2016 PENN STATE HYMENOPTERA POLLINATOR SURVEY

STATE GAME LANDS (SGL) 33
CENTRE COUNTY, PENNSYLVANIA



Prepared by Hannah L. Stout, Ph.D.

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Attention: Carolyn Mahan, Ph.D.
Professor of Biology & Environmental Studies
The Pennsylvania State University

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PROJECT REPORT

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1.0 INTRODUCTION

1.1. Background

<u>POLLINATORS</u>

"Pollinators" is a broad category of animals that includes insects (e.g. ants, bees, beetles, true bugs, butterflies, flies, moths, wasps), some mammals (e.g. bats), birds, and even reptiles. Perhaps the most iconic and prolific pollinators are bees. Bees pollinate ~75% of the fruits, nuts and vegetables that are grown in the United States (Moisset and Buchmann 2015).

Bees belong to the insect Order Hymenoptera, which also includes wasps, hornets and ants. "Bees" refers to insects of six Families of Hymenoptera:

1. **Andrenidae** (mining bees)
2. **Apidae** (cuckoo bees, carpenter bees, bumble bees, and *Apis mellifera*, the European honey bee)
3. **Colletidae** (plasterer bees, masked bees, yellow-faced bees)
4. **Halictidae** (sweat bees)
5. **Megachilidae** (leaf-cutter bees, mason bees)
6. **Melittidae** (oil-collecting bees)

There are approximately 4000 species of bees in North America, and at least 371 species of bees in Pennsylvania (Donovall and vanEngelsdorp 2010). One of these species is *A. mellifera*, the European honey bee. Hives of *A. mellifera* were brought to North America in the 1600s by European colonists, to provide settlers with honey and wax, and to help pollinate their introduced crops. In the 400 years since their introduction, *A. mellifera* continues to be the workhorse of large-scale agroecosystems, but a combination of internal and external factors have weakened their numbers, diminishing their reliability. With observed declines in *A. mellifera* populations at the forefront of headlines for the last decade, conservation of their populations became a worldwide priority.

More importantly, efforts are being made to decrease the overreliance on one bee species for pollination services, by increasing public awareness of the ecological importance of native bees. Park et al surveyed New York orchards, and found that native bees far outnumbered *A. mellifera* (2010). The "blue orchard bee", *Osmia lignaria*, is thought to be a more efficient pollinator of West Coast orchard crops than *A. mellifera* (Park et al 2010, Wilson and Messinger Carril 2016). In a study of native bee diversity in Georgia apple orchards, Schlueter and Stewart identified an abundant and locally-common species of mining bee (*Andrena crataegi*) as being an exceptional candidate for use in orchard apple production in that part of the state (2015).

There are a number of threats to native bee diversity—loss or fragmentation of habitat, pathogens, pesticide use, etc. Introduced species of plants can overtake a landscape and yet be incompatible or even inaccessible to native bees. Introduced bees (including the esteemed *A. mellifera*) can outcompete native bees for resources. The non-native giant resin bee (*Megachile sculpturalis*) is an aggressive leaf-cutter bee that is known to attack the native Eastern carpenter bee (*Xylocopa virginica*) and seize their nests (Roulston and Malfi 2012).

With diminished populations of native bees, native plant communities are at risk of losing their best pollinators. The eastern cucurbit bee (*Peponapis pruinosa*) collects pollen only from squash blossoms, and unlike many bees, is most active in the very early morning hours, when squash flowers are open. Later in the day, when most bees are active, squash flowers are closed. Similarly, for night-blooming flowers such as evening primroses, there are nocturnal bees that visit them (e.g. *Lasioglossum texanum*).

HYMENOPTERA SURVEYS

The first step in conserving a native bee community is to determine the bee species that comprise its populations. Hymenoptera surveys are a means of taking an inventory of native bee diversity. There are two main methods of collecting bees: active (using aerial nets) and passive (using bowl traps). Each method has their pros and cons. With aerial netting, all Hymenoptera-like insects seen on flowers are collected, because some bees resemble other types of Hymenoptera, such as wasps (*Fig. 1*), and because some insects of other Orders mimic bees and wasps (*Fig. 2*). A greater number of bees can be netted in a shorter amount of time, but a great number of non-bee insects are netted as well. The large number of netted specimens can significantly increase the time spent processing samples and identifying specimens. Also, netting requires collectors to handle live bees, wasps and biting flies.

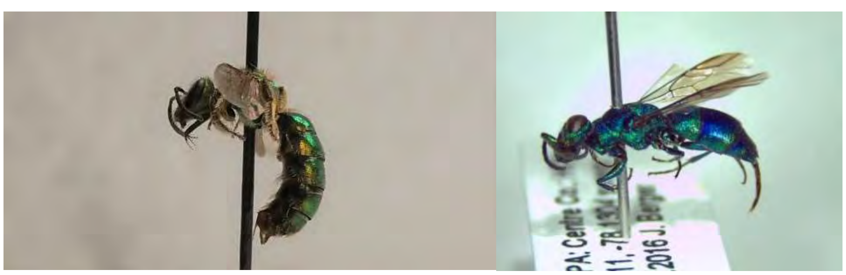


Figure 1. Left: sweat bee (Augochlorella aurata). Right: cuckoo wasp (Chrysis nitidula). Photos: H. Stout.

Figure 2. Bee and wasps mimics. Top: robber fly (Laphria sp.). Bottom: thick-headed fly (Physocephala sp.). Photos: H. Stout.

With bowl trapping, an array of colored bowls (usually blue, yellow and/or white) filled with a killing medium is placed in an open, vegetated area. Bees and other insects are attracted to the colored bowls and fall into the medium, and the dead specimens are collected after 8 to 24 hours. Using "bee bowls", it is possible to collect a smaller, but more diverse assemblage of bee species; however, unattended bowls are vulnerable to damage, and there are additional steps to processing the samples, such as carefully washing and drying the specimens. Fewer specimens may also quash the ability to perform valid statistical tests or to calculate diversity indices.

THE NAROW PROJECT: STATE GAME LANDS # 33 (SGL33)

The North American Rights-of-Way (NAROW) Research and Demonstration Project at SGL33 began in 1953, as a means of demonstrating the value of selective herbicide application to concerned hunters. Sixty-four years later, Penn State University's research at this site in central Pennsylvania continues to examine the effects of herbicides and other vegetation management practices on plant and animal communities.

Previous studies at SGL33 have examined the diversity of plants, mammals, birds, reptiles, amphibians, and butterflies that inhabit the treatment sites. With government, industry, and society increasingly focused on the conservation of pollinators and their habitats, it became clear to the Project Director and Sponsors that little is known about how different vegetation management methods used at power line rights-of-way affect our honey and native bee populations. In 2016, the first known survey of the Hymenoptera of SGL33 began.

1.2. Project Goals and Objectives

PROJECT GOALS

To survey Hymenoptera at SGL33, and then compare the diversity of bees among six different vegetative treatment types.

PROJECT OBJECTIVES

To examine the potential differences in bee diversity among different vegetative treatments, and to provide the Project's stakeholders with an analysis of bee density and diversity at SGL33, that will assist in making management recommendations for the future.

2.0 METHODS

2.1. Field Procedures

Bee surveys are performed when plants are flowering, on dry, warm, and windless days, and between the hours of 10 am and 4 pm. These conditions are when most bees will be actively foraging for nectar and pollen.

2.1.1. Field Collection – Sweep Nets

In order to collect bees during the peak periods of flowering activity, the 2016 field season at SGL33 began on 24 May 2016, and ended on 16 August 2016.

2.1.1.1. 2016 Sampling Schedule

24 May - 16 Aug 2016 (13 weeks)

4 Sample Periods
WEEK 1: 24 - 25 May
*WEEK 6: 28 - 29 June, 1 July
WEEK 10: 26 - 27 July
WEEK 13: 15 - 16 August

***29 June cancelled due to adverse weather conditions**

2.1.1.2. Survey Sites

To examine the potential differences in bee diversity among different vegetative treatments at SGL33, one site of each treatment type was selected. Sites were selected based on ease of access, to reduce the amount of hiking while carrying collecting equipment. There were six sites surveyed in 2016, all of which were located in Rush Township, Centre County, Pennsylvania:

HYDRAULIC FOLIAR (“**HY FOL**”)

Vegetative treatment: hydraulic equipment delivers a high-volume application of a water-based broad-leaf herbicide to leaves.
Approximate location: 350m NW of Hannah Furnace Road (*Fig. 3*)
Approximate center of survey site: 40.859819 -78.152086

Figure 3. Northwest view at "Hy Fol" site. Photo: D. Roberts.

STEM FOLIAR (“**STEM FOL**”)

Vegetative treatment: nozzle applicator selectively applies an ultra-low volume of an oil-based, broad-leaf herbicide to leaves.
Approximate location: 125m NW of Hannah Furnace Road (*Fig. 4*)
Approximate center of survey site: 40.858278 -78.150319

Figure 4. Northeast view at "Stem Fol" site. Photo: D. Roberts.

MOW (“**MOW**”)

Vegetative treatment: mechanical mowing and mulching of vegetation, without herbicide application.
Approximate location: 75m SE of Hannah Furnace Road (*Fig. 5*)
Approximate center of survey site: 40.856878 -78.148756

Figure 5. South view at "Mow" site. Photo: D. Roberts.

MOW WITH TREATMENT (“**MOW W/TX**”)

Vegetative treatment: mechanical mowing of vegetation, followed by an application of an oil-based herbicide to woody cuttings.
Approximate location: 175m NW of Strawband Beaver Road (*Fig. 6*)
Approximate center of survey site: 40.843722 -78.133597

Figure 6. Northwest view at "Mow w/ Tx" site. Photo: D. Roberts.

BASAL LOW VOLUME (“**BLV**”)

Vegetative treatment: low volume application of an oil-based herbicide to the root collar and trunk of shrubs and small trees.
Approximate location: 60m SE of Strawband Beaver Road (*Fig. 7*)
Approximate center of survey site: 40.842265, -78.131853

Figure 7. Southeast view at "BLV" site. Photo: D. Roberts.

HAND CUT (“**HAND**”)

Vegetative treatment: targeted cutting of woody vegetation, without herbicide application.
Approximate location: 205m SE of Strawband Beaver Road (*Fig. 8*)
Approximate center of survey site: 40.841131 -78.130544

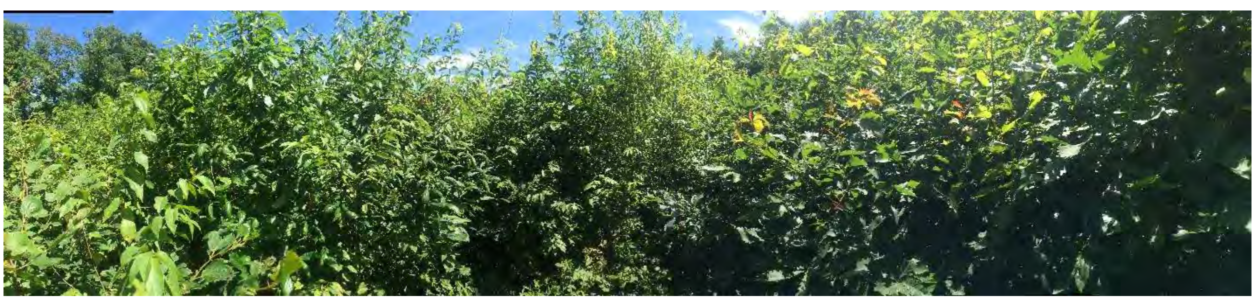


Figure 8. Undefined view of "Hand" site. Photo: D. Roberts.

Maps of the 2016 SGL33 Hymenoptera diversity survey sites are located in **Appendix A: Site Maps**.

2.1.1.3. Delineation of Active Collection Areas

On the first day of the field season, an active collection area of approximately 50m length by 25m width was delineated at each of the six survey sites. From the approximate center of the survey site, 25m was measured in either lengthwise direction, and 12.5m in either widthwise direction, and then flagging was attached at these points. The site number was written on the flagging, and the GPS coordinates of each corner were recorded. Flagging was left in place until the last field day of the season, therefore delineation needed to be done only once. On the last day of the field season, the active collection area flagging was removed from each site.

2.1.1.4. Kill Jars and Sample Jars

Upon arrival at the first site of each field day, each collector prepped "kill jars" and sample jars.

"Kill jars" are wide-mouthed glass jars of various sizes used to kill and temporarily store field-collected invertebrates. A layer of plaster on the bottom of the jar provides a porous medium for a volatile killing agent (such as potassium cyanide crystals or ethyl acetate). Depending on the collector's preference, kill jars were "charged" either with cyanide, or with a cosmetic cotton round partially dampened with ethyl acetate. Kill jars were "recharged" throughout the day, as needed.

Each survey site required one to two sample jars. The following information was written on a sticky label and attach to the outer side of each sample jar:

- **Survey site number**
- **Date**

Once finished at each site, kill jars were emptied into the sample jar labeled for that site.

2.1.1.5. Field Data Sheets

For each collection day in the field, each survey site had its own dedicated field data sheet. Upon arriving at the survey site, collectors filled out most of the field sheet: survey site number, initials, date, time of day, temperature, and general weather conditions (e.g. "mostly sunny", "slight breeze"). Collectors walked the site, noting predominant ground cover and the types and names of flowering vegetation. Photos were taken of the site and of the flowering vegetation. Animal tracks, signs or sightings were also recorded on the field data sheets.

The Field Data Sheet used in the 2016 SGL33 Hymenoptera diversity survey is located in **Appendix B: Field Form**.

2.1.1.6. Sweep Net Collection

Hymenoptera surveys were conducted for two consecutive days per month, for four months (May -August 2016). To account for potential bias caused by sampling in the morning vs. in the afternoon, the order of visiting sites alternated between the two monthly collection dates. For example:

24 May 2016: AM - sites 123. PM - sites 456
25 May 2016: AM - sites 456. PM - sites 123

The six survey sites were situated consecutively along the ROW, allowing for collectors to rotate between one set of three sites in the morning, and one set of the other three sites in the afternoon.

On each field day, each collector used aerial nets and aspirators to collect Hymenoptera (or suspected Hymenoptera) from flowering vegetation within the 50m x 25m active collection area at each of the survey sites (*Fig. 9*) (*Fig. 10*) (*Fig. 11*).

Figure 9. Mining bee (Andrena sp.) on Prunus. Photo: L. Russo.

Figure 10. Nomad bee (Nomada sp.) on Wild Strawberry. Photo: L. Russo.

