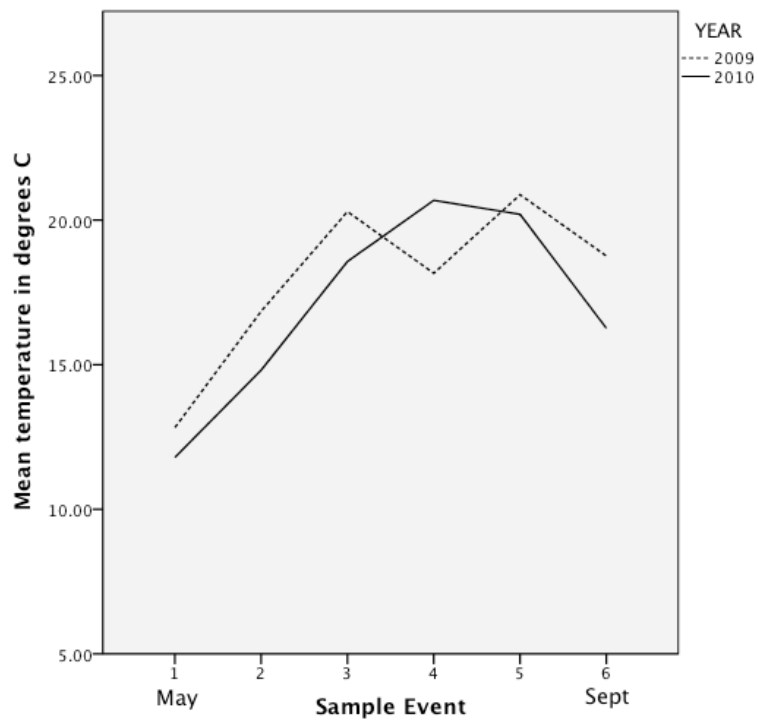


Figure 2.3. Average 48-hour temperature by sampling event for the 2 study years, sites averaged

Effects of Multiple Factors on Bee Diversity

Analysis of total bee abundance and species richness for all sampling events and years revealed moderate positive correlations with floral resource availability. There were weak and insignificant negative correlations between both bee diversity measures and average temperature (Table 2.3, section 1).

Nested multivariate ANOVA of bee abundance and species richness is presented in Table 2.3 section 2 and shows no significant effect of the sites, microhabitats, or the interaction between them on either bee diversity measure. Floral resource level had a significant effect on bee abundance and species richness ($P=0.001$ and $P=0.009$, respectively); temperature had an effect on abundance only ($P=0.026$).

To identify potential seasonal trends and account for the effect of repeated sampling, repeated measures MANOVA was performed to measure the influence of sampling event on bee abundance and species richness. Sample event did not have an effect on bee abundance, ($P=0.118$), but did have a significant effect on species richness ($P=0.023$). In this analysis, floral resource level had a significant effect on both measures ($P<0.0001$), but the effect of temperature was again insignificant (Table 2.3, section 3).

Table 2.3. (2.3.1) Correlations between bee abundance, species richness, floral resources, and average temperature; (2.3.2) MANOVA comparisons of abundance and richness by floral resource score, average temperature, site and microhabitat; and (2.3.3) MANOVA comparisons of abundance and richness by sample event; for all analyses, $n=29$ and $\alpha=0.05$ with correlations significant at $R=0.50$

2.3.1 Correlations		FLORAL RESOURCES	TEMP
ABUNDANCE	Pearson's R	0.440	-0.192
	Sig. (1-tailed)	0.009	0.159
RICHNESS	Pearson's R	0.374	-0.060
	Sig. (1-tailed)	0.023	0.379
2.3.2 Nested MANOVA			
Parameter	Variable	F	P
FLORAL RESOURCES	ABUNDANCE	10.857	0.001
	RICHNESS	7.089	0.009
TEMPERATURE	ABUNDANCE	5.176	0.026
	RICHNESS	1.280	0.261
SITE	ABUNDANCE	0.512	0.601
	RICHNESS	1.197	0.308
MICROHABITAT	ABUNDANCE	0.278	0.758
	RICHNESS	0.271	0.763
SITE * MICROHABITAT	ABUNDANCE	0.402	0.807
	RICHNESS	0.290	0.883
2.3.3 MANOVA with Sample Event as a Repeated Measure			
Parameter	Variable	F	P
FLORAL RESOURCES	ABUNDANCE	23.298	<0.001
	RICHNESS	21.791	<0.001
TEMPERATURE	ABUNDANCE	2.356	0.129
	RICHNESS	2.002	0.161
SAMPLE EVENT	ABUNDANCE	1.822	0.118
	RICHNESS	2.785	0.023

Community Analysis

To test for site-level community compositional differences by year, multi-response permutation procedures (MRPP) were performed and showed no significant difference ($A=-0.023$, $P=0.610$). Bray-Curtis ordination was performed to compare community structure by site-year in taxa space using the bee genera collected and environmental data. The resulting model allows a comparison of community similarity between sites and years, and is presented in Figure 2.4. Strongly correlated environmental variables were loaded on the ordination axes: floral resource score on axis 1 explained 23% of the variation in community composition ($R^2=0.23$) and average temperature on axis 2 explained an additional 48% of the variation ($R^2=0.48$).

Correlations from the ordination by the 17 generic groups are presented in Table 2.4. *Anthophora*, *Apis*, *Bombus*, *Hylaeus*, *Evylaeus*, and *Megachile* are highly correlated with floral resource level; *Ceratina*, *Synhalonia* and *Agapostemon* are highly correlated with average temperature; *Lasioglossum* (s.str.), *Lasioglossum* (*Dialictus*), and *Halictus* are highly correlated with both.

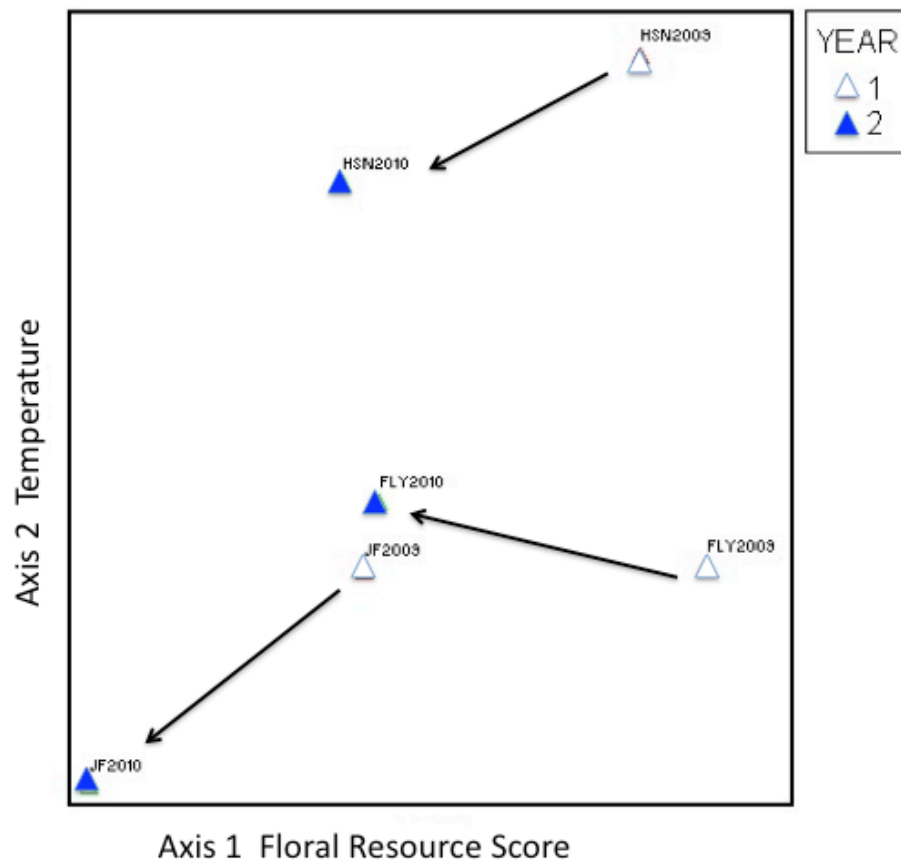


Figure 2.4. Bray-Curtis ordination showing sites by year in 2-dimensional taxa space with highly correlated environmental variables loaded on the axes. Floral resource score is loaded on Axis 1 ($R^2=0.23$) and average temperature is loaded on Axis 2 ($R^2=0.48$); ordination overall $R^2=0.716$. Arrow vectors denote direction of temporal change in community for each site from 2009 to 2010.

Table 2.4. Pearson's R by genus with floral resource score loaded on Axis 1 (FRS) and average temperature loaded on Axis 2 (AVG); strongly correlated at $R \geq 0.50$.

TAXA	Axis 1 FRS	Axis 2 AVG
<i>Andrena</i>	0.199	0.273
<i>Anthophora</i>	0.707	0.114
<i>Apis</i>	0.607	-0.290
<i>Bombus</i>	0.729	-0.114
<i>Ceratina</i>	0.164	0.822
<i>Diadasia</i>	0.069	-0.164
<i>Melissodes</i>	0.318	-0.206
<i>Synhalonia</i>	-0.212	0.536
<i>Hylaeus</i>	0.805	0.014
<i>Agapostemon</i>	0.342	0.954
<i>Lasioglossum</i> (s.str.)	0.524	0.769
<i>Dialictus</i>	0.649	0.849
<i>Evyllaes</i>	0.627	-0.222
<i>Halictus</i>	0.797	0.777
<i>Sphecodes</i>	0.361	0.197
<i>Megachile</i>	0.770	-0.129
<i>Osmia</i>	0.245	0.059

Discussion

Summary

This is the first study to describe the native bee community in these 3 important Willamette Valley wetlands and the relationships between bee diversity and floral resource availability. Observed species richness was comparable to other studies evaluating local bee fauna (Hines and Hendrix 2005, Matteson et al. 2008, Wojcik et al. 2008).

This study shows a correlation between the availability of melittophilous floral resources and the abundance of bees in the wetlands. Romey and Ascher (2007) described similar patterns of increasing bee diversity related to increased availability of forage plants in a recently logged New York forest system. Tuell et al. (2008) confirmed the relationship between bee abundance and floral resources in their study measuring floral area and the associated bee taxa richness, and Hines and Hendrix (2005) demonstrated that bumble bee diversity was positively correlated with floral resources in a grassland system. Other studies have shown that manipulating floral resources to provide and enhance bee forage may increase local populations (Wojcik et al. 2008, Potts et al. 2009).

Our study in the Willamette Valley highlights the potential importance of weed species in native systems with the 15 most frequently occurring plants in floral resource availability including 11 introduced species. These 15 species were the most frequently observed in the field to be visited by bees and to provide considerable,

season-long resources when taken as a whole. The role of invasive plants in managed native systems may in fact increase native bee carrying capacity, as described by Tepedino et al. (2008) with frequent bee visitations to invasive plants species in a national park setting.

Seasonal Progression and Subsequent Years

Higher bee abundance, species richness and floral resources in 2009 compared to 2010 may be explained in part by the difference in annual temperature trends, with 2010 being cooler than 2009, although the difference in accumulated degree days between these years was less than 5%. Pilot sampling conducted at WEW in 2008 produced abundance and richness numbers similar to those seen in 2010, implying that our sampling method without replacement in one year does not significantly alter the following year's results (Bergh, unpublished data). Thus, lower bee abundance and species richness in 2010 may reflect normal annual variability in addition to differences in temperature and availability of floral resources.

Including sample event in the analysis of the measured variables allowed us to account for the effect of time of season, but as such did not have an effect on mean bee abundance. Sample event did have an effect on bee richness, reflecting changing community structure with shifting proportions of early-, mid- and late-season bee species as time progressed through the sampling season. This effect of seasonality on both plant community composition and bee diversity was also observed in the manipulated forage scheme study conducted in northern California where four

seasonal groups of bees were observed: early-, mid-, late-, and full-season bees (Wojcik 2008).

Floral resource availability and bee abundance varied similarly by sample date, particularly in June (sample event #2) when floral resources were low and the fewest bees were collected. Larger sample sizes and additional years of sampling might change the significance levels in the tabulated comparisons, but floral resource availability appears to be the prime driver. Floral resources themselves are affected by many of the same variables that act on bee populations, including the noted difference in temperature; floral phenology is additionally driven by photoperiod.

Small and statistically insignificant negative correlations between temperature and bee abundance and temperature and species richness are mainly due to relatively high collection numbers on the 1st sample event in mid-May of each year when temperatures are cool and bees are relatively abundant.