Figure 11. B. Ross collecting Hymenoptera at SGL 33. Photo: K. Engstrom.

As some bees resemble other types of Hymenoptera, and some other insects mimic bees, all Hymenoptera-like insects seen on flowers were collected. After collecting from one survey area, collectors rotated to the next survey area.

For each field day, **one net hour** was spent at each of the six survey sites. "Net hours" are the total amount of time spent sweep net sampling at one site by all collectors (e.g. one collector netting at one site for one hour = two collectors netting at one site for 30 minutes. For the 2016 field season, a total of eight net hours were spent at each of the survey sites—four hours of morning collections, and four hours of afternoon collections.

2.1.1.7. End of Day

At the end of the day, the labeled sample jars and the field data forms from each of the sites were stored in plastic 3.8L zip-lock bags labeled with Site Name and Date Collected.

Upon returning from the field, field forms were removed from the zip-lock bags and scanned. All scanned forms and field photos were uploaded to an internet-based storage site ("Box") that was accessible to all collectors.

Specimens were not processed within 24 hours, therefore the labeled plastic zip-lock bags containing the labeled sample jars were stored in a freezer until the day of processing. Specimens were stored for approximately 2 to 4 months.

2.1.1.8. Quality Control Measures for the Field

Before leaving each survey site, collectors removed any trash or personal items, checked the field data sheets for completeness, and made sure all kill jars were emptied into the correct labeled sample jars. Before leaving the last site of the day, collectors ensured that the labeled sample jars were in the corresponding labeled plastic zip-lock bag with the corresponding field data forms.

2.1.2. Field Collection – Bowl Traps

Because Bowl Trap sampling using blue, yellow and white bowls has been found to be an effective means of surveying Hymenoptera diversity (Campbell and Harula 2007, Donovall and vanEngelsdorp 2010, Grundel et al 2011, Joshi et al 2015, Popic et al 2013, Roulston et al 2007), a "test run" of bowl-trapping was designed and conducted by Dr. Hannah Stout during the 2016 field season.

2.1.2.1. Sampling Schedule

Bowl trap sampling took place for one 24-hour period, from July 26 to July 27, 2016. Specifically, bowl traps were set in the late morning of July 26, 2016, and were retrieved at around noon on July 27, 2016.

2.1.2.2. Survey Site

The site selected for the Bowl Trap survey was located at 40.851261 -78.142213 , the approximate halfway point between Sites 1 and 6. The Bowl Trap survey site was located along Old Rt. 322, 1.1km from its intersection with Hannah Furnace Road, Rush Township, Centre County, PA (*Fig. 12*)(**Appendix A: Site Maps**).

Figure 12. Bowl Trap Survey Site. Southeast corner, Northwest view. Photo: H. Stout.

The Bowl Trap survey site was not located within an experimental vegetative treatment site, but was bordered by a Stem Foliar treatment site to the Northwest, and by a Hand Cut treatment site to the Southeast.

2.1.2.3. Delineation of Active Collection Area

Upon arrival at the Bowl Trap survey site, Dr. Stout measured and flagged a 30m x 25m plot for the placement of the bowl traps.

2.1.2.4. Bowl Traps

Within the 30m x 25m plot, six rows of six alternating blue, yellow and white disposable 350mL plastic bowls were placed approximately 4m apart. A total of 36 bowls were placed at the site (*Fig. 13*).

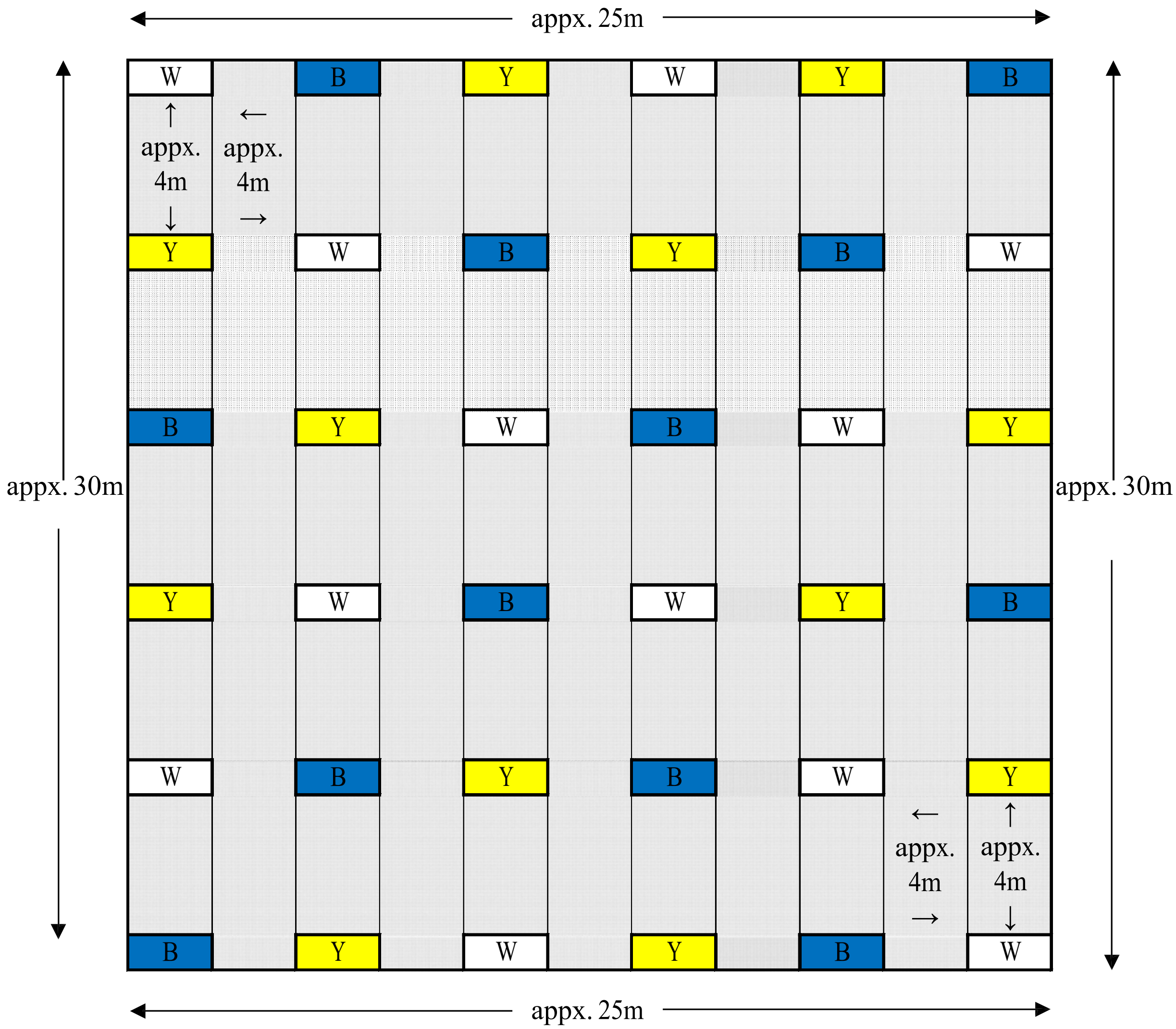


*Figure 13. Bowl Trap Schematic. *note: not to scale**

As each Bowl Trap was placed, approximately 300mL of a solution of water and unscented clear dish soap was added to each bowl.

2.1.2.5. Field Data

As with the Sweep Net surveys, date, time of day, temperature, and general weather conditions at the start and end of the Bowl Trap survey were recorded. Dr. Stout walked the site, noting predominant ground cover and the types and names of flowering and non-flowering vegetation present (*Fig. 14*). Photos were taken of the site and of the flowering vegetation. Animal tracks, signs or sightings were also recorded.

Figure 14. American Witchhazel (Hamamelis virginiana), an important late-season source of nectar and pollen. Photo: H. Stout.

2.1.2.6. Bowl Trap Collection

After 24 hours, Dr. Stout returned to collected the specimens from the bowl traps. Bowls were emptied and then rinsed into one of three labeled 3.07L plastic containers, one for each bowl color. To ensure that all bowls were collected, their position on a diagram was marked as they were emptied.

Before leaving the bowl trap collection site, Dr. Stout walked the perimeter and removed the flagging.

2.1.2.7. End of Day

Upon returning from the field, all field information and field photos were uploaded to an internet-based storage site ("Box") that was accessible to all collectors.

Specimens collected in bowl traps were strained from the soap and water solution, and then added to vials filled with 70% ethyl alcohol. Vials containing bowl trap samples were stored in a cool, dark and secure location until processed.

2.2. Lab Procedures

All sample processing, sample sorting, and specimen identification were performed by three entomologists (Dana Roberts, Dr. Laura Russo, and Dr. Stout) and two assistants (John Berger and Brad Ross), from September 19, 2016 to February 14, 2017. Sample processing and sorting were performed in Room 102 of the Headhouse III building, on the University Park campus of the Pennsylvania State University. Identification of specimens was performed at Room 102, or at various off-site locations (see **2.2.5 Specimen Identification**).

2.2.1. Sweep Net Sample Processing

Each sweep net sample was removed from the freezer approximately 30 minutes before processing. Once ready, the contents of each sample jar were emptied onto plain white paper. Plant or mineral objects in the sample were discarded. Using standard methods, larger insect specimens were pinned through the thorax, while smaller specimens were glued to paper points (*Fig. 15*).

Figure 15. Pinned and pointed specimens. Photo: H. Stout.

Two labels were then added to each specimen. The first was a Site Label (Site name, Site location information, and name of Collector), and the second was an Identifier Label (randomly assigned Specimen Number and corresponding QR Code).

Specimens from each sample were then placed into trays labeled with the site number, collection date, and time of day (AM or PM).

2.2.2. Bowl Trap Sample Processing

Bowl trap sample specimens were washed and dried according to the methods recommended by Dr. Sam Droege (Instructions available at: **http://bio2.elmira.edu/fieldbio/beemanual.pdf** . Video demonstrations available at **https://www.youtube.com/user/swdroege/videos**). After bowl trap sample specimens were washed and manually dried, they were placed in labeled sample jars, and then frozen for at least 24 hours before pinning/pointing and labeling (using the same methods as with the sweep net sample specimens).

2.2.3. Database Creation

Before specimens could be sorted and identified, an xls file named BEE SPECS was created. The BEE SPECS file had 56 separate worksheets: each time of day for each date and for each site, or for each color of bowl trap (e.g. “Site1PM25May16”, “Blue Bowl Traps”). To Column A of each worksheet, the final five digits of the specimen numbers for all of the specimens collected at that time/date/site were added. Then, data from the Site Labels were entered into Columns B through I (e.g. columns labeled Site Number, Time of Day, Month). Columns J through R were labeled for later identification (e.g. “Species”, “Identifier”, “Common Name”).

To merge the data into a usable file, a second xls file named BEE MERGE was created. The BEE MERGE file had three separate worksheets: one for Sweep Net Sites, one for Bowl Trap Sites, and one for Miscellaneous (for specimens collected at SGL33, but not as part of the diversity survey. Miscellaneous specimens were not included in the study). The 48 Sweep Net worksheets from BEE SPECS were merged into the BEE MERGE’s Sweep Net Site worksheet, and the three Bowl Trap worksheets from BEE SPECS were merged into the Bowl Trap Site worksheet of the BEE MERGE. (The BEE MERGE Miscellaneous worksheet contained the final five worksheets of the BEE SPECS).

When all data were merged into the BEE MERGE, each worksheet was sorted numerically by five-digit Specimen Number. BEE MERGE was then saved as a third xls file: MASTER BEE TABLE. Potential errors in data entry (e.g. duplicate Specimen Numbers) were highlighted for eventual correction. With MASTER BEE TABLE ready for identification data, sorting and identification could begin.

2.2.4. Specimen Sorting

Berger, Roberts, Ross, Dr. Russo, and Dr. Stout sorted specimens before identification. Specimens were sorted either by taxa (e.g. Family), or by morph type (e.g. wasps with the same sets of features). Bees were separated from the rest of the specimens. European honey bees (*Apis mellifera*) were sorted and identified by Roberts, and the remaining bees were given to Dr. Russo for off-site identification. The rest of the specimens (other Hymenoptera, flies, beetles, etc.) were kept in Room 102 for identification by Berger, Roberts, Ross, and Dr. Stout.

2.2.5. Specimen Identification

European honey bees (*Apis mellifera*) and all non-Hymenoptera specimens were identified in Room 102 of the Headhouse III building, on the University Park campus of the Pennsylvania State University. The majority of the remaining bees were identified at the Lab of Dr. Russo at University Park, and at the Lab of Dr. Droege, at the USGS Patuxent Wildlife Research Center in Beltsville, Maryland. One individual bee and all non-bee Hymenoptera (e.g. sawflies, wasps) were identified in three different locations: Room 102, the Fleischer Lab at University Park, and the Stout Lab in State College, Pennsylvania.

2.2.5.1. Taxonomic Effort

All specimens were identified to the lowest practical taxonomic level.

In the Sweep Net and Bowl Trap samples, there were a total of 1092 bees. 226 European honey bees (*Apis mellifera*) were identified by Roberts. One sweat bee (*Augochloropsis metallica*) was identified by Stout. The remaining 865 bees were identified to Species, Species Complex, or Family by two experts: Dr. Russo and Dr. Droege.

In the Net and Bowl samples, there were a total of 791 non-bee specimens. Due to damage or lack of available taxonomic expertise, some of these specimens could only be identified to Order, or to the Family ("common name") level. Two assistants (Berger and Ross) who had been trained in Family-level identifications of Diptera, Coleoptera, and Hemiptera (flies, beetles and true bugs) identified 39 specimens of these three Orders. Two entomologists (Roberts and Dr. Stout) identified the remaining 752 specimens to Family, Subfamily, Genus or Species.

2.2.5.2. Taxonomic References

Hymenoptera:

Printed Keys:

Bohart RM and AS Menke. 1976. Sphecid Wasps of the World: A Generic Revision. University of California Press. 695 pages.

Buck M, SA Marshall, and DKB Cheung. 2008. Identification Atlas of the Vespidae (Hymenoptera, Aculeata) of the northeastern Nearctic region. Canadian Journal of Arthropod Identification. 5: 1-492.

Hymenoptera of the World: An Identification Guide to Families. 1993. Goulet H and JT Huber, editors. Centre for Land and Biological Resources Research Ottawa, Ontario. Research Branch Agriculture Canada Publication l894/E. 668 pages.