Effect of Site and Microhabitat

The effect of floral resource availability on bee abundance is supported by the correlating differences seen between sites. WEW and Finley NWR had the highest level of floral resources and also the highest mean number of bees collected, whereas the third site, Jackson Frazier, had significantly lower abundance and diversity. We attribute these differences to site history and adjacent land use. Whereas Finley NWR is an undisturbed relict wetland site and WEW is a restoration site with the last major disturbance dating to approximately 60 years ago, Jackson Frazier has had more recent

large-scale disturbance in the form of a site-wide deep plowing event in the early 1980s. The topography and soil structure at Jackson Frazier are noticeably different than at the other two sites; there are fewer hummocks and bunchgrass mounds and fewer and patchier floral resources. The soil structure may represent a difference in habitat availability, particularly for ground-nesting bees, which utilize these soil mounds for nest and refugia sites. The limited floral resources may reflect this difference in topography or distance in time from the last large-scale disturbance.

Additionally, land use adjacent to Jackson Frazier includes residential development and fields planted to grass seed crops, while the habitat matrices of Finley NWR and WEW include fields planted to bee forage plants such as white clover (*Trifolium repens*) and highbush blueberry (*Vaccinium corymbosum*). This supports the premise that seasonal continuity of heterogeneous and patchy resources can support robust bee populations in a comparable way to the mass bloom of agricultural settings.

Microhabitat did not have a significant effect on bee abundance or species richness, and it appears that bee diversity is driven by factors acting at a larger scale than the microhabitat trap locations. This is somewhat expected as the traps are a visual attractant that can be seen from the air as well as the ground. Because of the patchy nature of floral resources in these 3 wet prairies, the microhabitats were not always immediately adjacent to or enclosed by the site's concentration of floral resources during each sample event. These findings contrast with those of Bartholomew and Prowell (2006) who showed lower bee diversity in a low wetland

compared with upland savanna. In their Louisiana pine system, floral resources were less diverse on the savanna than in the lowland, whereas Willamette Valley wetlands have comparable floral resource availability on wet prairies and oak savannas as shown in the microhabitat comparisons.

Community Response to Floral Resource Score

Members of the families Apidae and Halictidae, with one representative of the Colletidae family, were most strongly correlated with the environmental variables of floral resource score and average temperature. *Anthophora*, *Apis*, *Bombus*, and *Hylaeus* were correlated with floral resource score; *Ceratina*, *Synhalonia*, and *Agapostemon* were correlated with average temperature; and *Lasioglossum* (s.str.), *Lasioglossum* (*Dialictus*), and *Halictus* were correlated with both floral resource score and average temperature. These genera represent the range of sociality in bees, but it is notable that 6 of the 9 genera possess species that are either social or semi-social: *Apis*, *Bombus*, *Agapostemon*, *Lasioglossum* (s.str.), *Lasioglossum* (*Dialictus*), and *Halictus*. Some species of *Ceratina* may also exhibit social behavior (Michener 2007); it is unknown if any of the Pacific Northwest species are social.

Sampling once every three weeks throughout the season will logically produce the greatest effect from social and semi-social bee genera, which presents a challenge to the independence of this and any study that utilizes sampling at the same site over a period of time. This inherent lack of independence in sampling a population over time

is accepted as an unavoidable limitation in ecological studies, and we attempted to separate out the effect with the repeated measures MANOVA.

Conclusion

The ordination model showed that 71% of the variation in community composition could be explained by the combined effect of floral resource site score and average temperature. Because of the observational nature of this study, and because correlation does not equate with causation, the precise degree to which bee abundance could be predicted by floral resource availability is still unclear. Our model takes into account the effect of temperature and the differences in sites by year, but other variables act on bee diversity. Confounding factors may include the availability of acceptable nest sites, short duration weather events such as severe storms and droughts, local disturbance such as pesticide applications and tillage, and also those effects of factors that act on both the population and individual level, such as disease, predation, and competition for resources.

In favorable weather and at sites with adequate habitat, it appears that floral resource availability is a key predictor of local bee abundance, which along with temperature, explains the majority of the variability in bee diversity. This relationship was also observed in the Moron et al. (2008) wet meadow bee diversity study in Poland where even nesting site availability was proposed to be less significant to bee diversity than the availability of floral resources.

This is an important relationship to understand and study more thoroughly, particularly as many native bees are doorstep foragers and are locally limited by both suitable nesting sites and their proximity to food sources. Several weedy, introduced species were key in providing floral resources throughout the season and particularly during periods of patchy native bloom. The reliance of native bee populations on these floral resources should be taken into account by land managers in these and other systems as eradication or weed management activities are designed and implemented. Providing adequate replacement sources of forage for native bees when unwanted plant species are removed may help preserve bee populations on wet prairies and in other native areas during landscape disturbance that could otherwise be detrimental.

Future research should include evaluation of habitat as a predictor of native bee abundance, and include the proposed interaction between nesting habitat and proximity to forage source. The use of GIS analysis would greatly enhance this type of study.

Acknowledgements

This research was funded in part by a United States Bureau of Land Management Cost Share grant with Oregon State University. The author would like to thank Andrew Moldenke and William P. Stephen for assistance with bee identification and taxonomy, Richard Halse for review of botanical identifications, Melissa Scherr for assistance with community analysis, and John Lambrinos for manuscript review.

Chapter 3

Native Bee Diversity and Floral Resource Availability in Three Willamette Valley Blueberry Ecosystems

Abstract

The importance of bee pollinators to agriculture is widely documented, with the majority of work focusing on honey bees. Native bee pollinators are now receiving attention because of their ready availability in a variety of ecosystems and their potential for providing pollination in a climate of uncertainty about the commercial honey bee supply. With the ever-increasing demand for the ecosystem service of crop pollination, some growers are managing their farms to preserve and enhance native bee populations. Blueberries in particular are most efficiently pollinated by native bees, such as *Bombus* species, which forage during the cooler spring temperatures coinciding with crop bloom and provide buzz pollination which efficiently pollinates ericaceous flowers. In this study, 3 Willamette Valley, Oregon highbush blueberry farms were sampled over two years. Focusing on the relationship between bee diversity and post-crop bloom floral resources that provide forage for bees during the spring and summer months, it was determined that bee diversity and floral resource availability were highly correlated, particularly during crop bloom. Analysis of the bee guild revealed 13 species in 7 genera of long-season bees which were present at crop bloom and persisted through the growing season. In light of the relationship between bee abundance and floral resources, this study suggests that the availability of adequate, sequentially blooming bee forage plants can sustain and enhance pollinator populations on blueberry farms and potentially in other agroecosystems.

Keywords: native bees, blueberries, pollination, agroecosystems, floral resources

Introduction

Blueberry growers rely on a combination of bee pollinators to achieve maximum pollination, fruit set and crop yield. Commercial honeybees are thought to be the primary pollinator of blueberries, and wild bumble bees provide an enhancement of this ecosystem service. Bumble bees provide buzz pollination, which shakes pollen out of Ericaceous flowers and has been shown to be a more efficient method of blueberry pollination (Stubbs and Drummond 2001, Javorek et al. 2002). Other bees present in the native assemblage on farms during crop bloom in April and May also contribute significant pollination services (Isaacs and Kirk 2010). With continued concern about colony collapse disorder and decreased availability of honeybees for commercial pollination, several studies have examined the relationship between native bee diversity and mass crop bloom as well as the ecosystem services provided to farms by *in situ* native bees (Kearns et al. 1998, Richards 2001, Kremen et al. 2002). Bees have been shown to respond to the mass bloom of cropping systems, and their natural abundance in agricultural ecosystems carries with it potential for enhancing pollination (Westphal et al. 2003).

Wild bees need two landscape-level resources: forage and nesting habitat. Blueberries provide a high-quality, early season food resource for bees, and because they are a perennial crop, orchards and surrounding areas such as hedgerows may provide stable nesting habitat. High bee abundance is required to provide adequate pollination to crops. In order to sustain season-long robust populations and enhance pollinator populations for demand of blueberry bloom in early spring, we believe

forage availability must extend through the entire growing season from the earliest bee emergences in late winter (e.g., bumble bee queens) until the latest native bees enter diapause for overwintering in early fall (e.g., mated bumble bee females). Because of the relatively short flight range of bees, many of which are small-bodied or are behaviorally doorstep foragers, food sources must also be available locally (Stephen et al. 1969, Cane 2001). Though habitat fragmentation is a significant threat to native bee diversity in most ecosystems, large agricultural patches may meet the majority of the bee community needs (Altieri 1999, Kremen et al. 2004).

There are approximately 6,500-acres of highbush blueberries on small farms in Oregon, which produced 47.2-million pounds of fruit for the fresh, processed, and on-farm sale markets in 2009 (OBC 2010). Farms are managed conventionally or organically with many conventional growers using sustainable land management practices to actively preserve beneficial insects, particularly pollinators. Hedgerows, ornamental plantings and between-row cover crops provide some off-season floral resources on the farms. The surrounding Willamette Valley is a mosaic of ecosystems including riparian and wetland habitats, urban and industrial development, and a wide variety of farms and ranches. There are many transitional ecosystems in the form of wild, preserved native, restored, and managed recreational natural areas between developments; these ecotones can provide a florally-rich and permeable habitat matrix for invertebrates and other wildlife. Floral resources on a large scale are ubiquitous and diverse, but it was not known if the off-season bloom on the farms themselves was adequate to support locally robust, year-round native bee communities.

There are published baseline data about bee diversity and floral resource availability on blueberry farms, but much of this research is focused on the bee guild composition during crop bloom (MacKenzie and Eickwort 1996, Rao et al. 2008, Tuell et al. 2009). The goal of this project was to evaluate the season-long relationships between blueberry farm native bee populations and on-farm resource levels.

The objectives of the study were to describe the biodiversity of the bee fauna in each of the agroecosystems and to determine if bee diversity, particularly abundance, was correlated with the availability of floral resources through the growing season. We hypothesized that bee diversity would be positively correlated with the availability of floral resources. Our premise was that robust season-long bee populations translate to pollination services during crop bloom; thus members of the bee guild that were present during bloom and persisted throughout the growing season were particularly of interest, since they would be most impacted by the availability of floral resources after bloom.

Methods and Materials

Site Descriptions

Three Willamette Valley blueberry farms were selected for the study: from north to south, Farm H in Marion County (44.68N, 122.96W), Farm A in Benton County (44.65N, 123.22W) and Farm W in Benton County (44.49N, 123.26W). Farm H was conventionally farmed in 2009 and began the transition to organic practices for certification in 2010; Farm A is conventionally managed, and Farm W is certified organic. For each site, approximately 10-ha were included in the survey which represented the entirety of Farms A and W, and a subsample of Farm H. Each farm included an on-site residence and was bordered by agriculture, residential development, and roads. Each farm also stocked commercial honeybee colonies in April and May during blueberry bloom. Farm H stocked 8 hives per acre; Farm A stocked 2-3 hives per acre; and Farm W stocked 3-4 hives per acre.

Bee Sampling Method

Bees were collected using unscented blue vane traps which consist of two plastic vanes (10 x15cm) that fit together perpendicularly and snap into a lid. The lid is attached to a 950-mL clear plastic collecting jar (Stephen and Rao 2005). The trap assembly is hung from a stake at a level of 1-m from the ground. Bees are visually drawn to the trap, fly into the vanes, and drop into the collection jars. Prior to sampling initiation, 3 fixed trap locations were selected at each farm site: one trap was

placed within the blueberry rows, one on the last row of the stand, and one in a mixed hedgerow on an outside margin of the farm. Traps were approximately 250-m apart and their locations were static between sampling periods and years.

Sites were monitored between May and September in 2009 and 2010 at approximately 3-week intervals for a total of 6 sampling events per year (May 17, June 3, June 24, July 16, August 13, September 6 in 2009, and May 9, June 3, June 24, July 16, August 6, September 2 in 2010). Sampling dates were shifted as necessary to ensure nominally favorable weather and avoid any effects from large-scale or local field disturbances such as storms, spraying, or harvest.

For each sampling event, the traps were hung for a 48-hour period, then collected and transported to the laboratory where bee specimens were frozen, pinned, sorted and identified. Identifications were made using Hurd and Michener (1955), Stephen (1957), Stephen and Bohart et al. (1969), Roberts (1973*a* and 1973*b*), Michener (2007), and the Oregon State Arthropod Collection. In the absence of regionally reliable keys for some groups, individuals were sorted to morphospecies. Specimens are vouchered in the Rao Native Bee Collection at Oregon State University.

Floral Resource Scoring Method

Prior to beginning the study, an aerial map of each farm site was overlaid with a grid of numbered 100-m² plots. A list of random numbers, with replacement, was generated for each site to provide randomized plot selections for each of the 12

sampling events (6 in each year). At each sampling event, three plots were selected, separated into quadrants, and marked with flags. Each quadrant was walked in a serpentine pattern and the bee-foragable, melittophilous plant species in bloom were recorded. Plants were identified using Kozloff (2005) and Burrill et al. (1996). The quadrants were scored for percentage of area with plants in bloom that could provide forage for bees. Bare ground and plants that were either not in bloom or were in bloom but are not utilized by bees (grasses, sedges, and microflora not observed to be visited by bees, e.g., *Microsotis*) were not included in the score. Floral resource scores were simple percentages of cover of each quadrant in bloom. The scores for all 4 quadrants of each plot were averaged into a single plot score, then the three scores per site were averaged to a site-level floral resource score. This single site floral resource score was the measure used for statistical analyses.

Temperature Measurement Methods

The average temperature over each 48-hour sampling period was calculated from each site's local weather station data (IPPC 2011). The mean temperature was obtained by taking the highs and lows from the 3 calendar dates in which the sample event fell and averaging them into a mean temperature for the event.

Analysis

Bee biodiversity was calculated utilizing the Shannon Diversity Index. Chao1 species richness estimations were calculated to measure theoretical sampling performance. Analyses of the relationships between total bee abundance, species richness, floral resource availability, and average temperature were performed using correlations, multivariate analysis of variance (MANOVA) and least-squares linear regression in SPSS (2010).

Results

Bee Diversity

A total of 764 bees in 5 families, 17 genera and 57 species were collected from the 3 farms between 2009 and 2010 (Table 3.1). Mean number of bees per trap per sampling event was significantly higher in 2009 than in 2010, but there were no significant differences between farm sites (Figure 3.1). Mean bee abundance between sampling events was significantly lower in September when catches were far lower than in the other months ($P=0.03$). Diversity measures by sample event are presented in Table 3.2.

Total abundance and species richness were higher in 2009 with 576 individuals in 45 species compared to 173 individuals in 34 species in 2010 (Appendix C).

Apidae was the most abundant family with 387 individuals in 16 species, including 7 species of *Bombus* Latreille which comprised 28% of the total bee abundance. The European honey bee, *Apis mellifera* L., accounted for 17% of total abundance with their highest numbers in May when commercial hives are present in the field.

Halictidae was the most diverse family with 36 individuals in 27 species and morphospecies. *Halictus* Latreille and *Lasioglossum* (*Dialictus*) Robertson spp. represented 15% each of total bee abundance.

There were 12 genera in 5 families collected in the bee guild present in May of which 9 genera in Apidae and Halictidae persisted through the season: *Apis* L., *Bombus* Latreille, *Ceratina*, Latreille, *Synhalonia* Patton, *Agapostemon* Guérin-

Méneville, *Lasioglossum* (*Dialictus*), *Lasioglossum* (s.str.) Curtis, and *Halictus* Latreille. All of these genera were seen to forage and collect pollen on blueberry flowers during bloom in April and May, and 5 of the 7 *Bombus* spp. present on blueberry farms during the study were present in the May sample events.

Table 3.1. Bee diversity measures of blueberry farms for study years 2009-2010

	Farm H		Farm A		Farm W	
	<u>2009</u>	<u>2010</u>	<u>2009</u>	<u>2010</u>	<u>2009</u>	<u>2010</u>
Total Abundance	136	66	192	100	246	24
Species Richness	28	24	29	28	32	12
Chao1 Richness Estimate	39	53	50	42	64	23
Shannon Diversity	2.67	2.62	2.34	2.98	2.86	2.01
	<u>All Years</u>					
Total Abundance	202		292		270	
Species Richness	41		42		40	
Chao1 Richness Estimate	59		54		61	
Shannon Diversity	2.86		2.85		2.88	

Table 3.2. Bee diversity by sample event for study years 2009-2010

	Sample Event 1		Sample Event 2		Sample Event 3		Sample Event 4		Sample Event 5		Sample Event 6	
	<i>Mid May</i>		<i>Early June</i>		<i>Late June</i>		<i>Mid July</i>		<i>Mid Aug</i>		<i>Early Sept</i>	
	<u>2009</u>	<u>2010</u>	<u>2009</u>	<u>2010</u>	<u>2009</u>	<u>2010</u>	<u>2009</u>	<u>2010</u>	<u>2009</u>	<u>2010</u>	<u>2009</u>	<u>2010</u>
Total Abundance	202	67	103	21	85	44	77	28	97	13	26	N/A
Species Richness	35	15	17	7	16	17	24	16	15	11	8	N/A
Shannon Diversity	3.04	2.27	2.17	1.46	2.09	2.56	2.60	2.65	1.50	2.35	1.62	N/A

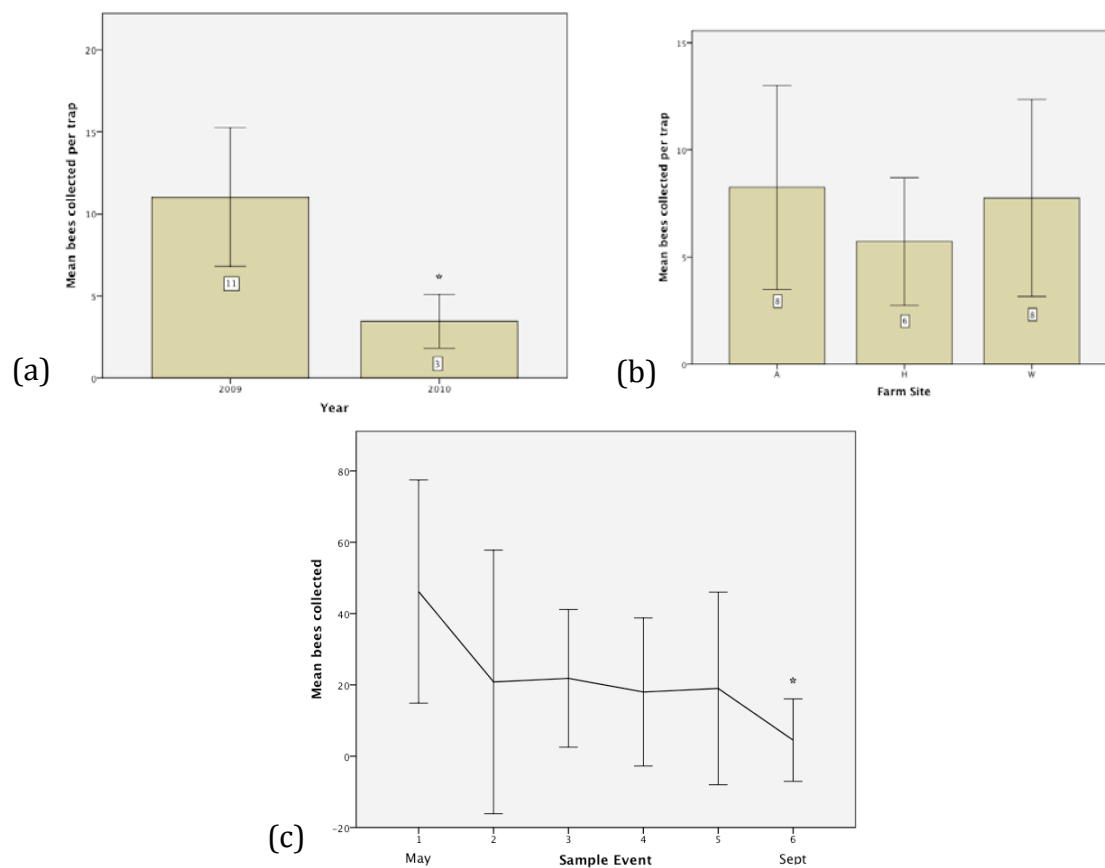


Figure 3.1. Mean bee abundance by (a) study years: 2009 and 2010 ($n=108$, $P=0.001$); (b) farm sites ($n=108$, $P=0.657$); and (c) sample events ($n=36$, $P=0.03$)

Floral Resources

Floral resource scores included 35 melittophilous plant species in 12 families and 31 genera (Appendix D). Plants included the blueberries themselves and 5 other cultivated species and varieties, 8 natives species, and 23 introduced species.

Phenological observations of these floral resources revealed 19 species that appeared in floral resource scores at least 3 times during each of the study years, which represents a bloom period of approximately 2 months (species are designated in the Appendix). Additionally 16 species were identified as providing a “favored” floral resource for bees as evidenced by heavy foraging (Table 3.3).

Mean floral resource site scores were similar from 2009 to 2010 and between sites and sample events (Figure 3.2).

Table 3.3. Plant species providing favored resources for bees as evidenced by heavy foraging; [I] introduced, [C] cultivated, [N] native

Family	Species	Common Name	Bloom
Asteraceae	<i>Centaurea nigrescens</i> ^[I]	Tyrol knapweed	Jun – July
	<i>Cichorium intybus</i> ^[I]	Chicory	Jun – Aug
	<i>Cirsium arvense</i> ^[I]	Canada thistle	Jun – July
	<i>Cirsium vulgare</i> ^[I]	Bull thistle	Jun – Aug
	<i>Hypochaeris radicata</i> ^[I]	Hairy cat's ear	May – Sept
	<i>Tagetes</i> cvs. ^[C]	Marigold	Jun – Aug
Dipsacaceae	<i>Dipsacus fullonum</i> ^[I]	Teasel	Jun – Aug
Ericaceae	<i>Vaccinium corymbosum</i> ^[C]	Highbush blueberry	April – May
Fabaceae	<i>Trifolium pratense</i> ^[I/C]	Red clover	May – Sept
	<i>Trifolium repens</i> ^[I/C]	White clover	Jun – Aug
Lamiaceae	<i>Lavandula angustifolia</i> ^[C]	Lavender	Jun – Aug
	<i>Mentha pulegium</i> ^[I]	Pennyroyal	Jun – Aug
	<i>Prunella vulgaris</i> ^[N]	Common selfheal	Jun – Aug
Rhamnaceae	<i>Ceanothus thyrisiflorus</i> ^[N/C]	Ceanothus	May – Jun
Rosaceae	<i>Rubus armeniacus</i> ^[I]	Himalayan blackberry	Jun – July
	<i>Rubus</i> spp. & cvs. ^[C]	Blackberry & Raspberry	Jun – July

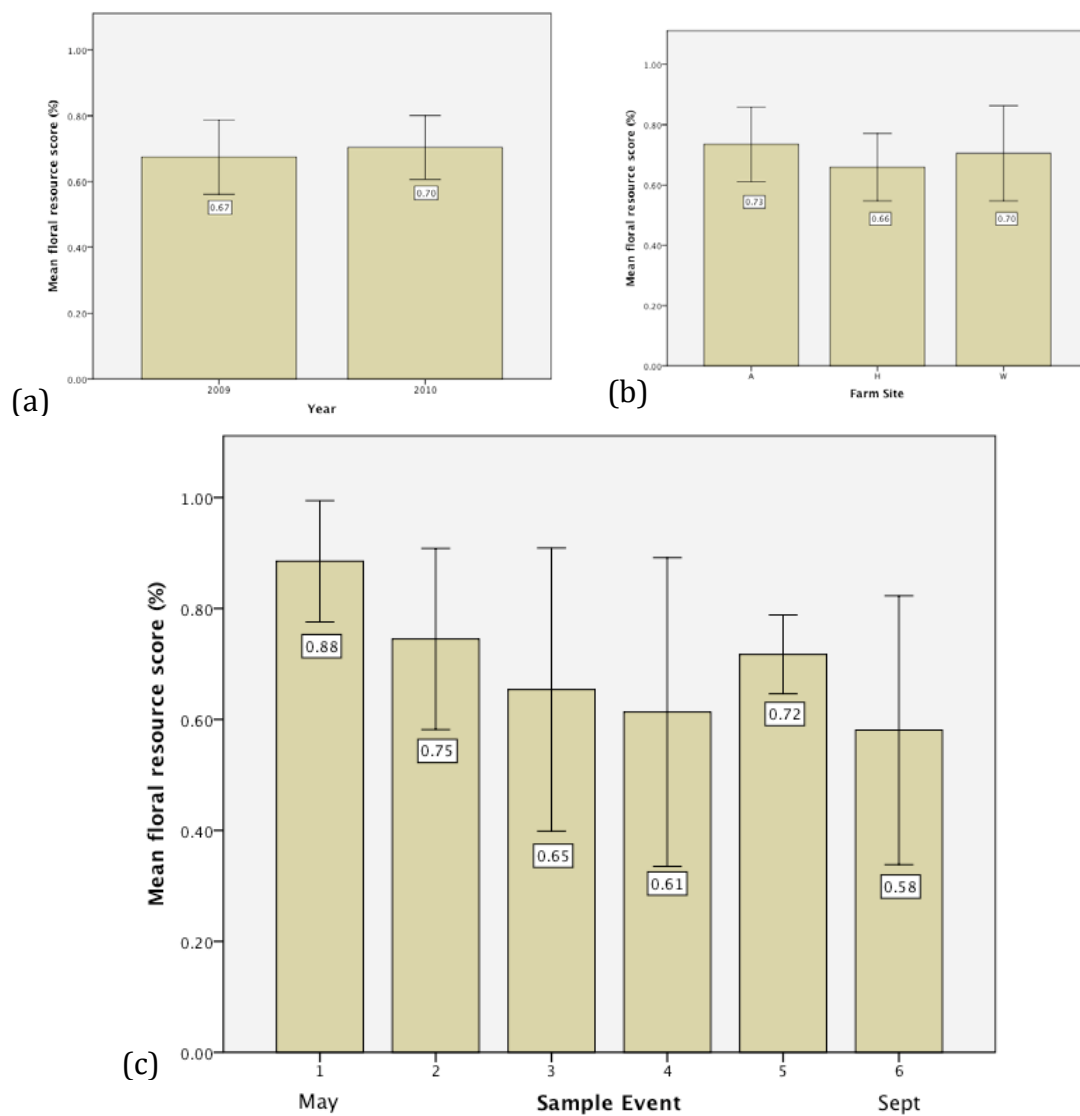


Figure 3.2. Mean floral resource site score by (a) years ($n=36$, $P=0.901$); (b) farm sites ($n=36$, $P=0.673$); and (c) sample events ($n=36$, $P=0.114$)

Temperature

Mean annual temperature trends by 48-hour sample event are presented in Figure 3.3.