Online keys:

Discover Life. **http://www.discoverlife.org/mp/20q?guide=Chrysididae**

Other Taxa:

Printed Keys:

McAlpine JF, BV Peterson, GE Shewell, HJ Teskey, JR Vockeroth, and DM Wood, editors. 1981. Manual of Nearctic Diptera. Vol. 1. Research Branch Agriculture Canada. Monogr. No. 27. Canadian Government Publication Centre, Hull. 674 pages.

McAlpine JF, BV Peterson, GE Shewell, HJ Teskey, JR Vockeroth, and DM Wood, editors. 1987. Manual of Nearctic Diptera. Vol. 2. Research Branch Agriculture Canada. Monogr. No. 28. Canadian Government Publication Centre, Hull. 658 pages.

Miranda GFG, AD Young, MM Locke, SA Marshall, JH Skevington, and FC Thompson. 2013. Key to the Genera of Nearctic Syrphidae. Canadian Journal of Arthropod Identification. 23: 1-351.

Online keys:

Key to the Asilid Genera of the Eastern U.S. **http://www.hr-rna.com/RNA/Rfly%20pages/Eastern%20genera%20key.htm**

2.2.6. Data Entry and Curation

Once specimens were identified to the lowest practical level, the corresponding taxonomic data, identification notes, and name of collector were added to MASTER BEE TABLE. Errors in data entry were corrected, and missing data were added.

For the purposes of this Report, a fourth and fifth xls file were created from the first two worksheets of MASTER BEE TABLE: REPORT_SWEEPMAIN and REPORT_BOWLTRAPS. Any errors in data entry that carried over from MASTER BEE TABLE were corrected, missing data were added, and any Specimen Numbers that lacked data (e.g. Site Number/Name, Taxonomic information) were deleted from the (but retained in the MASTER BEE TABLE, BEE SPECS and BEE MERGE files).

3.0 Results

Complete lists of all taxa collected in 2016 at SGL33 are located in **Appendix C: Taxa Lists**.

3.1. Bee Families per Treatment

To review, "bees" are a group of insects comprised of six Families:

- Andrenidae (mining bees)
- Apidae (cuckoo/carpenter/digger bees, bumble bees and honey bees)
- Colletidae (plasterer bees, masked bees)
- Halictidae (sweat bees)
- Megachilidae (leaf-cutter bees, mason bees)
- Melittidae (oil-collecting bees. RARE.)

During the 2016 field season, all six bee Families were collected at one SGL33 survey site (**Mow w/ Tx**). Five of the six bee Families were collected at four of the sites (**Hy Fol**, **Stem Fol**, **Mow** and **BLV**), and four of the six bee Families were collected at the **Hand** site.

The density, taxa richness, and diversity indices of bees for each treatment are described as follows:

3.1.1. Density

Bees from the Family Apidae outnumbered individuals from other bee Families for all sites except **Stem Fol**—the Family Halictidae had the highest number of individual bees at **Stem Fol**.

3.1.2. Taxa Richness

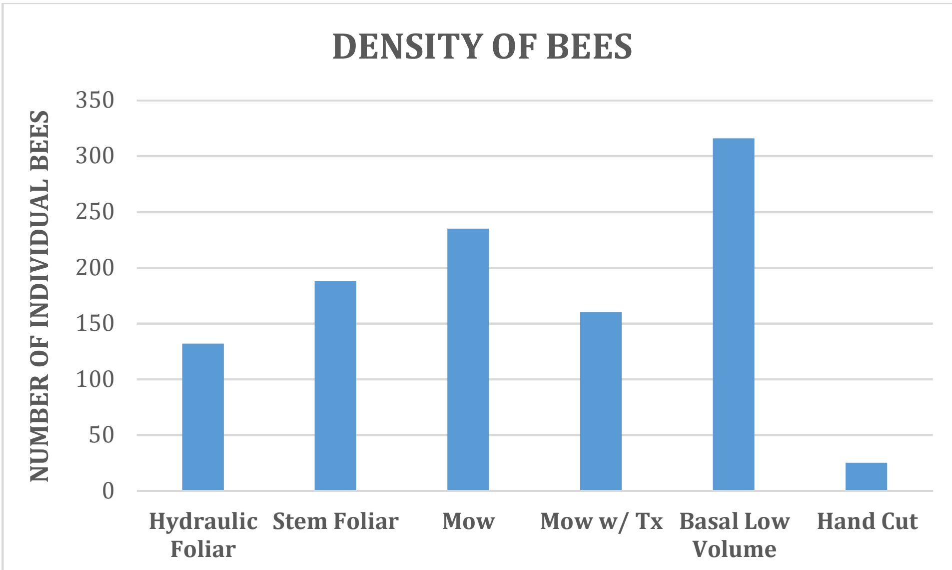
Bee taxa from the Family Apidae outnumbered taxa from other bee Families at the **Mow**, **Mow w/ Tx** , and **Hand** sites. The Family Halictidae had the greatest number of taxa at the **Stem Fol** site. Taxa of Apidae and Halictidae were equally the most numerous at the **Hy Fol** site, and at the **BLV** site, the greatest number of bee taxa was equal for the Families Andrenidae and Apidae.

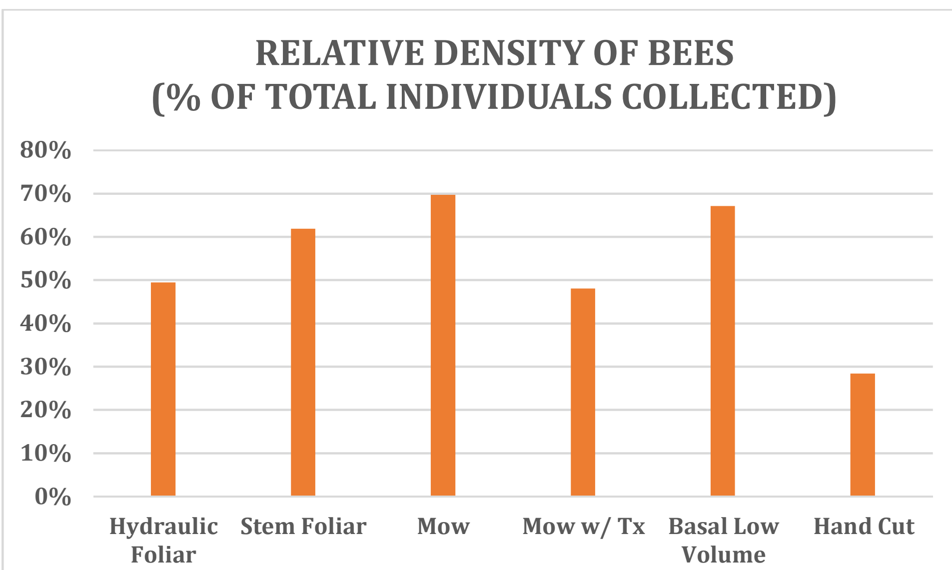
Charts illustrating the Family density and taxa richness of bees per treatment for the 2016 SGL33 survey can be found in **Appendix D: Bee Family Density and Taxa Richness per Treatment**.

3.2. Bees per Treatment

3.2.1. Density

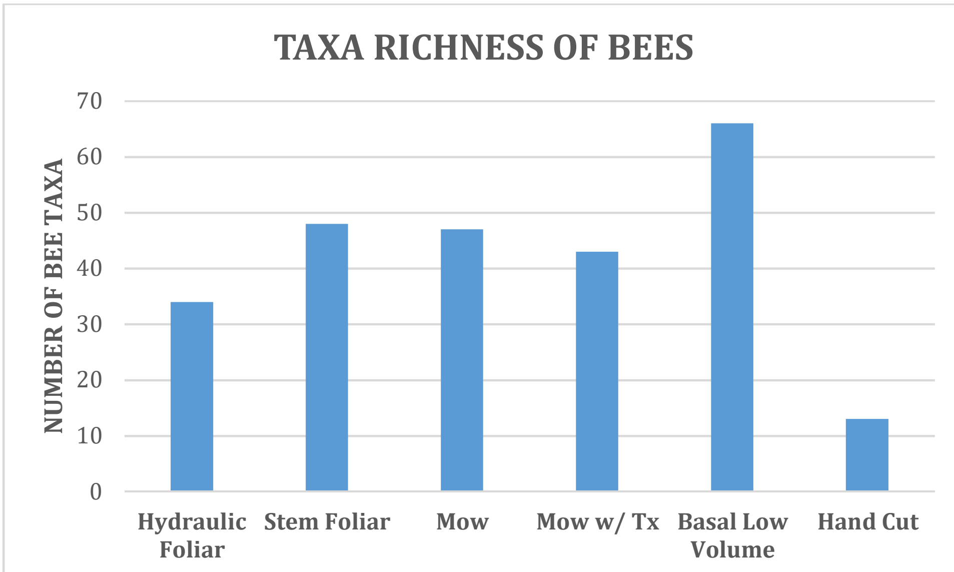
Bee density (here defined as the number of bees per site) was greatest at the Basal Low Volume (**BLV**) site (316 individual bees collected over the course of the season). However, relative bee density (here defined as the percent individual bees of all individuals collected, per site) was greatest at the **Mow** site (69.73% of all individuals collected at **Mow**).

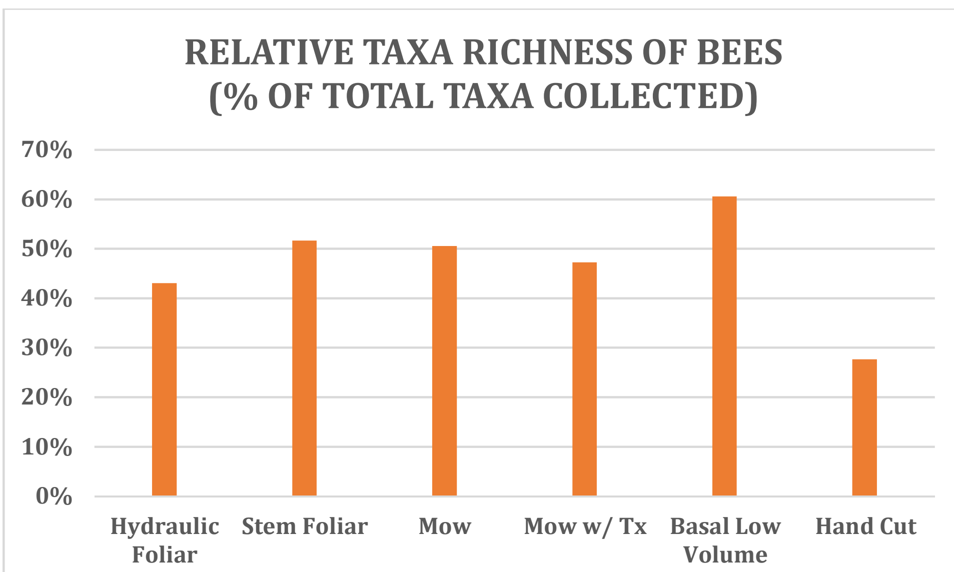




3.2.2. Taxa Richness

The number of bee taxa per site was greatest at the Basal Low Volume (**BLV**) site (66 taxa). The *relative* number of bee taxa per site (the percent bee taxa of all taxa collected, per site) was also greatest at the **BLV** site (60.55% of all taxa collected at **BLV**).





3.2.3. Diversity Indices

Diversity Indices (DIs) are mathematical methods of characterizing the diversity of a community, beyond taxa richness. Unlike taxa richness, DIs factor in the relative abundance of each taxa. Evenness (E) is the measure of the similarity of abundances among the taxa of a community on a 0 to 1 scale; for example, a community with an equal number of individuals per taxon will have an Evenness value of 1. Evenness is an essential component of a Diversity Index.

Two commonly-used DIs are the Shannon Diversity Index (H) and the Simpson's Index of Diversity (1 - D). From each of these Indices, Evenness can be calculated (e.g. Shannon's E_H and Simpson's E_D).

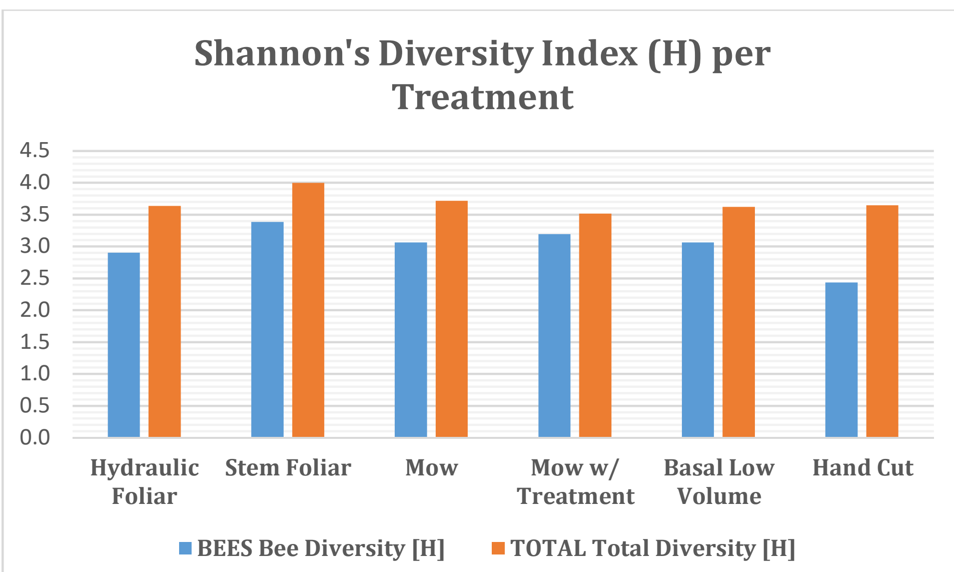
Shannon Diversity Index (H)

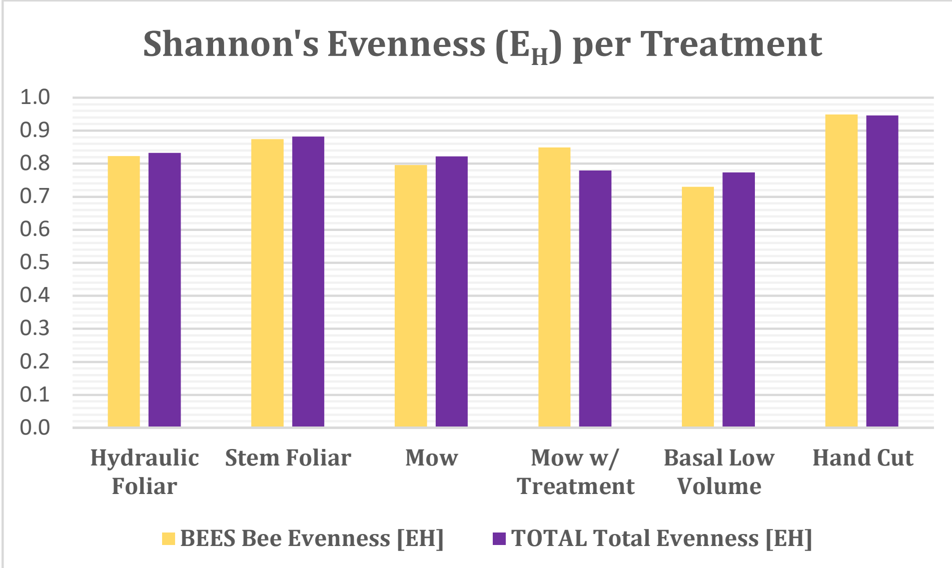
The Shannon Diversity Index (H) is a mathematical measure of diversity: it is calculated by multiplying -1 by the sum of the natural logarithms of the proportions of each taxon relative to the total number of taxa. Shannon's H accounts for both the abundance and the equitable distribution (evenness) of taxa in a community. All taxa are weighted evenly, therefore a few rare taxa can have a strong effect on the outcome.

For the total 2016 collections of bees and all specimens from the survey sites, the **Stem Foliar** site had the greatest value of Shannon's H (bee = 3.385, all = 3.999). For bees, the **Hand Cut** site had the lowest Shannon's H (bee = 2.435); for all specimens, the **Mow with Treatment** site had the lowest (3.515). Evenness (E_H) for both bees and for all specimens was greatest at the **Hand Cut** site (bees = 0.949, all = 0.946), and lowest at the **Basal Low Volume** site (bees = 0.730, all = 0.773).

SHANNON'S DIVERSITY AND EVENNESS

	BEES		**ALL SPECIMENS**	
Treatments	**Diversity [H]**	**Evenness [E_H]**	**Diversity [H]**	**Evenness [E_H]**
Hydraulic Foliar	2.902	0.823	3.637	0.832
Stem Foliar	**3.385**	0.874	**3.999**	0.882
Mow	3.062	0.795	3.716	0.822
Mow w/ Treatment	3.192	0.849	3.515	0.779
Basal Low Volume	3.060	0.730	3.619	0.773
Hand Cut	2.435	**0.949**	3.644	**0.946**



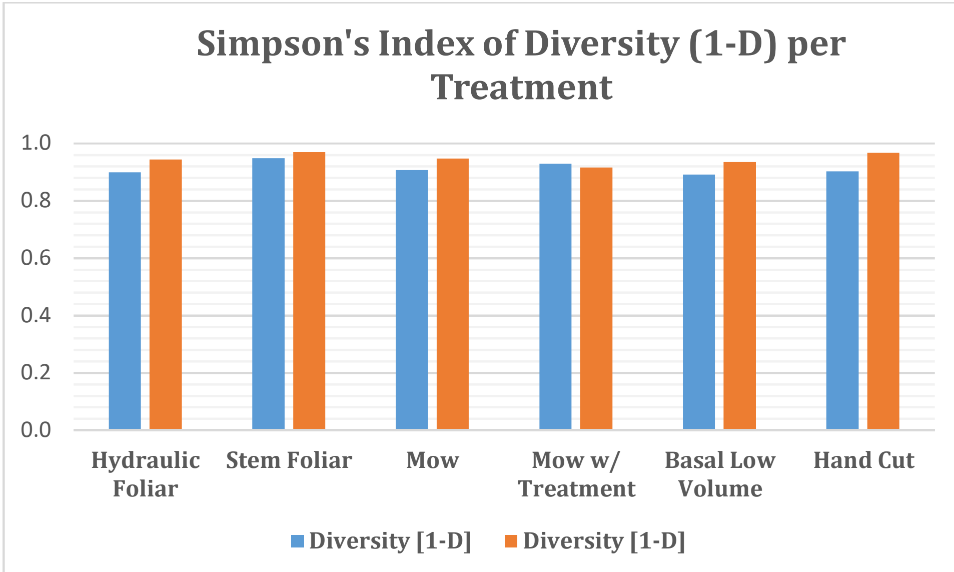


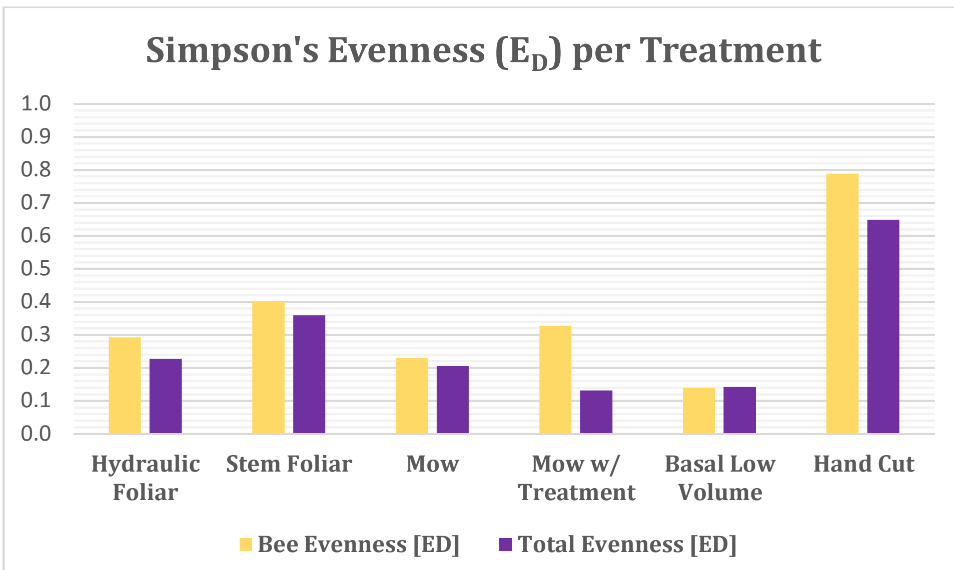
Simpson's Index of Diversity (1 - D)

Simpson's Index of Diversity (1 - D) is another mathematical measure of diversity. This Index represents the probability that two randomly selected individuals from one community are of different taxa. It is calculated by subtracting 1 from the sum of the squared proportions of each taxon relative to the total number of taxa. As with Shannon's H, Simpson's Index accounts for both the abundance and the evenness of taxa in a community. Unlike Shannon's H, Simpson's 1 - D places more weight on dominant and/or common taxa, therefore a few rare taxa do no have as much of an effect on the probability.

For the total 2016 collections of bees and all specimens from the survey sites, the **Stem Foliar** site had the greatest value of Simpson's 1-D (bee = 0.948, all = 0.970). The **Basal Low Volume** site had the lowest Simpson's 1-D for bees (0.891), and the **Mow with Treatment** site had the lowest for all specimens (0.916). Evenness (E_H) for both bees and for all specimens was greatest at the **Hand Cut** site (bees = 0.788, all = 0.649). Evenness for bees was lowest at the **Basal Low Volume** site (0.139), and lowest for all specimens at the **Mow with Treatment** site = 0.773).

SIMPSON'S INDEX OF DIVERSITY (1-D) AND EVENNESS (E_D)				
	BEES		ALL SPECIMENS	
Treatments	**Diversity [1-D]**	**Evenness [E_D]**	**Diversity [1-D]**	**Evenness [E_D]**
Hydraulic Foliar	0.899	0.292	0.944	0.227
Stem Foliar	**0.948**	0.399	**0.970**	0.359
Mow	0.907	0.229	0.947	0.205
Mow w/ Treatment	0.929	0.327	0.916	0.131
Basal Low Volume	0.891	0.139	0.935	0.142
Hand Cut	0.902	**0.788**	0.967	**0.649**





3.3. Bees Per Treatment by Month

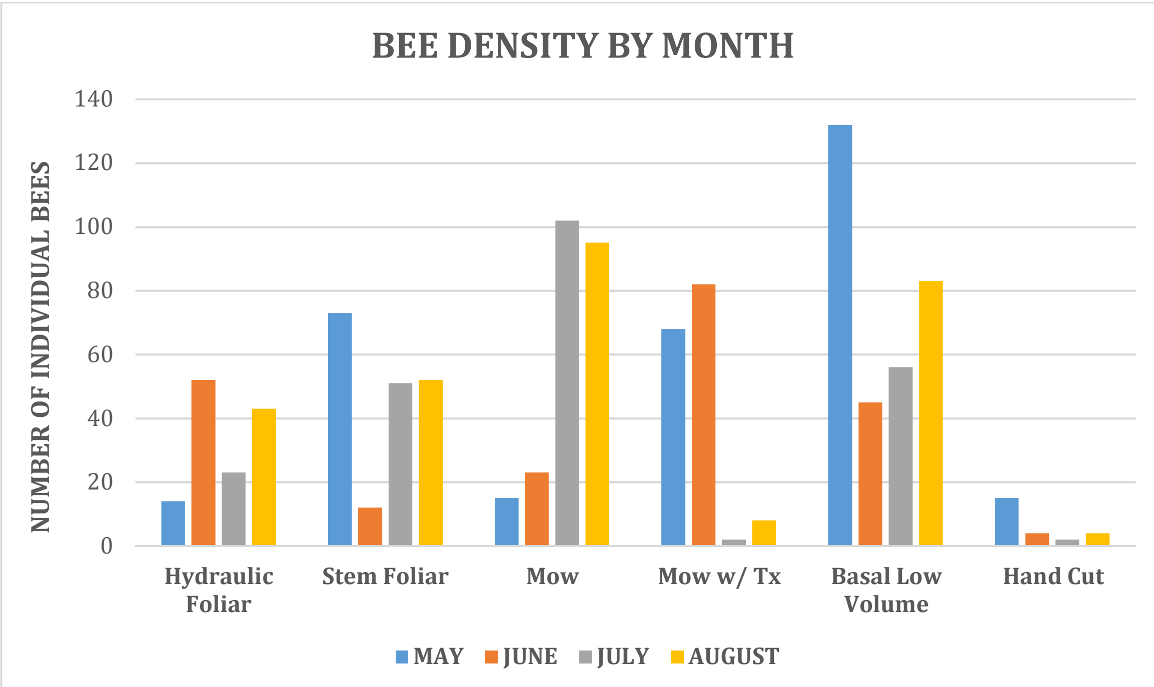
The density, taxa richness, and diversity indices of bees per treatment for each month are described as follows:

3.3.1. Density

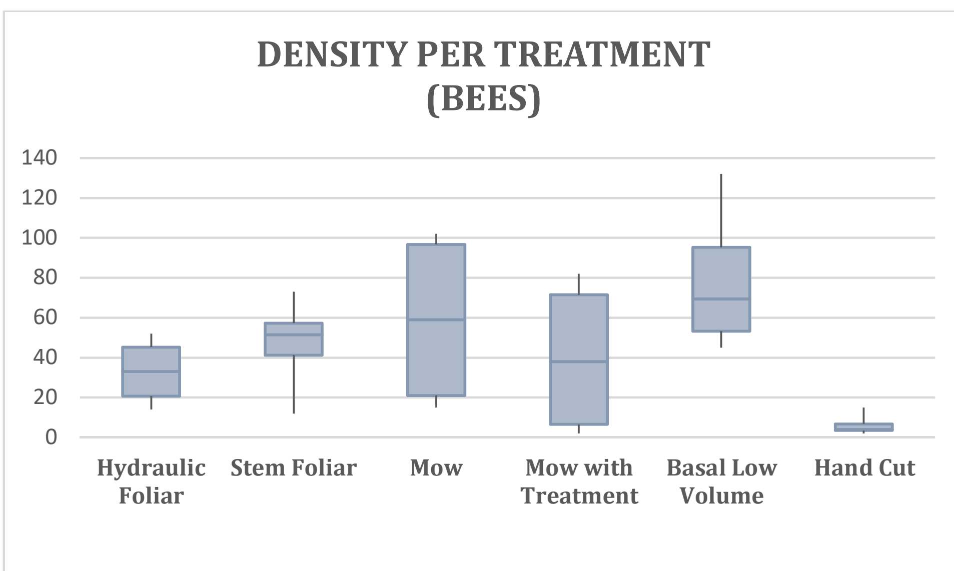
The months of greatest bee density for each site were:

May - Stem Foliar (**Stem Fol**), **BLV**, and Hand Cut (**Hand**) sites
June - Hydraulic Foliar (**Hy Fol**) and the Mow with Treatment (**Mow w/ Tx**) sites
July - **Mow** site

No sites had the greatest bee density in August.



Mean density of bees per month was greatest at the **BLV** site ($\bar{x}$ = 79.00, s = 38.77), but the mean was not significantly different from any but the **Hand** site ($\bar{x}$ = 6.25, s = 5.91). **Mow** and **Mow w/ Tx** had the greatest monthly variability in bee density, while **Hand** had the least. The monthly bee density of **Stem Fol** was skewed to the left, and was skewed to the right for **BLV**. **Hy Fol** had the most normal distribution of monthly bee density.