There were no statistically significant differences in average temperature by sample event between study years, however May and June were between 5-8°C cooler in 2010 than in 2009.

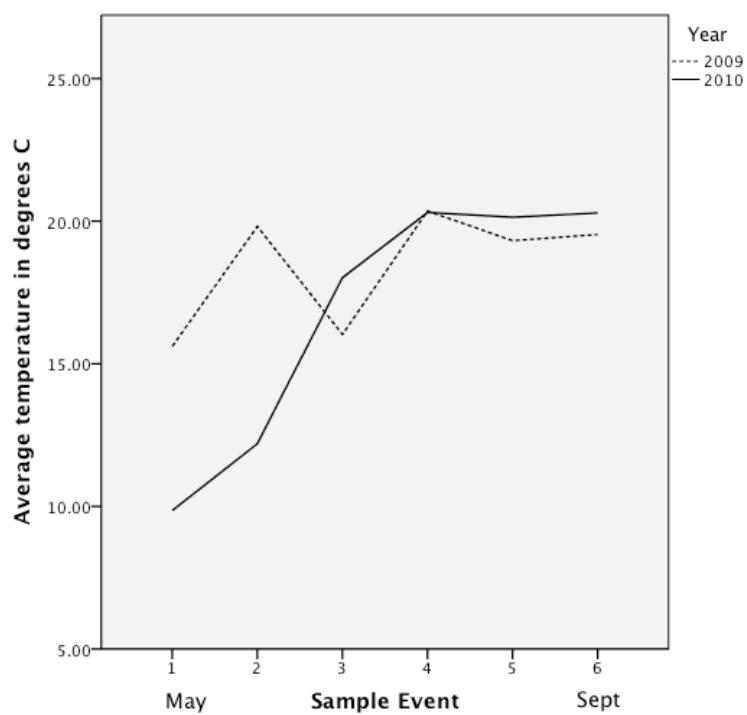


Figure 3.3. Average 48-hour temperature by sampling event for the 2 study years; sites averaged

Effects of Multiple Factors on Bee Diversity

Correlations between bee abundance, species richness, floral resource score and average temperature are presented in Table 3.4.1 and suggest the expected covariance between temperature and sample event. Bee abundance was highly correlated with floral resource score ($R=0.565$, $P=0.000$), as was species richness ($R=0.602$, $P=0.000$).

Multivariate analysis of variance (MANOVA) was used to evaluate the effect of floral resource score, average temperature and farm site on bee abundance and species richness (Table 3.4.2). Floral resource score had a significant effect on both bee diversity measures ($P=0.001$ and $P=0.000$, respectively). The effects of average temperature and site were not statistically significant. MANOVA with repeated measures to evaluate the effect of floral resource score and temperature by sample event confirmed the effect of floral resource score on abundance ($P=0.007$) and richness ($P=0.001$), and the covariance of temperature and sample event on species richness ($P=0.028$, Table 3.4.3). Contrast comparisons of each sample event showed that sample event #1 (May) had an effect on bee abundance ($P=0.006$) and species richness ($P=0.002$); other sample events had no statistically significant effect on either.

Figure 3.4 shows the linear relationship (a) between floral resource score and bee abundance ($R^2=0.36$) and (b) between floral resource score and species richness ($R^2=0.42$).

Table 3.4. (3.4.1) Correlations between bee abundance, species richness, sample event, floral resources, and average temperature; (3.4.2) MANOVA comparisons of abundance and species richness by floral resource score, average temperature, and farm site; and (3.4.3) repeated measures MANOVA comparisons of abundance and richness by sample event; for all analyses, $n=36$, R is significant at $\alpha=0.50$, and P is significant at $\alpha=0.05$.

3.4.1 Correlations		FLORAL RESOURCES	TEMP
ABUNDANCE	Pearson's R	0.565	-0.152
	Sig. (1-tailed)	0.000	0.376
RICHNESS	Pearson's R	0.602	-0.147
	Sig. (1-tailed)	0.000	0.392
SAMPLE EVENT	Pearson's R	-0.397	0.706
	Sig. (1-tailed)	0.017	0.000
3.4.2 Nested MANOVA			
Parameter	Variable	F	P
FLORAL RESOURCES	ABUNDANCE	13.147	0.001
	RICHNESS	16.627	0.000
TEMPERATURE	ABUNDANCE	0.079	0.780
	RICHNESS	0.170	0.683
SITE	ABUNDANCE	0.054	0.947
	RICHNESS	0.056	0.946
3.4.3 MANOVA with Sample Event as a Repeated Measure			
Parameter	Variable	F	P
FLORAL RESOURCES	ABUNDANCE	8.313	0.007
	RICHNESS	13.485	0.001
TEMPERATURE	ABUNDANCE	3.858	0.060
	RICHNESS	5.648	0.025
SAMPLE EVENT	ABUNDANCE	1.506	0.220
	RICHNESS	2.969	0.028

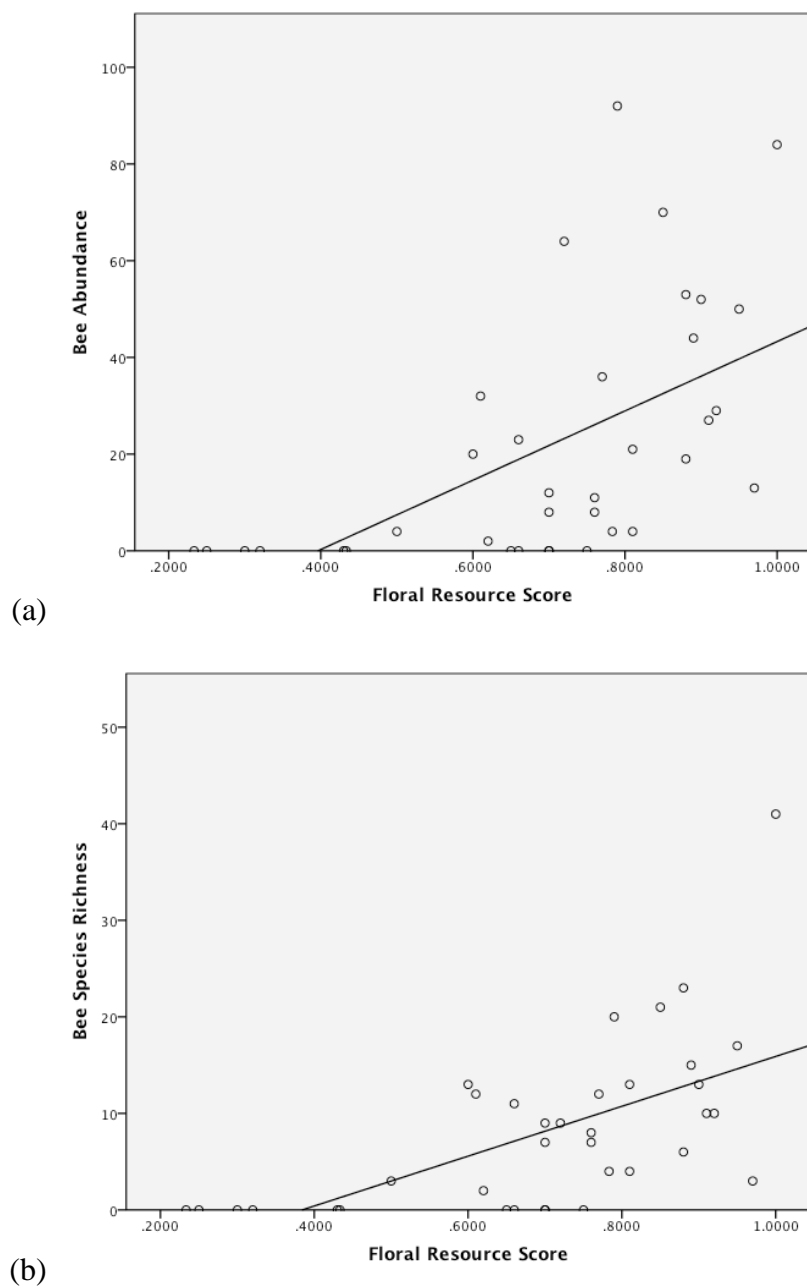


Figure 3.4. Scatter plots of overall bee abundance and species richness by floral resource scores with best fit lines of regression

To characterize these relationships for the period of blueberry bloom, correlations were examined for these measures for the May sample events of each year (sample event #1). In this analysis, the correlation between floral resource score and bee abundance was $R=0.754$ ($P=0.042$), and the correlation between floral resource score and bee species richness was $R=0.775$ ($P=0.035$); the linear relationships are presented in Figure 3.5.

The May bee guild included members from all 5 families in 12 genera and 35 species (Table 3.5). Of these bees, 13 were long-season species, present in samples from May through August or September, including 5 of the 7 total bumble bee species present on the blueberry farms.

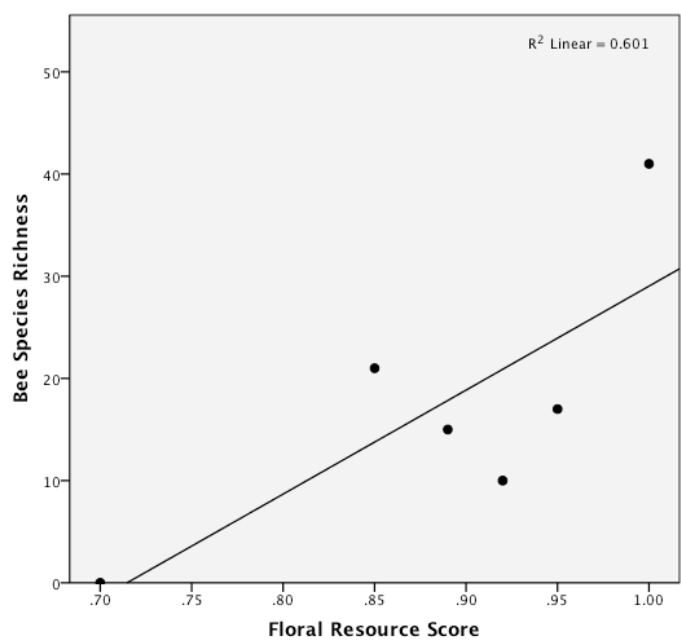
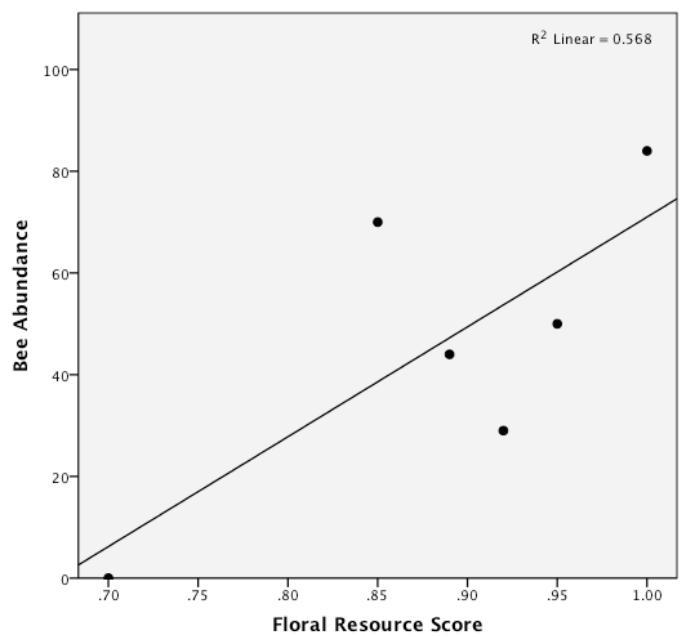


Figure 3.5. Scatter plots of May bee abundance and species richness by floral resource scores with best fit lines of regression

Table 3.5. May bee guild on 3 Willamette Valley blueberry farms, 2009-2010; long-season (May-Aug or May-Sept) bee species in bold; species numbers refer to morphospecies type identification.