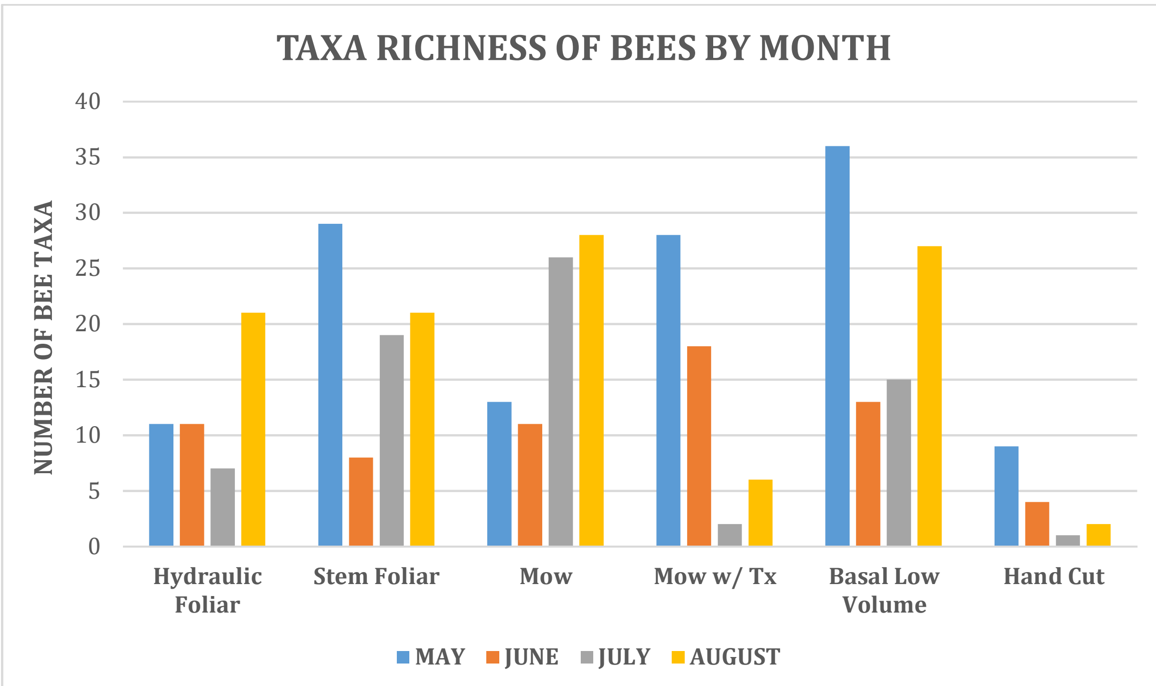


3.3.2. Taxa Richness

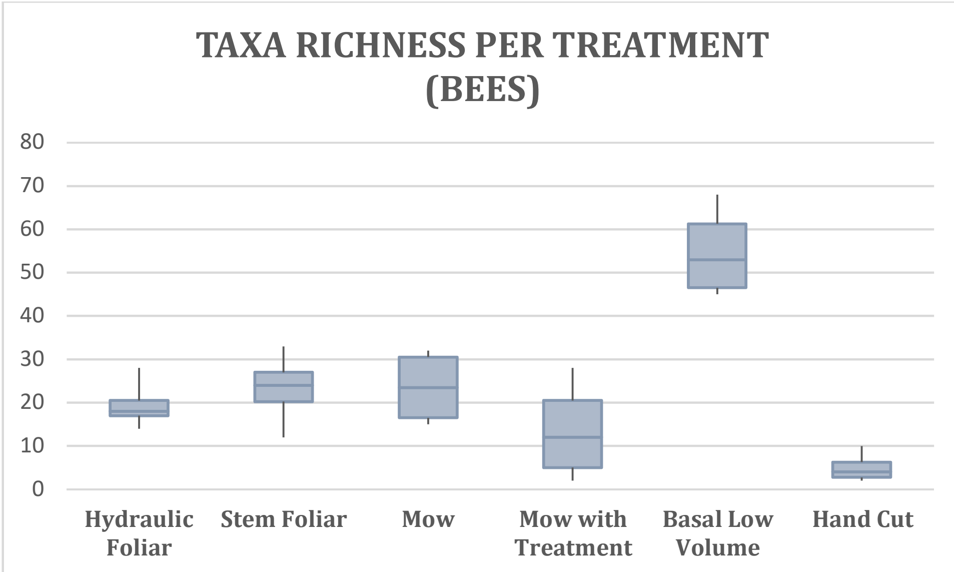
The months of greatest bee <u>taxa richness</u> for each site were:

> **May - Stem Fol**, **Mow w/ Tx**, **BLV**, and **Hand** sites
> **August - Hy Fol** and **Mow** sites

No sites had the greatest period of bee taxa richness in June or July.



As with density, the monthly taxa richness of bees per month was greatest at the **BLV** site ($\bar{x}$ = 22.75, s = 10.78), but was not significantly different from any but the **Hand** site ($\bar{x}$ = 4.00, s = 3.56). **Mow w/ Tx** had the greatest variability in richness, while **Hand** and **Hy Fol** had the least. Monthly taxa richness of all sites but **Stem Fol** and **Mow** were skewed to the right. **Stem Fol** had the most normal distribution of monthly richness of all sites.



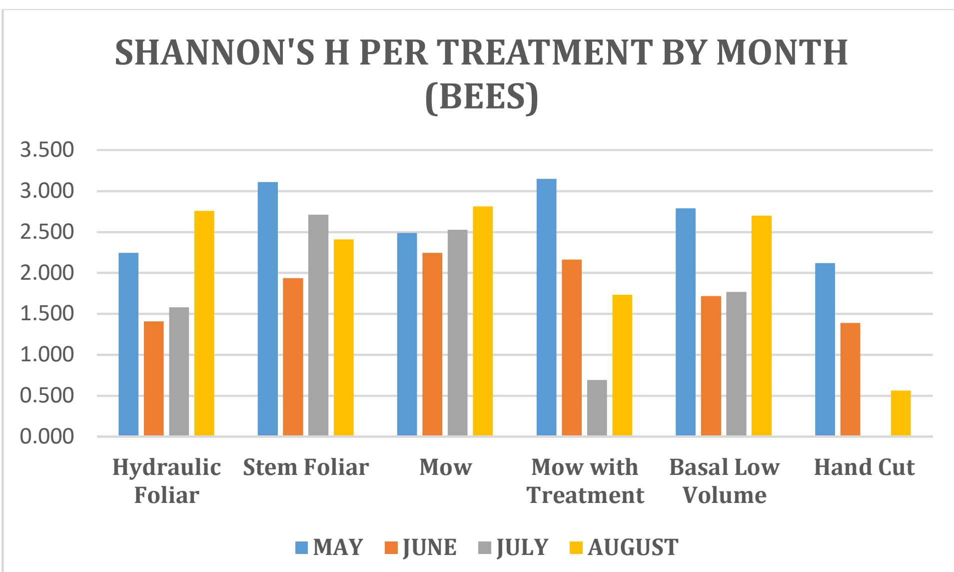
3.3.3. Diversity Indices

Shannon Diversity Index (H)

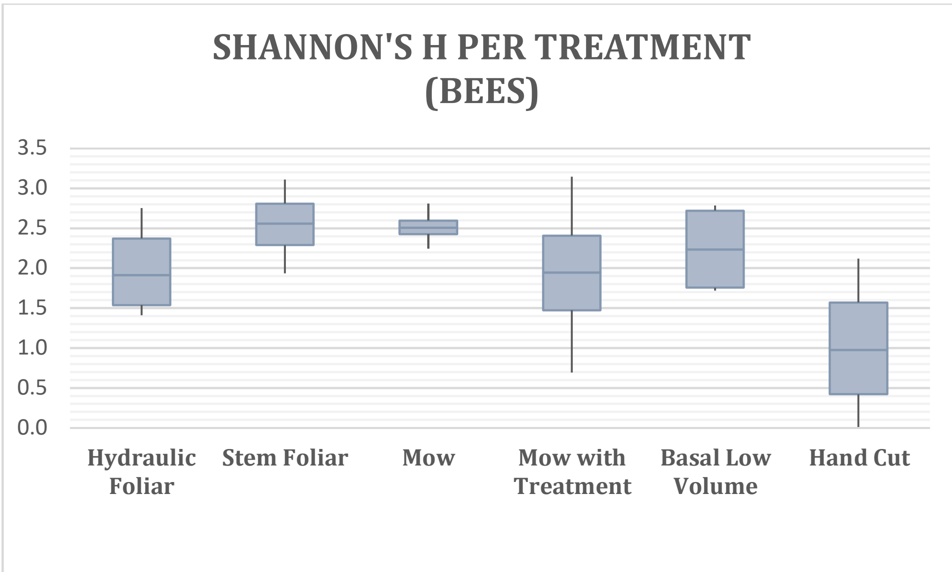
The months in which the Shannon Diversity Index (H) for bees was greatest for each site were:

May - Stem Fol, **Mow w/ Tx**, **BLV***, and **Hand** sites
August - Hy Fol and **Mow** sites

*BLV: Shannon's H for May and August were nearly equal



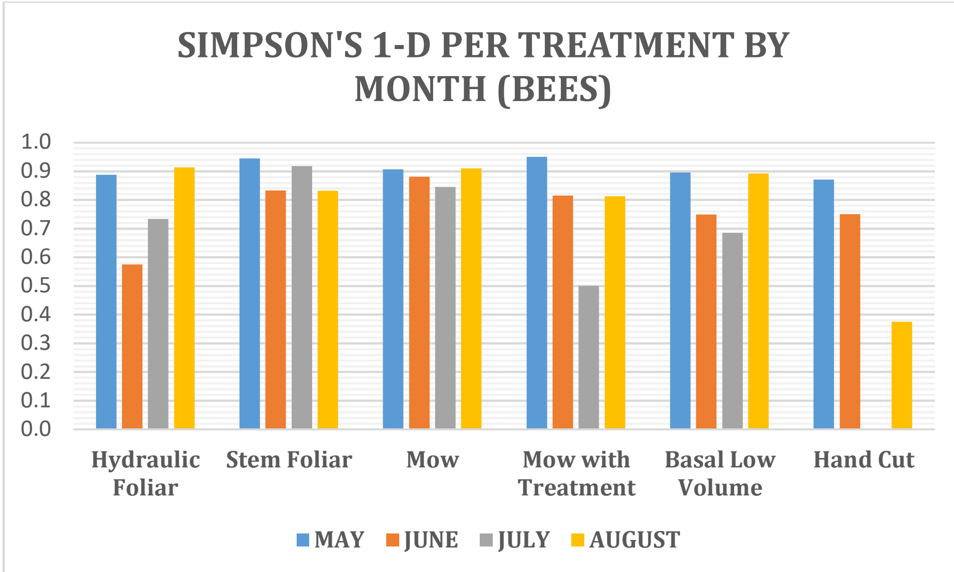
Using Shannon's Diversity Index (H), the diversity of bees per month did not differ significantly among any of the six treatment sites. **Hand** had the greatest variability, while **Mow** had the least. **Hy Fol** was skewed to the right; all of the other sites had a symmetric distribution. **Stem Fol** had the most normal distribution of monthly diversity.



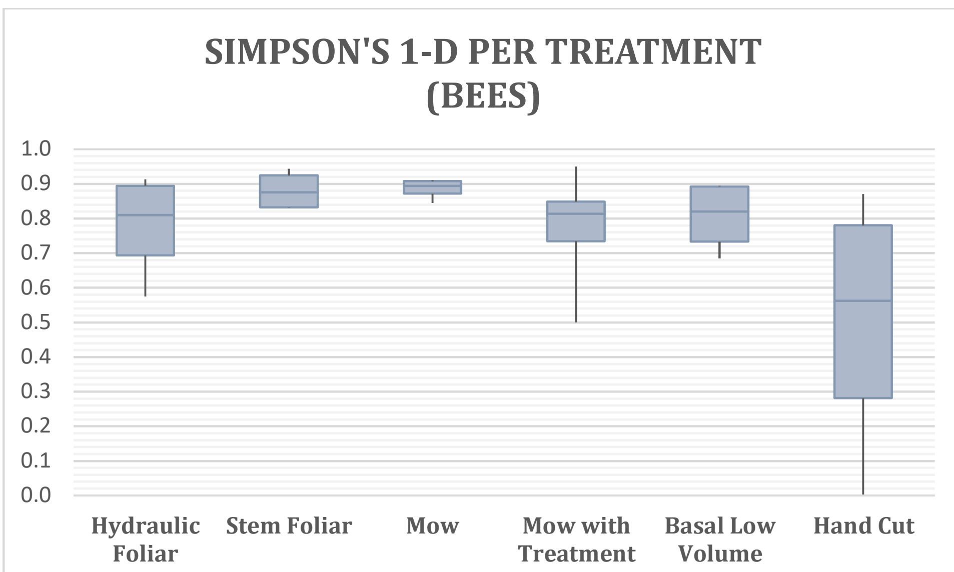
Simpson Index of Diversity (1-D)

The months in which the Simpson Index of Diversity (1-D) for bees was greatest for each site were:

May - Stem Fol, **Mow w/ Tx** and **Hand** sites
August - Hy Fol site
May and August - Mow and **BLV** sites



As with Shannon's Diversity Index, the Simpson's Index of Diversity for bees per month did not differ significantly among any of the six treatment sites. **Hand** had the greatest variability, and **Mow** had the least. All but **Stem Fol** were skewed to the left; **Stem Fol** was skewed to the right. No sites exhibited a normal distribution of monthly diversity.



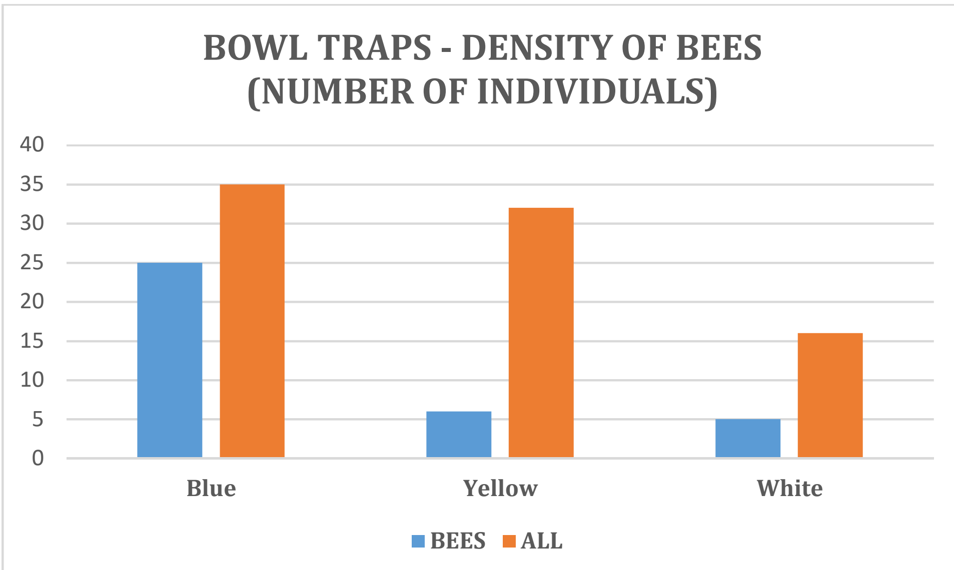
3.4. Bowl Traps

Because only one 24-hour period of bowl trapping was tested, and at one area outside of treatment site boundaries, the following represents a mere glimpse of observed differences in bee density, taxa richness, and diversity indices by bowl trap color.

3.4.1. Density

Bee density and total density were greatest in the blue traps (n = 25), followed by the yellow (n = 6) and the white (n = 5). This pattern differed for relative bee density—the blue traps had the greatest (71.43%), followed by the white (31.25%), and the yellow (18.75%).