Family	Species	Season
Andrenidae	<i>Andrena</i> sp. 2	May only
Apidae	<i>Apis mellifera</i>	May - Sept
	<i>Bombus californicus</i>	May - Sept
	<i>Bombus melanopygus</i>	May - June
	<i>Bombus mixtus</i>	May - Aug
	<i>Bombus nevadensis</i>	May - Aug
	<i>Bombus vosnesenskii</i>	May - Sept
	<i>Ceratina acantha</i>	May - Sept
	<i>Ceratina micheneri</i>	May - June
	<i>Synhalonia edwardsii</i>	May - July
Colletidae	<i>Hylaeus</i> sp. 2	May only
Halictidae	<i>Agapostemon texanus</i>	May - Aug
	<i>Agapostemon virescens</i>	May - Sept
	<i>Lasioglossum (Dialictus)</i> sp. 1A	May - Aug
	<i>Lasioglossum (Dialictus)</i> sp. 1B	May - July
	<i>Lasioglossum (Dialictus)</i> sp. 1C	May - July
	<i>Lasioglossum (Dialictus)</i> sp. 1D	May only
	<i>Lasioglossum (Dialictus)</i> sp. 2A	May - July
	<i>Lasioglossum (Dialictus)</i> sp. 5	May - June
	<i>Lasioglossum (Dialictus)</i> sp. 6	May - July
	<i>Lasioglossum (Dialictus)</i> sp. 8	May only
	<i>Halictus farinosus</i>	May - Aug
	<i>Halictus rubicundus</i>	May - July
	<i>Halictus tripartitus</i>	May - Sept
	<i>Lasioglossum mellipes</i>	May – July
	<i>Lasioglossum olympiae</i>	May – July
	<i>Lasioglossum pacificum</i>	May – Aug
	<i>Lasioglossum pavonotum</i>	May - July
	<i>Lasioglossum trizonatum</i>	May - Aug
	<i>Sphecodes</i> sp. 2	May only
Megachilidae	<i>Osmia</i> sp. 1	May only
	<i>Osmia</i> sp. 3	May only
	<i>Osmia</i> sp. 6	May – July
	<i>Osmia</i> sp. 12	May only
	<i>Osmia</i> sp. 13	May – June

Discussion and Conclusion

Summary

This study shows that bee abundance and species richness are highly correlated with season-long floral resources on these 3 Willamette Valley farms ($R_{\text{Abundance}}=0.565$, $P=0.000$ and ; $R_{\text{Richness}}=0.602$, $P=0.000$). The May bee guild, which coincides with crop bloom, is even more highly correlated with floral resource level than even the season-long community ($R_{\text{Abundance}}=0.754$, $P=0.042$; $R_{\text{Richness}}=0.775$, $P=0.035$).

Species present in the spring community make up 61% of the total taxa present and of these, 37% were long-season bee species that persisted in the field for all or most of the summer. Of the 7 genera of full-season bees, 6 are known to have social or semi-social member species: *Apis*, *Bombus*, *Agapostemon*, *Lasioglossum* (s.str.), *Lasioglossum* (*Dialictus*), and *Halictus*. The social relationships of the seventh genus, *Ceratina*, are uncertain but social behavior has been documented with some tropical species (Michener 2007); the sociality traits of Oregon *Ceratina* species are unknown.

The 57 species and 17 genera collected in this study represent greater diversity compared to previous studies in comparable systems where 23 species in 10 genera were documented (Rao and Stephen 2008). The difference in richness is attributed to the long sampling season utilized in this study, which extended beyond crop bloom into late summer in September. Additionally, 18 specimens of *Bombus griseocollis* were collected in this study, but this species was not collected previously on local blueberry farms (Rao et al. 2009). A native bee diversity study conducted in Michigan

highbush blueberries and including summer sampling had higher diversity than the Willamette Valley farms with 166 species in 30 genera, over half of which were present during crop bloom (Tuell et al. 2009).

There is an early-season mass bloom floral resource available to these bees in the form of the blueberry flowers, and it is the premise of this study that access to sequentially blooming forage plants for the remainder of the season serves to preserve and enhance bee populations for the following year when the crop is again in bloom. To the authors' knowledge, this is the first study to characterize the annual bee guild on these blueberry farms and describe their relationships with floral resources through the growing season.

Effect of Time and Farm Site

Differences in bee abundance between years are attributed to the cooler temperatures in May and early June of 2010, when conditions on all 3 farms were wetter and windier than in the previous year. Although some native bees, particularly *Bombus*, fly at cooler temperatures than do honey bees, there are still fewer in the field during cool, wet, or windy weather (MacKenzie and Averill 1995, Klowden 2007).

Differences between years may also represent some level of normal annual variability of some bee taxa.

Floral resources were less variable than bee abundance in part because the farms manage non-crop bloom in the same ways: during blueberry flowering, potential competition for pollinators in the form of non-crop plants was mitigated with mowing

and hedging to prevent synchronous bloom. After crop flower dehiscence and fruit set, the growers left most weeds in the field and allowed them, along with hedgerows and ornamental plantings, to flower. It is notable that of the 16 identified favored resources for bees in Table 3.3 over half are introduced species.

It was interesting that the analyses showed no statistically significant differences in mean bee abundance or floral resource availability between farms, and this is attributed to similar management methods despite one farm having organic certification, one being conventionally managed, and one in transition. The growers in this study participated, in part, because they were interested in the bee fauna on their farms and were already making management decisions to sustain and enhance their pollinator populations. In this study and in sampling in the Willamette Valley between 2005 and 2009 (Rao and Stephen 2010), the same 7 species of *Bombus* were collected in agricultural fields, and this may reflect somewhat stable community assemblages in blueberry agroecosystems.

As in the previous study on wet prairies, the effect of time as measured by sample event is significant for species richness, reflecting the changing community structure as the season progresses (Chapter 2). Rao et al. (2008) observed an effect on abundance via the interaction between blueberry farm sites and weekly sample events; this difference in findings is attributed to the difference in sampling frequency and duration. Social species and those bees which persist through the majority of the season, as shown in Table 3.5, are a continuous population during the spring and

summer on these blueberry farms, with the community structure changing with population shifts of species which are early-, mid-, or late-season bees.

Community Response to Floral Resource Availability

The relationships illustrated in this study are based on correlations and can therefore not be treated as predictive or causal, but we have shown that floral resource availability describes much of the variation in abundance and species richness of native bees. Regression of the data for the entire sampling season from May to September showed that 36% of bee abundance could be explained by floral resource score and 42% of species richness could be explained by floral resource score. In the regression models for May alone, the period of crop bloom, floral resource score explained 57% of the bee abundance and 60% of species richness. Of note in the May model were 13 species of long-season bees. To the degree that bee populations are limited by available food resources, it's theoretically possible to enhance their numbers by supplementing floral resources and thereby enhancing the pollination services provided by native bees the following spring. Access to forage in the months of August and September is thus critically important to ensure that species which overwinter as mated females have adequate time to mate successfully and accumulate fat stores before the onset of cold temperatures and diapause.

Future research in this area should include landscape analysis to characterize and quantify habitat availability, particularly for species present in the May guild.

This measure may explain a significant amount of the remaining variation in the observed bee abundance and species richness.

Conclusion

Blueberry farms provide a massive resource of melittophilous early-season forage for native bees. Crop bloom roughly coincides with the nest initiation season for long-season bees and short-season, early-emerging bees. Since many native bees are small-bodied doorstep foragers, it is likely that nest initiation takes place in the vicinity of abundant floral resources. Successful efforts to enhance bee populations with supplemental forage could foster high bee abundance, particularly of long-season bees which are present through the spring and summer months. The utilization of existing patches of flowering plants, including weeds, and provision of additional plantings, particularly to provide adequate sequential bloom, may be practical approaches to maximize pollination. The plants which provided “favored” forage resources for bees as described in Table 3.3 might be preserved on site where they exist already (weedy species) and new plantings could be designed with these resources in mind as well as those presented in Appendices B and D.

In addition to habitat fragmentation, which limits both floral resources and nesting habitat for native bees, threats to bee diversity include agricultural intensification, urban and industrial development, pathogens and parasites, and off-target pesticide effects (Goulson 2005, Steffan-Dewenter 2008). Perennially cropped blueberry agroecosystems are potentially stable refuges for native bees, particularly

when they are managed to provide floral resources through the spring and summer months and to minimize detrimental disturbance effects of farm management activities such as plowing and pesticide applications.

Acknowledgements

This research was funded in part by a grant from Western Sustainable Research and Education and the Oregon Blueberry Commission. The author would like to thank William P. Stephen and Andrew Moldenke for their assistance with bee identification and taxonomy.

Chapter 4

Discussion

Review of Findings

Overall native bee abundance was greater in the wetland systems than on the blueberry farms, but species richness between the two site types were similar. Both systems had higher bee diversity in 2009 than in 2010, which was attributed to differences in average temperatures, particularly in spring. As is common in bee diversity studies, Apidae and Halictidae were the dominant families in terms of both abundance and diversity among the 5 families collected. Bumble bee diversity was notable for 7 species representing 21-28% of the total bee abundance: *Bombus appositus*, *B. californicus*, *B. griseocollis*, *B. melanopygus*, *B. mixtus*, *B. nevadensis*, and *B. vosnesenskii*. Also notable was the presence in two wetland sites of a rare oligolectic bee species, *Melissodes pullatella*, which had been observed at West Eugene Wetlands in previous years (Severns and Moldenke 2010) and was collected at both the WEW site and Finley National Wildlife Refuge during the course of this study. This is, to our knowledge, the first record of this species at Finley NWR. Distribution of this member of the Apidae family is not well documented in the Pacific Northwest, and its presence at Finley NWR may be indicative of either an isolated remnant population or recovery.

Though community composition was different between the two site types and each of the wetland sites, Shannon Diversity measures were similar. Given the

proximity of each of the blueberry farms to adjacent wild or managed native areas and the proximity of each of the wetland sites to adjacent agriculture, these similarities are likely a function of permeability in the landscape and access to a variety of nesting and forage resources.

Both studies presented evidence of a positive correlation between bee abundance and floral resource availability. These correlations varied between the ecosystem types but described similar relationships between bees and landscape floral resources. With the similarities in native bee diversity between the two studies, it appears that in the presence of favorable weather conditions, floral resource availability is a prime driver of bee abundance regardless of landscape type.

In the wetland sites, 42 plant species were identified as food sources for bees based on observed foraging. Of these, 15 plants appeared in floral resource scores more than 3 consecutive times per season, which translates to availability in the field of at least 2 months; thus, these plants provide a seasonally stable forage source for native bees in Willamette Valley wetlands. In the blueberries, 35 plant species were included in the floral resource scores providing forage for bees. Of these, 16 species were identified as providing a “treasured” or “favored” resource for bees as evidenced by heavy foraging and frequent bee visits. These species are among those that could be preserved on or added to agricultural sites to enhance floral resource availability after blueberry bloom. Their presence on the farm sites explains why floral resources on blueberry farms were high in spring and similar between sampling events, while seasonal abundance in the wetlands sites was more variable with the highest mean

floral resource scores in mid- to late-summer. Though both sites had weedy introduced species, the overall availability of bloom was less variable on the farms than in the wetlands. The native bee assemblage in both site types most likely also utilized floral resources in the adjacent landscape, which were relatively abundant if heterogeneous.

Management recommendations for enhancing melittophilous floral resources include preservation and supplemental plantings of the favored plant species identified in Chapters 2 and 3. In wet prairie systems, rotational removal of weed species as opposed to total eradication would protect bee forage resources while restoration is underway and before native plants are fully established and blooming. Delay of late summer-early fall activities which remove bloom, such as mowing or burning, may protect resources for late-season bees until they enter diapause. On blueberry farms, preservation and supplementation of flowering edges and hedgerows can provide floral resources for bees before and after crop bloom. Unmowed rows and field margins that contain flowering weed species are another source of bee forage that can be preserved on farm with little expense or effort of the grower.