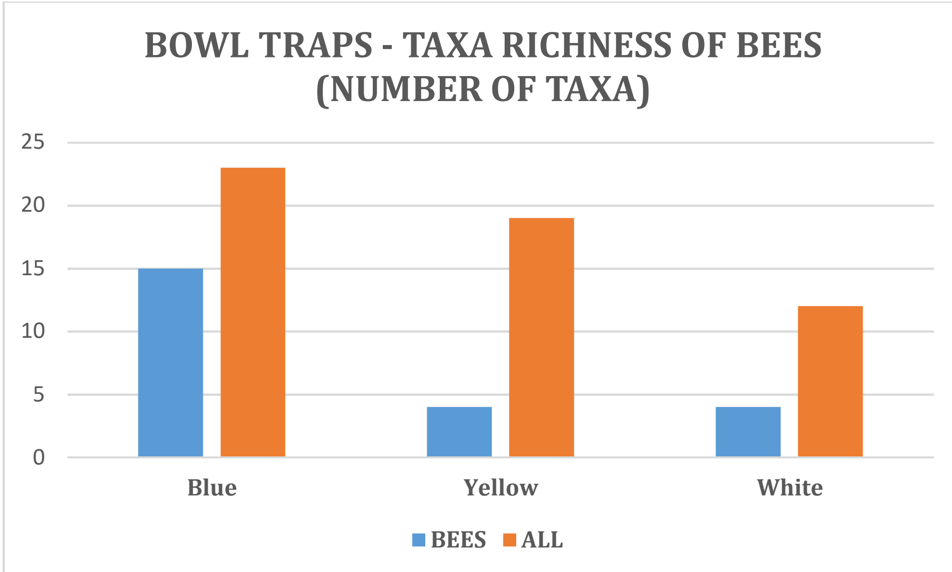
BOWL TRAPS - DENSITY OF BEES (NUMBER OF INDIVIDUALS)			
BOWL COLOR	**BEES**	**ALL**	**BEES/ALLL**
Blue	**25**	**35**	**71.43%**
Yellow	6	32	18.75%
White	5	16	31.25%



3.4.2. Taxa Richness

Taxa richness of bees and of all individuals was greatest in the blue traps (n=15), and was equal in the yellow and white traps (n=4). As with relative bee density, the relative taxa richness of bees was greatest for the blue bowl traps (65%), followed by the white (33.33%) and the yellow (21.05%).

BOWL TRAPS - TAXA RICHNESS OF BEES (NUMBER OF TAXA)			
BOWL COLOR	**BEES**	**ALL**	**BEES/ALL**
Blue	**15**	**23**	**65.22%**
Yellow	4	19	21.05%
White	4	12	33.33%



3.4.3. Diversity Indices

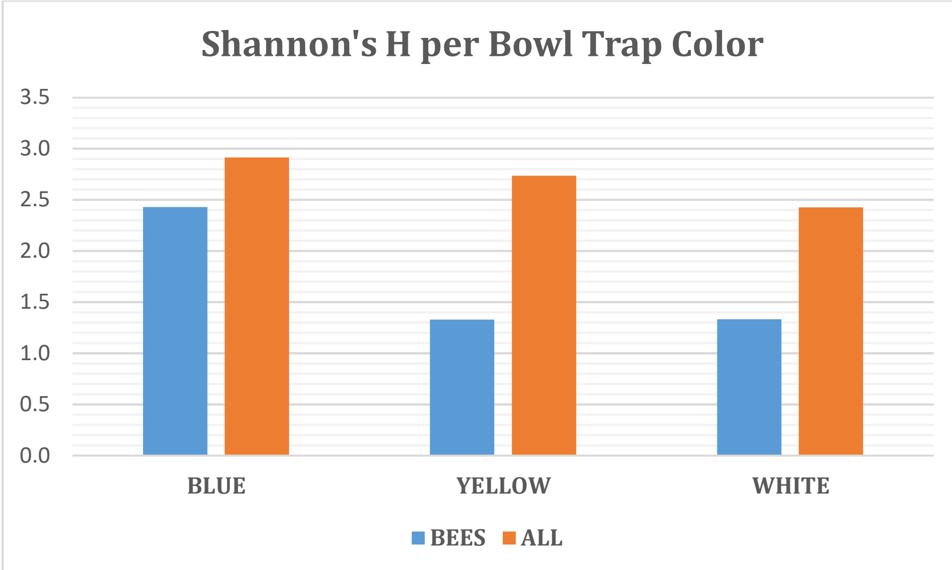
<u>*Shannon's Diversity Index (H)*</u>

Bees - The value of H was greatest for the blue bowl traps (H = 2.431), and were nearly similar for the yellow and the white traps (yellow = 1.330, white = 1.332).

Total – For all individuals collected, the Value of H was greatest for the blue traps (H = 2.914), followed by the yellow traps (H = 2.737), and the white traps (H = 2.426).

BOWL TRAPS - SHANNON'S H AND E_H

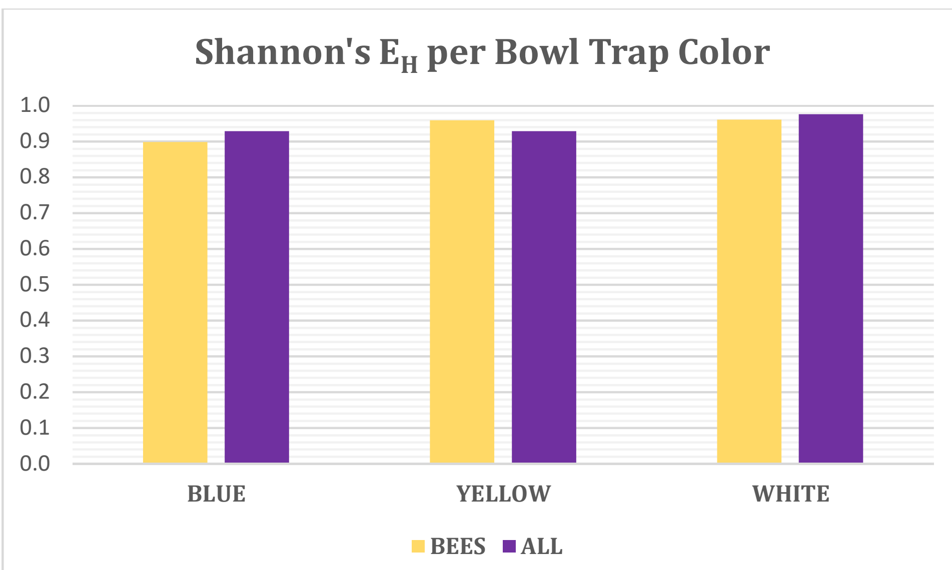
	BEES		ALL SPECIMENS	
	H	**E_H**	**H**	**E_H**
BLUE	2.431	0.898	2.914	0.929
YELLOW	1.330	0.959	2.737	0.929
WHITE	1.332	0.961	2.426	0.976



Shannon's Evenness (E_H)

Bees - The value of E_H was slightly lower for the blue bowl traps (E_H = 0.898) than for the yellow and the white traps (yellow = 0.959, white = 0.961).

Total – For all individuals collected, the Value of E_H was equal for the blue and yellow traps (H = 0.929), and slightly higher for the white traps (H = 0.976).

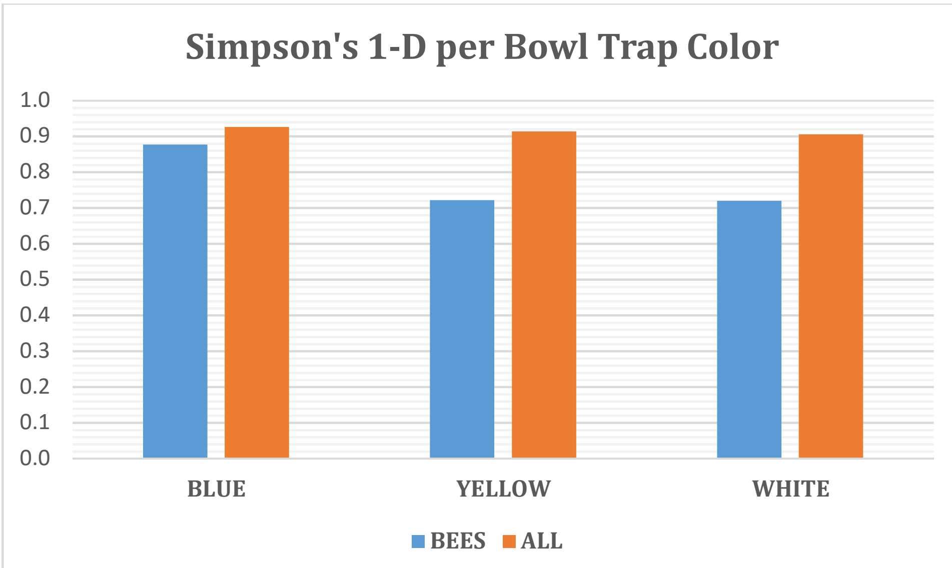


Simpson's Index of Diversity (1-D)

Bees - The value of 1-D was greatest for the blue bowl traps (0.877), and were nearly similar for the yellow and the white traps (yellow = 0.722, white = 0.720).

Total – For all individuals collected, the values of 1-D for all three colors were similar (blue = 0.926, yellow = 0.914, white = 0.906).

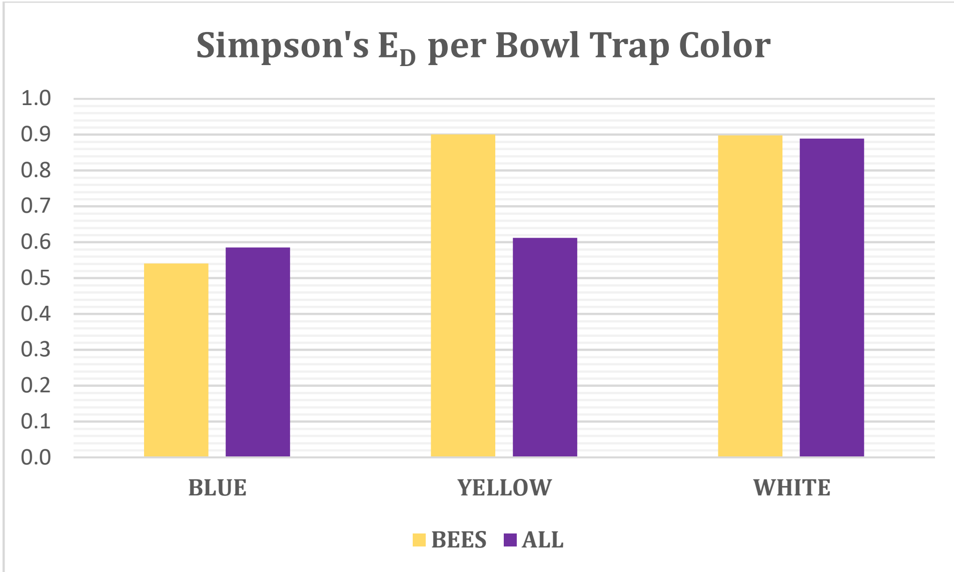
BOWL TRAPS – SIMPSON'S 1-D AND E_D				
	BEES		ALL SPECIMENS	
	H	E_H	H	E_H
BLUE	0.877	0.541	0.926	0.585
YELLOW	0.722	0.900	0.914	0.612
WHITE	0.720	0.898	0.906	0.889



Simpson's Evenness (E_D)

Bees - The value of E_D was lower for the blue bowl traps (0.541) than for the nearly-equal yellow and the white traps (yellow = 0.900, white = 0.898).

Total – For all individuals collected, the Value of E_D was lowest for the blue traps (0.585), slightly higher for the yellow traps (E_D = 0.612), and highest for the white traps (E_D = 0.889).



4.0 Discussion

4.1. Treatment Differences

The following table is a summary of results for each treatment type. Results per month are not depicted. Each site is ranked according to its total density, taxa richness, Shannon's H and E_H, and Simpson's 1-D and E_D.:

SGL33 - Bee Survey 2016 - Summary of Results

	Hydraulic Foliar	Stem Foliar	Mow	Mow w/ Treatment	Basal Low Volume	Hand Cut
HERBICIDES?	YES	YES	NO	YES	YES	NO
LOW OR HIGH VOLUME?	HIGH	ULTRA LOW	-	LOW	LOW	-
WATER OR OIL-BASED?	WATER	OIL	-	WATER	OIL	-
SELECTIVE? (mechanical or herbicidal)	NO	YES	NO	YES	YES	YES
Rankings						
DENSITY	5th (132)	3rd (188)	2nd (235)	4th (160)	**1st (316)**	6th (25)
TAXA RICHNESS	5th (34)	2nd (48)	3rd (47)	4th (43)	**1st (66)**	6th (13)
SHANNON'S DIVERSITY INDEX	5th (2.902)	**1st (3.385)**	3rd (3.062)	2nd (3.192)	4th (3.060)	6th (2.435)
SHANNON'S EVENNESS	4th (0.83)	2nd (0.874)	5th (0.795)	3rd (0.849)	6th (0.730)	**1st (0.9489)**
SIMPSON'S INDEX OF DIVERSITY	5th (0.899)	**1st (0.948)**	3rd (0.907)	2nd (0.929)	6th (0.891)	4th (0.902)
SIMPSON'S EVENNESS	4th (0.292)	2nd (0.399)	5th (0.229)	3rd (0.327)	6th (0.139)	**1st (0.788)**

Without context, the **Hand Cut** treatment site appears to have had the lowest overall density, taxa richness, and diversity (per Shannon's H) of the six sites. However, the **Hand Cut** site was increasingly difficult to navigate on foot as the season progressed, therefore specimens were netted from only a small portion of the delineated active collection area. Because the active collection area of the **Hand Cut** site was considerably smaller than those of the other five sites, inferences regarding treatment effects cannot be made using the data from this site, and the **Hand Cut** site is not included in the following statements comparing observed differences in bee populations among treatment sites:

- The most bees, the most bee taxa, and the most diverse assemblages of bee taxa were collected from sites at which a low (**Basal Low Volume**), or ultra-low (**Stem Foliar**) volume of an oil-based herbicide is applied selectively.

- The least diverse assemblages of bee taxa were collected from sites that use broadly-applied treatments, whether herbicidal (**Hydraulic Foliar**) or mechanical (**Mow**).

- The site at which a broad, high-volume application of a water-based herbicide is applied (**Hydraulic Foliar**) had the fewest bees and the fewest bee taxa, relative to the size of the active collection area.

- When comparing treatments per month, distribution patterns of density, richness, and diversity varied significantly among treatments. Differences among sites were often not significant, but skewed distributions of many monthly data preclude simple comparisons of means. Data from a reference (i.e. untreated) site are needed to make inferences regarding "normal" or "ideal" density, richness, and diversity.

Overall, an array of fascinating bee specimens was collected from each site. The "yellow bumble bee", *Bombus fervidus*, which is listed as "Vulnerable" on the IUCN Red List of Threatened Species (iucnredlist.org), was collected only at the **Hydraulic Foliar** site. At the **Mow with Treatment** site, a rare oil-collecting bee, *Macropis ciliata*, was found. This species belongs to a family of bees that visits only loosestrife flowers. Specialist bees such as these are usually not as abundant as generalists, and are especially vulnerable to threats such as habitat loss. Specialist bees (per Fowler 2016a, 2016b) were collected at all six sites:

Specialist Bees Collected at SGL33

Plant	Bee	Status	Hy Fol	Stem Fol	Mow	Mow w/ Tx	BLV	Hand
Aster family (e.g. goldenrods)	*Andrena nubecula*	patchy			X			
	Colletes simulans		X		X	X	X	
	Megachile pugnata	uncommon			X		X	
	Melissodes trinodus	uncommon			X		X	
Heather family (e.g. blueberries)	*Andrena carolina*	patchy		X		X	X	
	Andrena vicina			X		X	X	
	Colletes validus	uncommon		X				
	Osmia atriventris				X			X
Loosestrife	*Macropis ciliata*	rare				X		

We expect a positive correlation between an abundance of diverse flowering vegetation and a rich community of bees. Contrary to popular belief, the use of herbicides does not necessarily decrease plant abundance and diversity; in fact, the selective use of herbicides can have a positive effect on flowering vegetation. A study at the Albany Pine Bush Preserve found that 2 years after a mow + herbicide treatment, native solitary bee density and diversity were not significantly different between the treated sites and the untreated reference sites (Bried and Dillon 2012). The relationship between bee diversity and herbicide use is not black and white.

4.2. Study Limitations

4.2.1. Sampling Effort

As stated in the previous section, the **Hand Cut** treatment site was increasingly difficult to navigate on foot as the season progressed, therefore specimens were netted from only a small portion of the delineated collection area.

4.2.2. Taxonomic effort

All specimens were identified to the lowest practical (and cost-effective) level by three trained entomologists and by two vertebrate biologists. Some Hymenoptera and Diptera taxa are notoriously difficult to identify to species, and often require consultation with experts. Numerous Dipera and Coleoptera specimens were identified only to the Family ("common name") level, and several damaged specimens were identified only to Order. For the purposes of this report, identification of Hymenoptera to the generic level and identification of other insect Orders to the "common name" level was deemed sufficient; however, better insight into site diversity and potential treatment effects can only be gained with species-level identification of all specimens.

4.3. Recommendations

The 2016 SGL33 Hymenoptera Diversity Survey provides much-needed baseline data regarding the effects of rights-of-way vegetative treatments on the density and diversity of our native bees. It is crucial that we continue to add to this database. 2016 is a mere snapshot; long-term monitoring via similar surveys could reveal trends, and allow us to identify more specific factors that help or harm native bee populations.

Future surveys of bee populations at SGL33 should include the following:

Add Reference Site – Without the inclusion of a reference site for SGL33 in 2016, comparisons of bee density, taxa richness and diversity among treatments for that year lack context. Data from a reference site would allow inferences regarding the characteristics and dynamics of a "normal" population of bees for that area.

Change documentation of flowering vegetation - For the 2016 survey at SGL33, collectors were asked to document, in writing, all flowering vegetation on field data sheets for every day in the field. Because not all of the collectors had experience with plant identification, documentation of flowering vegetation at the treatment sites was inconsistent, and treatment differences in plant abundance and diversity could not be examined in this study. In the future, collectors will be asked instead to photograph all flowering vegetation present at each of the sites, for every day in the field. Collectors will then upload their photos to the internet-based storage site ("Box"), and flowering plants will be identified by their photos.

Adjust site boundaries - Because of the dense woody growth at the **Hand** site, only a small portion of the delineated collection area could be sampled. In the future, the active collection area of the **Hand** site should be increased, so that the area sampled is approximately equal to that of other sites.

Consider using bowl traps at treatment sites - Although the use of Bowl Traps is recommended for Hymenoptera diversity surveys, bowl traps were only employed as a "test run" for one 24-hour period, and at one site that was not within a treatment area. Although site diversity and treatment effects cannot be gleaned from these bowl trap data, four unique bee species were collected using bowl traps: a mining bee (*Calliopsis andreniformis*), a specialist squash bee (*Peponapis pruinosa*), a furrow sweat bee (*Lasioglossum tegulare*), and a leaf-cutter bee (*Hoplitis producta*). Therefore, we cannot discount the value of bowl trapping, and we cannot rule out the use of bowl traps in future studies.

With the growing concern for the future of our native bees, solutions regarding the conservation and promotion of their populations have been proposed. One such solution is to add native flowering plants and suitable habitat to the millions of acres of areas such as roadsides, railway corridors, and *utility rights-of-way* (Hopwood 2008, Wojcik and Buchmann 2012). There are an estimated five to eight million acres of power line rights-of-way in the United States (Russell et al 2005), and these millions of acres may hold a key to preserving our pollinators. But first, we need to know more about the potential effects of different vegetative treatments on populations of our native bees. The 2016 Hymenoptera Diversity Survey of SGL33 represents an important step toward acquiring this knowledge.

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APPENDICES

APPENDIX A
SITE MAPS

2016 SGL33 Hymenoptera Diversity Survey - All Sites

2016 SGL33 Hymenoptera Diversity Survey - Upper Sites

2016 SGL33 Hymenoptera Diversity Survey - Lower Sites

2016 SGL33 Hymenoptera Diversity Survey - Bowl Trap Site

APPENDIX B
FIELD FORM

SGL33 HYMENOPTERA POLLINATOR SURVEY - 2016

SITE NUMBER: **COLLECTOR INITIALS:**

DATE: **TIME OF DAY:**
TEMPERATURE:

GENERAL WEATHER CONDITIONS:

NOTES ON PREDOMINANT GROUND COVER:

NOTES ON FLOWERING VEGETATION:

ADDITIONAL NOTES:

APPENDIX C
TAXA LISTS

BEE TAXA	"SWEEPMAIN" (8 collection days)						"BOWLTRAP" (1 collection day)		
	Hy Fol	Stem Fol	Mow	Mow w/Tx	BLV	Hand	Blue	Yellow	White
ANDRENIDAE (mining bees)									
***Andrena* sp.** (a mining bee)	2		4		22				
Andrena brevipalpis					2				
Andrena carlini ("Carlin's mining bee")	2	4	1	3	1				
Andrena carolina		7		5	6				
Andrena ceanothi		2		5	1				
Andrena crataegi ("Hawthorn mining bee")					2				
Andrena cressonii ("Cresson's mining bee")					1				
Andrena imitatrix			1		14				
Andrena mandibularis		2			2	1			
Andrena milwaukeensis ("Milwaukee mining bee")					1				
Andrena miserabilis ("miserable mining bee")					1				
Andrena nivalis ("snowy mining bee")	1	2		17	7				
Andrena nubecula ("cloudy-winged mining bee")			1						
Andrena personata			1	1	1				
Andrena rugosa ("rugose mining bee")					2				
Andrena spireana	3			1					
Andrena tridens					1				
Andrena truncatum	1								
Andrena vicina ("neighborly mining bee")		1		6	3				
Andrena virginiana ("Virginia mining bee")		28	3						
Andrena wilkella ("Wilke's mining bee")	1	1	1	5	1				
Calliopsis andreniformis								1	
APIDAE (cuckoo/carpenter/digger bees, bumble bees and honey bees)									
Apis mellifera ("European honey bee")	35	11	58	32	88	2			
***Bombus* sp.** (unspecified bumble bee)	2	1							
Bombus bimaculatus ("two-spotted bumble bee")	3	5	3	2	3				
Bombus fernaldae ("Fernald's cuckoo bumble bee")			1						
****Bombus fervidus*** ("yellow bumble bee" ****VULNERABLE***)	1								
Bombus griseocollis ("brown-belted bumble bee")	1			1	1				
Bombus impatiens ("common eastern bumble bee")	1	9	5	11	35	4			
Bombus sandersoni ("Sanderson's bumble bee")					1				
Bombus vagans ("half-black bumble bee")	4	4	5	1	6	3			
***Ceratina* sp.** (small carpenter bee)	1	2	3	2	3		1		
Ceratina calcarata ("spurred ceratina")		2	1	4	2				
Ceratina dupla ("doubled ceratina")	9	9	18	1	17	3	7		2
Ceratina miqmaki ("Miqmak ceratina")	3		3	1	2	1			
Ceratina strenua ("nimble ceratina")					4		1		
Epeolus scutellaris (a variegated cuckoo bee)			1	1					
***Holcopasites* sp.** (a cuckoo bee)					1				1
***Melissodes* sp.** (a long-horned bee)			1						
Melissodes trinodis			1		1		1		
***Nomada* sp.** (a nomad bee)									
***Nomada bidentata* group**				4	1	1			
Nomada cressonii ("Cresson's nomad bee")			1	2		2			
Nomada luteoloides				1	1				
Nomada maculata ("spotted nomad bee")				3					
Nomada pygmaea ("pygmy nomad bee")		1	3		2	2			
Peponapis pruinosa (squash bee, "Eastern cucurbit bee")							1		
Xylocopa virginica ("eastern/large carpenter bee")		1	2	2	1				
COLLETIDAE (plasterer bees, masked/yellow-faced bees)									
***Colletes* sp.** (a cellophane/polyester bee)									
Colletes simulans	1		3	2	1				
Colletes validus ("blueberry cellophane bee")		1							
***Hylaeus* sp.** (a masked/yellow-faced bee)									
Hylaeus affinis	1	1		1	2				
Hylaeus affinis/modestus	9	10	25		2			2	
Hylaeus annulatus		4	2						
Hylaeus mesillae ("Mesilla masked bee")	10		1	1	1				
Hylaeus modestus ("modest masked bee")	11	3	4		1				
HALICTIDAE (sweat bees)									
Augochlora pura ("pure golden green sweat bee")		1	4	1	1				
Augochlorella aurata	2	5	5	5	4		2	2	
***Augochloropsis* sp.** (a green sweat bee)									
Augochloropsis metallica					1				
Augochloropsis metallica fulgida	1	3	3	1	2				
***Halictus* sp.** (an end-banded furrow bee)									
Halictus confusus ("Southern bronze furrow bee")	4	4	9	1	2				
Halictus ligatus	1	3	9	3	25		3		
Halictus rubicundus ("orange-legged furrow bee")		1	1						
***Lasioglossum* sp.** (a base-banded furrow bee)	2	3	3	2	3	3			
Lasioglossum abanci		1				1	1		
Lasioglossum apocyni		1							
Lasioglossum coriaceum	3	2	2				1		
Lasioglossum cressonii	3	8	5	5	3	1	1		1
Lasioglossum ephialtum			1	1	2		2		
Lasioglossum foxii		1			1				
Lasioglossum heterognathum	2	17	6	1	2				1
Lasioglossum hitchensi		1							
Lasioglossum imitatum		2							

pollinator
cleptoparasite/social parasite
introduced species (pollinator)

BEE TAXA	"SWEEPMAIN" (8 collection days)						"BOWLTRAP" (1 collection day)		
	Hy Fol	Stem Fol	Mow	Mow w/Tx	BLV	Hand	Blue	Yellow	White
Lasioglossum sp. (cont.)									
Lasioglossum leucozonium ("white-zoned mining/furrow bee")		1							
Lasioglossum lineatulum	3	2		7	1				
Lasioglossum paradmirandum					1				
Lasioglossum quebecense (a nocturnal sweat bee)		3			1				
Lasioglossum tegulare							1		
Lasioglossum versans		6	4		1				
***Sphecodes* sp.** (a cuckoo bee)	1	1	1		1				
MEGACHILIDAE (leaf-cutter bees, mason bees)									
***Coelioxys* sp.** (cuckoo leaf-cutter bee)									
Coelioxys octodentata ("eight-toothed cuckoo leaf-cutter bee")					1				
Coelioxys rufitarsis ("red-footed cuckoo leaf-cutter bee")					1				
Coelioxys sayi ("Say's cuckoo leaf-cutter bee")					1				
***Heriades* sp.** (a leaf-cutter bee)									
Heriades leavitti (***new state record for PA**)				1					
Heriades leavitti/variolosa			1						
***Hoplitis* sp.** (a leaf-cutter bee)									
Hoplitis pilosifrons			1						
Hoplitis producta							1		
***Megachile* sp.** (a leaf-cutter/resin bee)									
Megachile campanulae ("bellflower resin bee")					1				
Megachile gemula ("small-handed leaf-cutter bee")		1	1	1	1				
Megachile inermis ("unarmed leaf-cutter bee")					1				
Megachile latimanus ("broad-handed leaf-cutter bee")				7	4				
Megachile mendica ("flat-tailed leaf-cutter bee")	3		4	4	4				
Megachile pugnata ("pugnacious leaf-cutter bee")			2		1		1		
Megachile relativa	4	2	18		5				
***Osmia* sp.** (a mason bee)									
Osmia atriventris ("Maine blueberry bee")			2			1	1	1	
Osmia bucephala ("bufflehead mason bee")		1							
Osmia cornifrons ("horn-faced bee")	1	5		2					
Osmia inspergens		2							
Osmia pumila					1				
Osmia taurus				2					
*MELITTIDAE (oil-collecting bees ****RARE***)									
****Macropis ciliata*** ("ciliary oil-collecting bee")				1					
TOTAL INDIVIDUAL BEES PER SITE	132	188	235	160	316	25	25	6	5
Individuals of Bee Taxa = __% of the Total (Bees + Other Taxa):	49.44%	61.84%	69.73%	48.05%	67.09%	28.41%	71.43%	18.75%	31.25%
TOTAL BEE TAXA PER SITE	34	48	47	43	66	13	15	4	4
Bee Taxa = __% of the Total (Bee + Other Taxa):	43.04%	51.61%	51.09%	47.25%	61.11%	27.66%	65.22%	21.05%	33.33%