The different approaches and focus of each of the studies were informed by the interests of the funding agencies which requested and collaborated in the research.

Study Limitations

Inference from these studies was limited by their observational design and non-random site selection. Independence in ecological sampling design that utilizes the

same sites for each sample event is difficult to assert. Floral resource scores may be somewhat independent on the individual level as the scored plots were randomly selected for each sample event and therefore were unaffected by any other sample event or plot, but on the landscape level, floral resource availability at any one time is related to the plant community structure and fecundity of previous weeks, months, and years. Sampling the bee community in 3-week intervals may result in independence with short-lived annual species, but there is a lack of independence with the social and/or long-lived species.

The potential biases of the blue vane trap are unknown, though we may presume as with pan trapping that there is little to no collector bias with this method; passive traps like pan traps are generally accepted as more efficient and unbiased than transect walks and plot observational methods (Westphal et al. 2008). Additionally there may be species not collected in the direct catches which were intended to corroborate the diversity observed in the traps. There are bee taxa which are known to be excluded from pan trap collections (Wilson et al. 2008), thus it may be inferred that there are taxa which are not captured with the blue vane traps. We therefore cannot know which, if any, bee taxa are not represented in the results.

Finally, annual variance is perhaps only partly explained by differences in weather conditions and average temperatures. Bee populations may vary independent of environmental factors for reasons that are unknown. In some sample events, the weather and flora at the time of trap set were suggestive of high bee abundance, but the resulting catches were small and there was no readily apparent explanation for

these low catch sample events. It has been suggested that bees may avoid an area with persistent pesticide residues (Skym unpublished data), but this was determined to be an unlikely explanation in either system where spray applications are preemptively disclosed and affected areas are posted. Whatever the reason or reasons for these periodic decreases in bee abundance, additional sampling years would be beneficial to capture and evaluate the annual variability and better characterize the population dynamics of native bees in these systems.

Conclusion

Statistical results and native bee assemblages in these two ecosystems were broadly similar, which is suggestive of a relatively stable bee population in the Willamette Valley. These studies corroborated previous research suggesting significant positive relationships between bee diversity and floral resource availability in the landscape (Hines and Hendrix 2005, Tependino 2008, Wojcik 2008). These types of studies which document baseline populations are increasingly important in the face of ongoing landscape disturbance in the form of development, conversion, and agricultural intensification. While there is uncertainty about the nature and magnitude of global and local pollinator declines (Steffan-Dewenter 2005), there is a need for tools that will help growers, land managers, and stakeholders to fully evaluate the land management factors that impact biodiversity. Predictive modeling that describes changes in pollinator populations as a function of changing land use would be useful for determining what the effects of large scale disturbances would be on bee and other

invertebrate communities (Kaiser-Bunbury et al. 2010). Additionally, pollinators have been proposed as potential bioindicators (Kevan 1999), and a model that measures changes in bee populations alongside simulated changes in landscape and ecosystem phenology would have widespread application for assessing environmental impacts of climate change (Liang 2009, Hegland et al. 2009). Land use change effects could be evaluated in conjunction with the associated value of the *in situ* ecosystem services (Rouquette 2009), and climate change scenarios could be likewise simulated to predict changes in plant-pollinator interactions, such as phenological decoupling (Hegland et al. 2009).

Future Research

This research would be enhanced by corroborating experimental results. Though a manipulative design would be difficult to achieve at a scale appropriate for inference, it would be valuable to confirm and expand on our findings and create predictive tools for a variety of applications.

The status and distribution of locally vulnerable bee populations such as *Melissodes pullatella* and *Bombus occidentalis* should be determined to inform management and conservation efforts, if appropriate. Both species are rare, and recent observations could represent either remnant populations or recovery (Rao and Stephen 2007, Severns and Moldenke 2010).

Efforts to conserve and enhance native bee populations on wet prairies and in blueberry agroecosystems are undertaken by the individual land managers at their

discretion. The recent recovery plan for Willamette Valley prairies did include invertebrates and rare plants, but did not specifically address native bee monitoring or conservation (USFWS 2010). Agency support for ongoing monitoring and research is needed.

Bibliography

- Altieri, M. A. 1999. The ecological role of biodiversity in agroecosystems. *Agriculture Ecosystems and Environment* 74: 19-31.
- Bartholomew, C.S. and D. Prowell. 2006. Comparison of bee diversity in upland and wet flatwood longleaf pine savannas in Louisiana (Hymenoptera: Apoidea). *Journal of the Kansas Entomological Society* 79: 199-206.
- Burrill, L.C., S.A. Dewey, D.W. Cudney, and B.E. Nelson. 1996. *Weeds of the West*. Western Society of Weed Science, Las Cruces. 630pp.
- Cane, J.H. 2001. Habitat fragmentation and native bees: a premature verdict? *Conservation Ecology* 5(1): 3. [online] URL: <http://www.consecol.org/vol5/iss1/art3/>
- Freitas, B. M., V.L. Imperatriz-Fonseca, L.M. Medina, A.M.P. Kleinert, L. Galetto, G. Nates-Parra et al. 2009. Diversity, threats and conservation of native bees in the Neotropics. *Apidologie* 40(3): 332-346.
- Goulson, D., G.C. Lyle, and B. Darvill. 2008. Decline and conservation of bumble bees. *Annual Review of Entomology* 53: 191-208.
- Goulson, D., M.E. Hanley, B. Darvill, J.S. Ellis, and M.E. Knight. 2005. Causes of rarity in bumblebees. *Biological Conservation* 122: 1-8.
- Greer, L. 1999. Alternative pollinators: native bees. ATTRA Horticultural Technical Note. National Center for Appropriate Technology, Fayetteville. 14 pp.

- Harris, L.F. and S.D. Johnson. 2004. The consequences of habitat fragmentation for plant-pollinator mutualisms. *International Journal of Tropical Insect Science* 24: 29-43.
- Hegland, S.J., A. Nielsen, A. Lazaro, A. Bjerknes, and O. Totland. 2009. How does climate warming affect plant-pollinator interactions? *Ecology Letters* 2009: 184-195.
- Hines, H.M. and S.D. Hendrix. 2005. Bumble bee (Hymenoptera: Apidae) diversity and abundance in tallgrass prairie patches: effects of local and landscape floral resources. *Environmental Entomology* 34: 1477-1484.
- Hurd, P.D. and C.D. Michener. 1955. *Bulletin of the California Insect Survey: The Megachiline Bees of California (Hymenoptera: Megachilidae). Volume 3.* University of California Press, Berkeley. 247pp.
- IPPC: USPest.org. Accessed 01/02/2011. Integrated Plant Protection Center; Oregon State University. [online] URL: <http://uspest.org/OR/indexMETAR.html>
- Isaacs, R. and A.K. Kirk. 2010. Pollination services provided to small and large highbush blueberry fields by wild and managed bees. *Journal of Applied Ecology* 47(4): 841-849.
- Javorek, S.K., K.E. MacKenzie, and S.P. Vander Kloet. 2002. Comparative pollination effectiveness among bees (Hymenoptera: Apidae) on lowbush blueberry (Ericaceae: *Vaccinium angustifolium*).
- Kaiser-Bunbury C.N., S. Muff, J. Memmott, C.B. Muller, and A. Caflisch. 2010. The robustness of pollination networks to the loss of species and interactions: a

quantitative approach incorporating pollinator behaviour. *Ecology Letters* 13: 442-452.

Kearns, C., D.W. Inouye, and N.M. Waser. 1998. Endangered mutualisms: the conservation of plant-pollinator interactions. *Annu. Rev. Ecol. Evol. Syst* 29: 83-112.

Kevan, P.G. 1999. Pollinators as bioindicators of the state of the environment: species, activity, and diversity. *Agriculture, Ecosystems, and Environment* 74: 373-393.

Klowden, M.J. 2007. *Physiological Systems in Insects*. Second edition. Academic Press: Burlington, MA. 415 pp.

Kluser, S., P. Neumann, M.P. Chauzat, and J.S. Pettis. 2010. Global honey bee colony collapse disorders and other threats to insect pollinators. United Nations Environmental Program, Nairobi. 12 pp.

Kozloff, E.N. 2005. *Plants of Western Oregon, Washington & British Columbia*. Timber Press, Portland. 608pp.

Kremen, C., N.M. Williams, and R.W. Thorp. 2002. Crop pollination from native bees at risk from agricultural intensification. *PNAS* 99(26): 16812-16816.

Kremen, C., N.M. Williams, R.L. Bugg, J.P. Fay, and R.W. Thorp. 2004. The area requirements of an ecosystem service: crop pollination by native bee communities in California. *Ecology Letters* 7: 1109-1119.

- Liang, L. and M.D. Schwartz. 2009. Landscape phenology: an integrative approach to seasonal vegetation dynamics. *Landscape Ecology* 24: 465-472.
- MacKenzie, K.E. and A.L. Averill. 1995. Bee (Hymenoptera: Apoidea) diversity and abundance on cranberry in southeastern Massachusetts. *Annals of the Entomological Society of America* 88(3): 334-348.
- MacKenzie, K.E. and G.C. Eickwort. 1996. Diversity and abundance of bees (Hymenoptera: Apidae) foraging on highbush blueberry (*Vaccinium corymbosum* L.) in central New York. *Journal of the Kansas Entomological Society* 69(4): 185-194.
- Matteson, K. C., J.S. Ascher, and G.A. Langellotto. 2008. Bee richness and abundance in New York City urban gardens. *Annals of the Entomological Society of America* 101(1): 140-150.
- McCune, B. and J.B. Grace. 2002. *Analysis of Ecological Communities*. MjM Software Design, Gleneden Beach. 300pp.
- McCune, B. and M. J. Mefford. 2008. *PC-ORD. Multivariate Analysis of Ecological Data*. Version 5.0. MjM Software Design, Gleneden Beach, Oregon.
- Michener, C.D. 2007. *The Bees of the World*. Second edition. The Johns Hopkins University Press, Baltimore. 992 pp.
- Mitsch, W. J., and J.G. Gosselink. 2000. *Wetlands*. 3rd ed. John Wiley & Sons, Inc, New York. 920 pp.

- Moron, D., H. Szentgyorgyi, M. Wantuch, W. Celary, C. Westphal, J. Settele, and M. Woyciechowski. 2008. Diversity of wild bees in wet meadows: implications for conservation. *Wetlands* 28: 975-983.
- Oregon Blueberry Commission (OBC). 2010. 2010 Oregon Blueberry Industry Facts at a Glance. [online] URL: <http://www.oregonblueberry.com/facts.html>
- Potts, S.G., B. Vulliamy, A. Dafni, G. Ne'eman, and P. Willmer. 2003. Linking bees and flowers: how do floral communities structure pollinator communities? *Ecology* 84: 2628-2642.
- Potts, S.G., B.A. Woodcock, S.P.M. Roberts, T. Tscheulin, E.S. Pilgrim, V.K. Brown, and J.R. Tallowin. 2009. Enhancing pollinator biodiversity in intensive grasslands. *Journal of Applied Ecology* 46: 369-379.
- Rao, S. and W.P. Stephen. 2007. *Bombus* (*Bombus*) *occidentalis* (Hymenoptera: Apiformes): in decline or recovery? *The Pan-Pacific Entomologist* 83: 360-362.
- Rao, S. and W.P. Stephen. 2010. Abundance and diversity of native bumblebees associated with agricultural crops: The Willamette Valley Experience. *Psyche* 2010: 9 pages. [online] URL: <http://www.hindawi.com/journals/psyche/2010/354072.html>
- Rao, S., W.P. Stephen, and J.E. Bergh. 2008. Comparison of red clover pollination by commercial and native bees in seed production fields in the Willamette Valley. *Seed Production Research at Oregon State University* 127: 59-61.

- Rao, S., W.P. Stephen, and L. White. 2009. Native bee pollinator diversity in Oregon blueberries. *ISHS Acta Hort.* 810: 539-548.
- Richards, A. J. 2001. Does low biodiversity resulting from modern agricultural practice affect crop pollination and yield? *Annals of Botany* 88: 165-172.
- Roberts, R.B. 1973. Bees of northwestern America: *Agapostemon* (Hymenoptera: Halictidae). Agricultural Experiment Station, Oregon State University, Corvallis.
- Roberts, R.B. 1973. Bees of northwestern America: *Halictus* (Hymenoptera: Halictidae). Agricultural Experiment Station, Oregon State University, Corvallis.
- Romey, W.L., J.S. Ascher, D.A. Powell, and M. Yanek. 2007. Impacts of logging on midsummer diversity of native bees (Apoidea) in a Northern hardwood forest. *Journal of the Kansas Entomological Society* 80: 327-338.
- Rouquette, J.R., H. Posthumus, D.J.G. Gowing, G. Tucker, Q.L. Dawson, T.M. Hess, and J. Morris. 2009. Valuing nature-conservation interests on agricultural floodplains. *Journal of Applied Ecology* 46: 289-296.
- Severns, P. and A. Moldenke. 2010. Management tradeoffs between focal species and biodiversity: endemic plant conservation and solitary bee extinction. *Biodiversity and Conservation* 19(12): 3605-3609.
- SPSS for Mac, Release 19.0.0. 2010. Chicago: SPSS Inc.

- Steffan-Dewenter, I. and C. Westphal. 2008. The interplay of pollinator diversity, pollination services and landscape change. *Journal of Applied Ecology* 45: 737-741.
- Steffan-Dewenter, I., S.G. Potts, and L. Packer. 2005. Pollinator diversity and crop pollination services are at risk. *Trends in Ecology and Evolution* 20(12): 651-652.
- Stephen, W.P. 1957. Bumble Bees of Western America (Hymenoptera: Apoidea). AES-OSU Publication, Technical Bulletin 40.
- Stephen, W.P. and S. Rao. 2005. Unscented color traps for non-*Apis* bees (Hymenoptera: Apiformes). *Journal of the Kansas Entomological Society* 78(4): 373-380.
- Stephen, W.P., G.E. Bohart, and P.F. Torchio. 1969. The biology and external morphology of bees; with a synopsis of the genera of northwestern America. Agricultural Experiment Station, Oregon State University, Corvallis.
- Stubbs, C.S. and F.A. Drummond. 2001. *Bombus impatiens* (Hymenoptera: Apidae): an alternative to *Apis mellifera* (Hymenoptera: Apidae) for lowbush blueberry pollination. *Journal of Economic Entomology* 94(3): 609-618.
- Tepedino, V.J., B.A. Bradley, and T.L. Griswold. 2008. Might flowers of invasive plants increase native bee carrying capacity? Intimations from Capitol Reef National Park, Utah. *Natural Areas Journal* 28: 44-50.

- Tuell, J. K., J.S. Ascher, and R. Isaacs. 2009. Wild bees (Hymenoptera: Apoidea: Anthophila) of Michigan highbush blueberry agroecosystem. *Annals of the Entomological Society of America* 102(2): 275-287.
- Tuell, J.K., A.K. Fiedler, D.A. Landis, and R. Isaacs. 2008. Visitation by wild and managed bees (Hymenoptera: Apoidea) to Eastern U.S. native plants for use in conservation programs. *Environmental Entomology* 37: 707-718.
- United States Environmental Protection Agency (EPA). 2004. Wetlands Overview. Accessed 10/12/2008. [online] URL: <http://www.epa.gov/owow/wetlands/pdf/overview.pdf>
- United States Fish and Wildlife Service (USFWS). 2010. Recovery plan or the prairie species of Western Oregon and Southwestern Washington. 255 pp. [online] URL: <http://www.fws.gov/oregonfwo/Species/PrairieSpecies/Documents/PrairieSpeciesFinalRecoveryPlan.pdf>
- West Eugene Wetlands (WEW). 2009. West Eugene Wetlands Education Center Website. Accessed 10/12/2008. [online] URL: <http://www.wewetlands.org/>
- Westphal, C., I. Steffan-Dewenter, and T. Tscharntke. 2003. Mass flowering crops enhance pollinator densities at a landscape scale. *Ecology Letters* 6: 961-965.
- Westphal, C., R. Bommarco, G. Carre, E. Lamborn, N. Morison, T. Petanidou, S.G. Potts, S.P.M. Roberts, H. Szentgyorgyi, T. Tscheulin, B.E. Vaissiere, M. Wojciechowski, J.C. Biesmeijer, W.E. Kunin, J. Settele, and I. Steffan-Dewenter. 2008. Measuring bee diversity in different European habitats and biogeographical regions. *Ecological Monographs* 78: 653-671.

Wilson, J.S., T. Griswold, and O.J. Messinger. 2008. Sampling bee communities (Hymenoptera: Apiformes) in a Desert Landscape: are pan traps sufficient? *Journal of the Kansas Entomological Society* 81(3): 288-300.

Wojcik, V.A., G.W. Frankie, R.W. Thorp, and J.L. Hernandez. 2008. Seasonality in bees and their floral resource plants at a constructed urban bee habitat in Berkeley, California. *Journal of the Kansas Entomological Society* 81: 15-28.

APPENDIX A

Appendix A. Bee species of three Willamette Valley wetland sites, 2009-2010

Species/Morphospecies	Nesting Habitat	Pollen Specificity	Finley NWR		West Eugene Wetlands		Jackson Frazier	
			2009	2010	2009	2010	2009	2010
Andrenidae								
<i>Andrena</i> Fabricius								
<i>Andrena nigrocaerulea</i> Cockerell	S	P			1			
<i>Andrena</i> sp. 1	S	unk	2					
<i>Andrena</i> sp. 2	S	unk					2	
<i>Andrena</i> sp. 4	S	unk	1		1			
<i>Andrena</i> sp. 5	S	unk			1		1	
Apidae								
<i>Anthophora</i> Latreille								
<i>Anthophora bomboidea stanfordiana</i> Cockerell	S	P	1		1		1	
<i>Anthophora</i> spp.	S	P	1					
<i>Apis mellifera</i> Linnaeus*	C	P	128	40	8	12	26	9
<i>Bombus appositus</i> Cresson	C	P	12	4	8	4	6	5
<i>Bombus californicus</i> Smith	C	P	22	6	6	18	8	2
<i>Bombus griseocollis</i> (Degeer)	C	P	72	4	20	2	2	
<i>Bombus melanopygus</i> Nylander	C	P			1			
<i>Bombus mixtus</i> Cresson	C	P	2	2	3		2	
<i>Bombus nevadensis</i> Cresson	C	P			2	1	1	
<i>Bombus vosnesenskii</i> Radoszkowski	C	P	60	1	5	3	42	4
<i>Ceratina acantha</i> Provancher	P	P	2		8	14		
<i>Ceratina micheneri</i> Daly	P	P			4			
<i>Ceratina nanula</i> Cockerell	P	P			1			
<i>Ceratina tejonensis</i> Cresson	P	P			1			
<i>Diadasia nigrifrons</i> (Cresson)	S	O	2	8				
<i>Melissodes lupina</i> Cresson	S	P	2				1	
<i>Melissodes metenuea</i> Cockerell	S	P	39	4	4		12	4
<i>Melissodes microsticta</i> Cockerell	S	P					1	
<i>Melissodes pallidesignata</i> Cockerell	S	P	1				6	3
<i>Melissodes pullatella</i> LaBerge	S	P			2		2	
<i>Melissodes rivalis</i> Cresson	S	P	2		3	7	10	
<i>Melissodes robustior</i> Cockerell	S	P	1				2	
<i>Synhalonia edwardsii</i> (Cresson)	S	P			5	5	4	
Colletidae								
<i>Hylaeus</i> Fabricius								
<i>Hylaeus</i> sp. 1	P/C	P			1		1	
<i>Hylaeus</i> sp. 3	P/C	P	1					
<i>Hylaeus</i> sp. 4	P/C	P	1					
Halictidae								
<i>Agapostemon texanus</i> Cresson	S	P	1	1	13	7	1	
<i>Agapostemon virescens</i> Fabricius	S	P	13	14	124	112	1	1
<i>Lasioglossum (Dialictus)</i> Robertson								
<i>Lasioglossum (Dialictus)</i> sp. 1A ⁽¹⁾	S	unk	12	1	18	3		
<i>Lasioglossum (Dialictus)</i> sp. 1B ⁽¹⁾	S	unk	4	1	6	1		
<i>Lasioglossum (Dialictus)</i> sp. 1C ⁽¹⁾	S	unk	2		8	4		
<i>Lasioglossum (Dialictus)</i> sp. 1D ⁽¹⁾	S	unk			1			
<i>Lasioglossum (Dialictus)</i> sp. 2A	S	unk	1		2	3	1	
<i>Lasioglossum (Dialictus)</i> sp. 3A	S	unk	1		18	10		
<i>Lasioglossum (Dialictus)</i> sp. 5	S	unk	2		1			
<i>Lasioglossum (Dialictus)</i> sp. 8	S	unk	3		13	2		
<i>Lasioglossum (Dialictus)</i> sp. M1 ⁽²⁾	S	unk			2			
<i>Lasioglossum (Dialictus)</i> sp. M2 ⁽²⁾	S	unk			1			
<i>Lasioglossum (Dialictus)</i> sp. M3 ⁽²⁾	S	unk	1				1	
<i>Lasioglossum (Evylaeus)</i> Robertson								
<i>Lasioglossum (Evylaeus)</i> sp.	S	unk	3					

Species/Morphospecies	Nesting Habitat	Pollen Specificity	Finley NWR		West Eugene Wetlands		Jackson Frazier	
			2009	2010	2009	2010	2009	2010
<i>Lasioglossum (Evylaeus) sp.</i>	S	unk	3					
<i>Halictus farinosus</i> Smith	S	P	33	15	82	27	2	2
<i>Halictus ligatus</i> Say	S	P	2		1			
<i>Halictus rubicundus</i> (Christ)	S	P	6	1	7	10	2	
<i>Halictus tripartitus</i> Cockerell	S	P	13	8	1		1	
<i>Lasioglossum mellipes</i> (Crawford)	S	P	2		10	3	4	
<i>Lasioglossum olympiae</i> (Cockerell)	S	P	6	4	4	3	6	
<i>Lasioglossum pacificum</i> (Cockerell)	S	P	3	5	45	7	2	
<i>Lasioglossum pavonotum</i> (Cockerell)	S	P	1		11	1		
<i>Lasioglossum sisymbrium</i> (Cockerell)	S	P	2		6	2		
<i>Lasioglossum titusi</i> (Crawford)	S	P			6	9	1	
<i>Lasioglossum trizonatum</i> (Cresson)	S	P	6	1	5	2	2	
<i>Sphecodes</i> Latreille								
<i>Sphecodes</i> sp. 1	S	CP			2			
<i>Sphecodes</i> sp. 3	S	CP	1					
<i>Sphecodes</i> sp. 4	S	CP	1					
Megachilidae								
<i>Megachile brevis</i> Say	S/C	P	1		1			
<i>Megachile melanophaea</i> Smith	S/C	O					1	
<i>Megachile pascoensis</i> Mitchell	S	O	1		1			
<i>Megachile perihirta</i> Cockerell	S/C	P	4	3			1	
<i>Osmia coloradensis</i> Cresson	C	P			1			
<i>Osmia</i> Panzer								
<i>Osmia</i> sp. 1	S/P/C	unk	10	26	4	4	1	
<i>Osmia</i> sp. 3	S/P/C	unk			1			
<i>Osmia</i> sp. 5	S/P/C	unk	1		1		1	
<i>Osmia</i> sp. 6	S/P/C	unk	1					
<i>Osmia</i> sp. 11	S/P/C	unk			1			
Total			489	149	483	276	158	30

Morphospecies numbers were assigned based on all bees collected in the Willamette Valley of Oregon between 2008 and 2010; numbers are therefore not consecutive and refer to the type specimen in the reference collection vouchered at Oregon State University.

⁽¹⁾ *Dialictus* morphospecies separated here, but number series may represent a single species with variable phenotype

⁽²⁾ *Dialictus* sp. M1/M2/M3 (males) not matched to female morphospecies in the absence of a reliable key

Nesting habitat: S=soil, C=cavity, P=pith; Pollen Specificity: O=oligolectic, P=polylectic, CP=cleptoparasitic

APPENDIX B

Appendix B. Plant species included in floral resource scores in three Willamette Valley wetland sites, 2009-2010

Plant Taxa	Family	Native or Introduced	May	June	July	August	September
<i>Achillea millefolium</i> L.	Asteraceae	N			X	X	X
<i>Brodiaea elegans</i> Hoover	Liliaceae	N	X	X			
<i>Camassia quamash</i> (Pursh) Greene	Liliaceae	N	X	X			
<i>Centaurea nigrescens</i> ¹ Willd.	Asteraceae	I			X	X	
<i>Cirsium arvense</i>¹ (L.) Scop.	Asteraceae	I		X	X		
<i>Cirsium vulgare</i>¹ (Savi) Ten.	Asteraceae	I		X	X	X	
<i>Clarkia purpurea</i> (W. Curtis) A. Nelson & J.F. Macbr.	Onagraceae	N		X	X		
<i>Crataegus douglasii</i> Lindl.	Rosaceae	N	X	X			
<i>Daucus carota</i> L.	Apiaceae	I			X	X	X
<i>Dipsacus fullonum</i> L.	Dipsacaceae	I			X	X	
<i>Epilobium densiflorum</i> (Lindley) Hoch & Raven	Onagraceae	N			X	X	
<i>Eriophyllum lanatum</i> (Pursh) Forbes	Asteraceae	N		X	X		
<i>Grindelia integrifolia</i> DC.	Asteraceae	N	X	X			
<i>Heracleum lanatum</i> Michx.	Apiaceae	N			X	X	
<i>Hypochaeris radicata</i> L.	Asteraceae	I	X	X	X	X	X
<i>Lathyrus latifolius</i> L.	Fabaceae	I			X	X	X
<i>Leucanthemum vulgare</i> Lam.	Asteraceae	I	X	X	X	X	
<i>Lomatium nudicaule</i> (Pursh) J.M. Coult. & Rose	Apiaceae	N	X				
<i>Lotus corniculatus</i> L.	Fabaceae	I	X	X	X		
<i>Lotus formosissimus</i> Greene	Fabaceae	N	X	X	X		
<i>Madia sativa</i> Molina	Asteraceae	N			X	X	
<i>Medicago lupulina</i> L.	Fabaceae	I		X	X		
<i>Mentha pulegium</i> L.	Lamiaceae	I		X	X	X	
<i>Microseris laciniata</i> (Hook.) Sch. Bip.	Asteraceae	N	X	X			
<i>Parentucellia viscosa</i> (L.) Caruel	Scrophulariaceae	I		X	X	X	X
<i>Plagiobothrys figuratus</i> (Piper) I.M. Johnst. ex M. Peck	Boraginaceae	N		X	X		
<i>Potentilla gracilis</i> Douglas ex Hook.	Rosaceae	N		X	X		
<i>Prunella vulgaris</i> L.	Lamiaceae	N		X	X	X	X
<i>Ranunculus occidentalis</i> Nutt.	Ranunculaceae	N	X	X			
<i>Rosa woodsii</i> Lindl.	Rosaceae	N	X	X	X	X	
<i>Rubus armeniacus</i> ¹ Focke	Rosaceae	I		X	X		

Plant Taxa	Family	Native or Introduced	May	June	July	August	September
<i>Sidalcea campestris</i> Greene	Malvaceae	N			X	X	
<i>Sidalcea nelsoniana</i> ² Piper	Malvaceae	N			X	X	
<i>Sisyrinchium idahoense</i> E.P. Bicknell	Iridaceae	N			X	X	
<i>Spiraea douglasii</i> Hook.	Rosaceae	N			X	X	
<i>Symphotrichum hallii</i> (A. Gray) G.L. Nesom	Asteraceae	N			X	X	
<i>Tanacetum vulgare</i> L.	Asteraceae	I			X	X	X
<i>Taraxacum officinale</i> F.H. Wigg.	Asteraceae	N		X	X		X
<i>Tragopogon porrifolius</i> L.	Asteraceae	I		X	X		
<i>Trifolium repens</i> L.	Fabaceae	I	X	X		X	X
<i>Vicia sativa</i> L.	Fabaceae	I		X	X	X	
<i>Zigadenus venenosus</i> S. Watson	Liliaceae	N	X				

Species in **bold** were included in floral resource scores >3 times/year.

⁽¹⁾ Oregon Department of Agriculture "B" designated weed; quarantine

⁽²⁾ Oregon protected status; threatened

Legend: N=native; I=introduced

APPENDIX C

Appendix C. Bee species of three Willamette Valley blueberry farms, 2009-2010

Species/Morphospecies	Nesting Habitat	Pollen Specificity	Anderson - Farm A		Helms - Farm B		Wilt - Farm C	
			2009	2010	2009	2010	2009	2010
Andrenidae								
<i>Andrena</i> Fabricius								
<i>Andrena</i> sp. 2	S	unk			1			
Apidae								
<i>Anthophora bomboides stanfordiana</i> Cockerell	S	P		2				
<i>Apis mellifera</i> Linnaeus*	C	P	4	4	41	25	41	9
<i>Bombus appositus</i> Cresson	C	P		3	1	1	2	
<i>Bombus californicus</i> Smith	C	P	6	3	2	1	13	1
<i>Bombus griseocollis</i> (Degeer)	C	P	16			1	1	
<i>Bombus melanopygus</i> Nylander	C	P		7			1	
<i>Bombus mixtus</i> Cresson	C	P	3	1	6	2	4	
<i>Bombus nevadensis</i> Cresson	C	P	3				1	
<i>Bombus vosnesenskii</i> Radoszkowski	C	P	90	3	21		16	3
<i>Ceratina acantha</i> Provancher	P	P	1		6	3	1	1
<i>Ceratina micheneri</i> Daly	P	P			3			
<i>Melissodes metenua</i> Cockerell	S	P	1	1		1	1	1
<i>Melissodes pallidisignata</i> Cockerell	S	P		2				
<i>Melissodes rivalis</i> Cresson	S	P	1		2	3		1
<i>Melissodes robustior</i> Cockerell	S	P	1	2	6		1	
<i>Synhalonia edwardsii</i> (Cresson)	S	P	2	1	4	3		
Colletidae								
<i>Hylaeus</i> Fabricius								
<i>Hylaeus</i> sp. 2	P/C	P			1			
Halictidae								
<i>Agapostemon texanus</i> Cresson	S	P	4	5	3	2	1	
<i>Agapostemon virescens</i> Fabricius	S	P	9	11	5		12	
<i>Lasioglossum (Dialictus)</i> Robertson								
<i>Lasioglossum (Dialictus)</i> sp. 1A ⁽¹⁾	S	unk	1	12		3	30	2
<i>Lasioglossum (Dialictus)</i> sp. 1B ⁽¹⁾	S	unk		10		1	4	1
<i>Lasioglossum (Dialictus)</i> sp. 1C ⁽¹⁾	S	unk	2	3		1	15	
<i>Lasioglossum (Dialictus)</i> sp. 1D ⁽¹⁾	S	unk					1	
<i>Lasioglossum (Dialictus)</i> sp. 2A	S	unk			2	1	6	
<i>Lasioglossum (Dialictus)</i> sp. 4A	S	unk				1		
<i>Lasioglossum (Dialictus)</i> sp. 5	S	unk	1		1		7	
<i>Lasioglossum (Dialictus)</i> sp. 6	S	unk		1	1	1	1	
<i>Lasioglossum (Dialictus)</i> sp. 7	S	unk	1	1			1	1
<i>Lasioglossum (Dialictus)</i> sp. 8	S	unk					1	
<i>Lasioglossum (Evylaeus)</i> Robertson								
<i>Lasioglossum (Evylaeus)</i> sp.	S	unk	1					
<i>Halictus farinosus</i> Smith	S	P	18	3	5	2	4	
<i>Halictus rubicundus</i> (Christ)	S	P	2		1	5	2	1
<i>Halictus tripartitus</i> Cockerell	S	P	6	14	5	2	44	
<i>Lasioglossum mellipes</i> (Crawford)	S	P	3	1	1	3	2	
<i>Lasioglossum olympiae</i> (Cockerell)	S	P			1		1	
<i>Lasioglossum pacificum</i> (Cockerell)	S	P	3	1	1	1	9	2
<i>Lasioglossum pavonotum</i> (Cockerell)	S	P	3	1		1	4	
<i>Lasioglossum sisymbrium</i> (Cockerell)	S	P	3	1		1		
<i>Lasioglossum titusi</i> (Crawford)	S	P						1
<i>Lasioglossum trizonatum</i> (Cresson)	S	P	3	4		1	17	
<i>Sphecodes</i> Latreille								
<i>Sphecodes</i> sp. 2	S	CP	1					

Species/Morphospecies	Nesting Habitat	Pollen Specificity	Anderson - Farm A		Helms - Farm B		Wilt - Farm C	
			2009	2010	2009	2010	2009	2010
<i>Sphecodes</i> sp. 3	S	CP		1				
Megachilidae								
<i>Heriades cressoni</i> Michener	S/C	P			2			
<i>Megachile perihirta</i> Cockerell	S/C	P	2					
<i>Osmia</i> Panzer								
<i>Osmia</i> sp. 1	S/P/C	unk	1					
<i>Osmia</i> sp. 2	S/P/C	unk		1				
<i>Osmia</i> sp. 3	S/P/C	unk			10		1	
<i>Osmia</i> sp. 6	S/P/C	unk			2		1	
<i>Osmia</i> sp. 12	S/P/C	unk			1			
<i>Osmia</i> sp. 13	S/P/C	unk		1	1			
Total			192	100	136	66	246	24

Morphospecies numbers were assigned based on all bees collected in the Willamette Valley of Oregon between 2008 and 2010; numbers are therefore not consecutive and refer to the type specimen in the reference collection vouchered at Oregon State University.

⁽¹⁾ *Dialictus* morphospecies separated here, but number series may represent a single species with variable phenotype

Nesting habitat: S=soil, C=cavity, P=pith; Pollen Specificity: O=oligolectic, P=polylectic, CP=cleptoparasitic

APPENDIX D

Appendix D. Plant species included in floral resource scores on three Willamette Valley blueberry farms, 2009-2010

Plant Taxa	Family	Native, Introduced or Cultivated	Sample Event 2 Early Jun	Sample Event 3 Late Jun	Sample Event 4 Mid Jul	Sample Event 5 Mid Aug	Sample Event 6 Early Sep
<i>Achillea millefolium</i> L.	Asteraceae	N		x	x	x	x
<i>Anthemis cotula</i> L.	Asteraceae	I	x	x			
<i>Bellis perennis</i> L.	Asteraceae	I	x	x	x		
<i>Brassica rapa</i> L.	Brassicaceae	I	x				
<i>Ceanothus thyrsiflorus</i> Eschsch.	Rhamnaceae	N/C	x				
<i>Centaurea nigrescens</i> ¹ Willd.	Asteraceae	I		x	x		
<i>Cichorium intybus</i> L.	Asteraceae	I		x	x	x	
<i>Cirsium arvense</i> ¹ (L.) Scop.	Asteraceae	I	x	x			
<i>Cirsium vulgare</i>¹ (Savi) Ten.	Asteraceae	I	x	x	x		
<i>Cornus sericea</i> L.	Cornaceae	N/C	x				
<i>Daucus carota</i> L.	Apiaceae	I		x	x	x	
<i>Dipsacus fullonum</i> L.	Dipsacaceae	I		x	x		
<i>Heracleum lanatum</i> Michx.	Apiaceae	N		x	x		
<i>Hypochaeris radicata</i> L.	Asteraceae	I	x	x	x	x	x
<i>Lavandula angustifolia</i> Mill.	Lamiaceae	C	x	x	x	x	
<i>Leucanthemum vulgare</i> Lam.	Asteraceae	I	x	x	x		
<i>Lotus corniculatus</i> L.	Fabaceae	I	x	x			
<i>Malva neglecta</i> Wallr.	Malvaceae	I	x	x			
<i>Matricaria discoidea</i> DC.	Asteraceae	I	x	x	x	x	
<i>Medicago lupulina</i> L.	Fabaceae	I	x	x			
<i>Mentha pulegium</i> L.	Lamiaceae	I	x	x	x		
<i>Microseris laciniata</i> (Hook.) Sch. Bip.	Asteraceae	N	x				
<i>Plagiobothrys figuratus</i> (Piper) I.M. Johnst. ex M. Peck	Boraginaceae	N	x	x			
<i>Prunella vulgaris</i> L.	Lamiaceae	N	x	x	x	x	
<i>Rosa</i> L. cultivated varieties	Rosaceae	C	x	x	x	x	
<i>Rubus armeniacus</i> ¹ Focke	Rosaceae	I	x	x			
<i>Rubus</i> L. cultivated varieties	Rosaceae	C	x	x			
<i>Tagetes</i> L.	Asteraceae	C		x	x	x	
<i>Taraxacum officinale</i> F.H. Wigg.	Asteraceae	N	x	x		x	
<i>Tragopogon porrifolius</i> L.	Asteraceae	I	x	x			
<i>Trifolium arvense</i> L.	Fabaceae	I	x	x	x		
<i>Trifolium pratense</i> L.	Fabaceae	I		x	x		
<i>Trifolium repens</i> L.	Fabaceae	I	x		x	x	
<i>Vaccinium corymbosum</i> L.	Ericaceae	I	x				
<i>Vicia sativa</i> L.	Fabaceae	I	x	x	x		

⁽¹⁾ Oregon Department of Agriculture "B" designated weed; quarantine⁽²⁾ Oregon protected status; threatenedPlant taxa in **bold type** represent species observed in greater than 3 sample events in either or both years