Legend:
- pollinator
- cleptoparasite/social parasite
- introduced species

BEE TAXA	"SWEEPMAIN" (8 collection days)						"BOWLTRAP" (1 collection day)		
	Hy Fol	Stem Fol	Mow	Mow w/Tx	BLV	Hand	Blue	Yellow	White
ANDRENIDAE (mining bees)									
Number of Andrenidae Individuals Per Site	10	47	12	43	68	1	0	1	0
Number of Andrenidae Taxa Per Site	**6**	**8**	**7**	**8**	**17**	**1**	**0**	**1**	**0**
APIDAE (cuckoo/carpenter/digger bees, bumblebees and honeybees)									
Number of Apidae Individuals Per Site	60	45	106	68	169	18	11	0	3
Number of Apidae Taxa Per Site	**10**	**10**	**15**	**15**	**17**	**8**	**5**	**0**	**2**
COLLETIDAE (plasterer/masked bees)									
Number of Colletidae Individuals Per Site	32	19	35	4	7	0	0	2	0
Number of Colletidae Taxa Per Site	**5**	**5**	**5**	**3**	**5**	**0**	**0**	**1**	**0**
HALICTIDAE (sweat bees)									
Number of Halictidae Individuals Per Site	22	66	53	27	51	5	11	2	2
Number of Halictidae Taxa Per Site	**10**	**20**	**13**	**10**	**16**	**3**	**7**	**1**	**2**
MEGACHILIDAE (leaf-cutter/mason bees)									
Number of Megachilidae Individuals Per Site	8	11	29	17	21	1	3	1	0
Number of Megachilidae Taxa Per Site	**3**	**5**	**7**	**6**	**11**	**1**	**3**	**1**	**0**
MELITTIDAE (oil-collecting bees)									
Number of Melittidae Individuals Per Site	0	0	0	1	0	0	0	0	0
Number of Melittidae Taxa Per Site	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**
TOTAL BEE TAXA PER SITE	**34**	**48**	**47**	**43**	**66**	**13**	**15**	**4**	**4**
NUMBER OF BEE FAMILIES REPRESENTED PER SITE	**5**	**5**	**5**	**6**	**5**	**4**	**3**	**4**	**2**

OTHER TAXA	"SWEEPMAIN" (8 collection days)						"BOWLTRAP" (1 collection day)		
	Hy Fol	Stem Fol	Mow	Mow w/Tx	BLV	Hand	Blue	Yellow	White
Coleoptera (beetles)									
Cantharidae (soldier beetles)									
Chauliognathus pennsylvanicus (goldenrod soldier beetle, PA leatherwing beetle)	1		1		2				
Cerambycidae (long-horned beetles)									
Typocerus sp. (a flower long-horned beetle)			2						
Chrysomelidae	1	1	1	1			1		1
Chrysochus auratus (dogbane beetle)			1						
Diabrotica undecimpunctata (spotted cucumber beetle)					1				
Curculionidae									
Curculio sp. (an acorn weevil)				2					
Mordellidae (tumbling flower beetles)							1		
Ripiphoridae (wedge-shaped beetles)									
Ripiphorus sp. (parasite of ground-nesting bees)				2					
Diptera (true flies)	2		1			1	2		
Asilidae (robber flies)									
Eudioctria sp.			1	1					
Holocephala sp. ("gnat ogre")					1				
Laphria sp. (a bumblebee mimic)	1		1						
**Orthogonis stygia* (a spider wasp mimic. **RARE*)			1						
Bombyliidae (bee flies. parasitoid of solitary bees)									
Bombylius major ("greater bee fly")			1	1					
Bombylius pygmaeus			1	1					
Villa lateralis (a bee mimic)	1			2	2				
Calliphoridae (blow flies, "green bottle flies")	2					1			
Conopidae (thick-headed flies)				1					
Myopa sp. (parasite of honey bees and mining bees)		1							
Physocephala sp. (a solitary wasp mimic)		1	3	2	4				
Stylogaster sp.		1							
Dolichopodidae (long-legged flies)				1				1	1
Dryomyzidae (dryomyzid flies)						1			
Micropezidae (stilt-legged flies, mimic of ichneumon wasps)	1					2			
Mydidae (mydas flies, mimic of spider wasps)					1				
Phoridae (humpbacked flies, "scuttle flies")			1	1					
Sarcophagidae (flesh flies)		1				1		1	2
Scathophagidae (dung flies)		1							
Sciomyzidae (marsh flies)				1					
Tetanocera sp.		1							
Syrphidae (hover flies, flower flies)			1	3	3	2	1		
Chalcosyrphus sp. (a wasp mimic)			1						
Criorhina sp. (a bumblebee mimic)				1					
Eristalis tenax (drone fly, mimic of honeybees)		1	1	4	2				
Mallota sp. (a bumblebee/carpenter bee mimic)	1	2		3	3	3			
Sphaerophoria sp. (a bee mimic)	1		4						
Spilomyia alcimus (a yellowjacket mimic)					1				
Spilomyia fusca (a baldfaced hornet mimic)		2		1					
Spilomyia longicornis (a yellowjacket mimic)		1			4				
Syrphus sp. (a bee mimic)	2	2	1	3		1			
Toxomerus sp. (a bee mimic)	3	12	3	6	8	7			
Trichopsomyia sp. (a wasp or bee mimic)					1				
Xylota sp. (a wasp or bee mimic)					1				
Tabanidae (horse flies, deer flies)						1			
Tachinidae (tachinid flies)	1	2	1		1	3		1	
Tephritidae (fruit flies)									
Eutreta sp.					1			1	
Hemiptera (true bugs)			1						
Fulgoroidea (planthoppers)								1	
Miroidea									
Miridae (plant bugs)	1	1							
Hymenoptera (bees, wasps, and ants)									
Braconidae (braconid wasps)									
-Agathidinae				1					
-Alysiinae						1			
-Braconinae	1			1					
-Orgilinae								2	
-Rogadinae						1	1		
Cephidae (stem sawflies)				1					
Chalcididae (chalcidid wasps)									
Brachymeria sp.					1				
Conura sp.		1							
Chrysididae (cuckoo wasps)									
Chrysis nitidula						1			
Elampus sp.	10	3	1	16	2			2	1
Crabronidae (crabronid wasps, "square-headed wasps")									
Aphilanthops sp.				3					
Bembix sp. (a sand wasp)			1						
Cerceris sp. ("weevil wasp")	43	22	26	84	56				
Ectemnius sp.	1	3	1						
Gorytes sp. (a sand wasp)			1						
Lestica sp.		1							
Nysson sp.								1	
Philanthus sp. ("beewolf")	1		1	1	1				
Trypoxylon sp.		1							
Cynipidae (gall wasps)								1	
Diapriidae (diapriid wasps)								7	2
Eucharitidae (eucharitid wasps)	1								

OTHER TAXA	"SWEEPMAIN" (8 collection days)						"BOWLTRAP" (1 collection day)		
	Hy Fol	Stem Fol	Mow	Mow w/Tx	BLV	Hand	Blue	Yellow	White
Eulophidae (eulophid wasps)			1						
Formicidae (ants)									
-**Formicinae**	1			1					
Gasteruptiidae ("carrot wasps")									
Gasteruption sp.	2								
Ichneumonidae (ichneumon wasps)									
-**Acaenitinae**			1						
-**Anomaloninae**	7	6	3	1	11	3			
-**Banchinae**	1				2				
Banchus sp.		1		1					
Exetastes sp.	3								
-**Campopleginae**	2	4		1	1	4			
-**Cremastinae**	4								
-**Ctenopelmatinae**	3			1	1				
-**Diplazontinae**	1					1			
-**Ichneumoninae**				2	2	7		2	
-**Metopiinae**									
Metopius sp.					1				
-**Ophioninae**				1					
Thyreodon atricolor			1						
-**Phygadeuontinae**	1	1		1		2		2	1
-**Pimplinae**		1			2				
Pimpla pedalis						2			
-**Tryphoninae**	1	1	1	1	1				
Phytodietus sp.		1				1			
Pamphiliidae (web-spinning sawflies)		1			1	2			
Pelecinidae (pelecinid wasps)									
Pelecinus polyturator						1			
Perilampidae (perilampid wasps)	1								
Pompilidae (spider wasps)									
Aporinellus sp.							2		2
Arachnospila sp.								1	
Ceropales sp.			2	1					
Minagenia sp.						1			1
Poecilopompilus interruptus		2							
Priocnemis sp.						1			
Pteromalidae (pteromalid wasps)	1	1					1	1	
Scelionidae (scelionid wasps)							1		
Sphecidae ("thread-waisted wasps")									
Ammophila sp.	2	1		3	7				
Podalonia sp. ("cutworm wasp")	2		2	1	2				
Tenthredinidae (common sawflies)	8	3	7	3		2		2	
Tiphiidae (tiphiid wasps)									
Tiphia sp.						1			
Trigonalidae (trigonalid wasps)									
Lycogaster pullata				1					
Vespidae (hornets, mason wasps, paper wasps, potter wasps, yellowjackets)									
-**Eumeninae** (mason wasps, potter wasps)	1								
Ancistrocerus adiabatus		3			2	1			
Ancistrocerus antilope	4	11	5		1				
Ancistrocerus parietum			1			1			
Ancistrocerus unifasciatus	1								
Eumenes crucifera		3		2					
Eumenes fraternus (potter wasp)				1					
Eumenes verticalis	1			1					
Euodynerus boscii	6	1	7		6	2			
Euodynerus foraminatus		1	1	2	2	1			
Euodynerus hidalgo			1						
Monobia quadridens ("four-toothed mason wasp")		2							
Parancistrocerus pedestris	1								
Parancistrocerus pennsylvanicus				1	1	1			
Symmorphus sp.					1				
Symmorphus albomarginatus			1						
-**Polistinae** (paper wasps)									
Polistes bellicosus		1							
Polistes dorsalis	2	4	1						
Polistes fuscatus (golden paper wasp, Northern paper wasp)			2	1					
Polistes metricus	1								
-**Vespinae** (hornets, yellowjackets)									
Dolichovespula arctica (parasitic yellowjacket)					1				
Dolichovespula maculata (baldfaced hornet)		1	3		5				
Vespula flavopilosa ("downy yellowjacket")	2	1	1		3				
Vespula maculifrons (Eastern yellowjacket)	1	3	2	1	4	2			
Vespula vidua ("ground hornet")				1					
Xiphydriidae (xiphydriid wasps, wood wasps)									
Xiphydria sp.		1			2				
<u>Mecoptera</u> (scorpionflies and hangingflies)									
Panorpidae (common scorpionflies)									
Panorpa sp.						1			

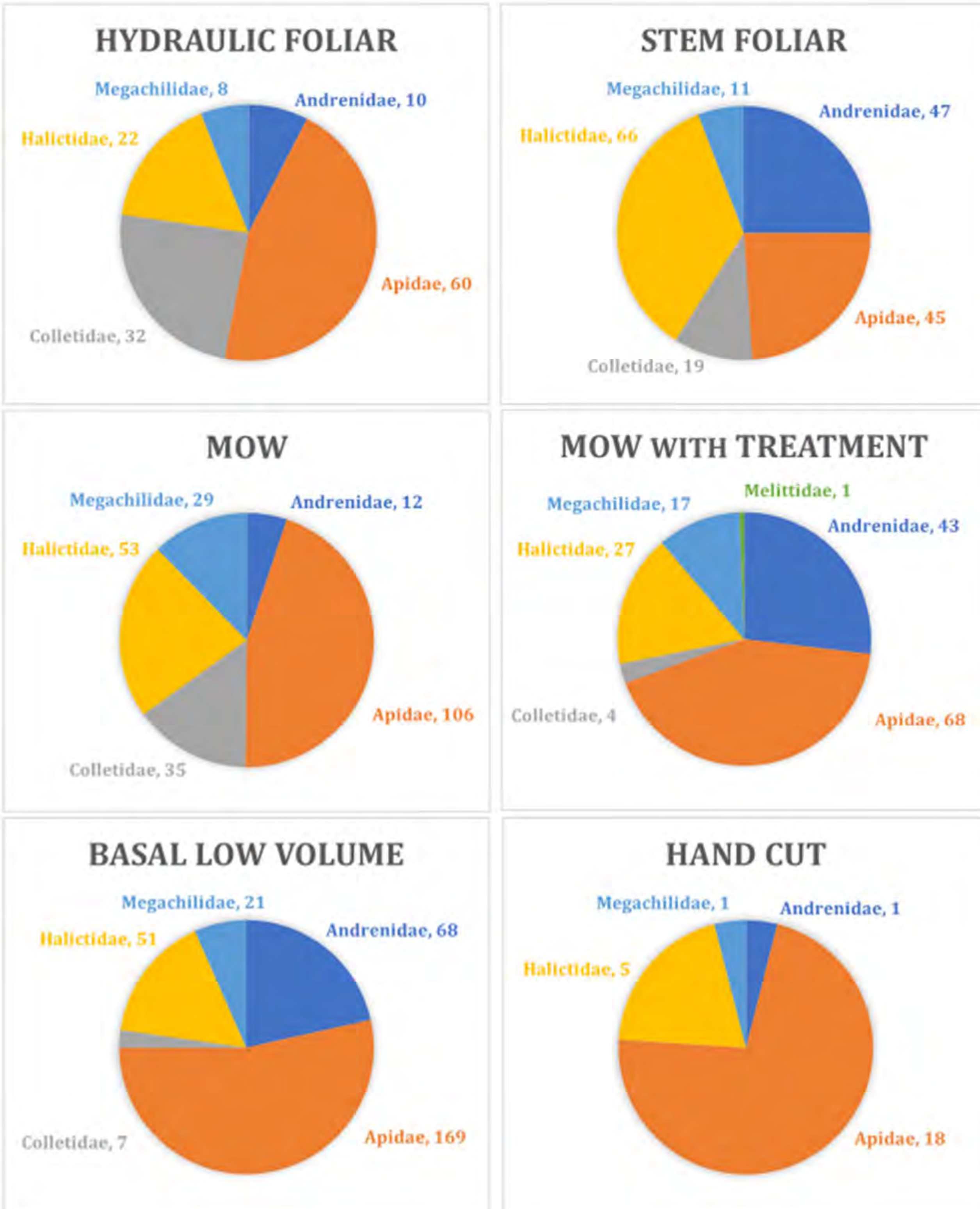
	Hy Fol	Stem Fol	Mow	Mow w/Tx	BLV	Hand	Blue	Yellow	White
Total Number of Individuals:	135	116	102	173	155	63	10	26	11
Individuals of Other Taxa = __% of the Total (Bees + Other Taxa):	50.56%	38.16%	30.27%	51.95%	32.91%	71.59%	28.57%	81.25%	68.75%
Total Number of Taxa:	45	45	45	48	42	34	8	15	8
Other Taxa = __% of the Total (Bee + Other Taxa):	56.96%	48.39%	48.91%	52.75%	38.89%	72.34%	34.78%	78.95%	66.67%

APPENDIX D

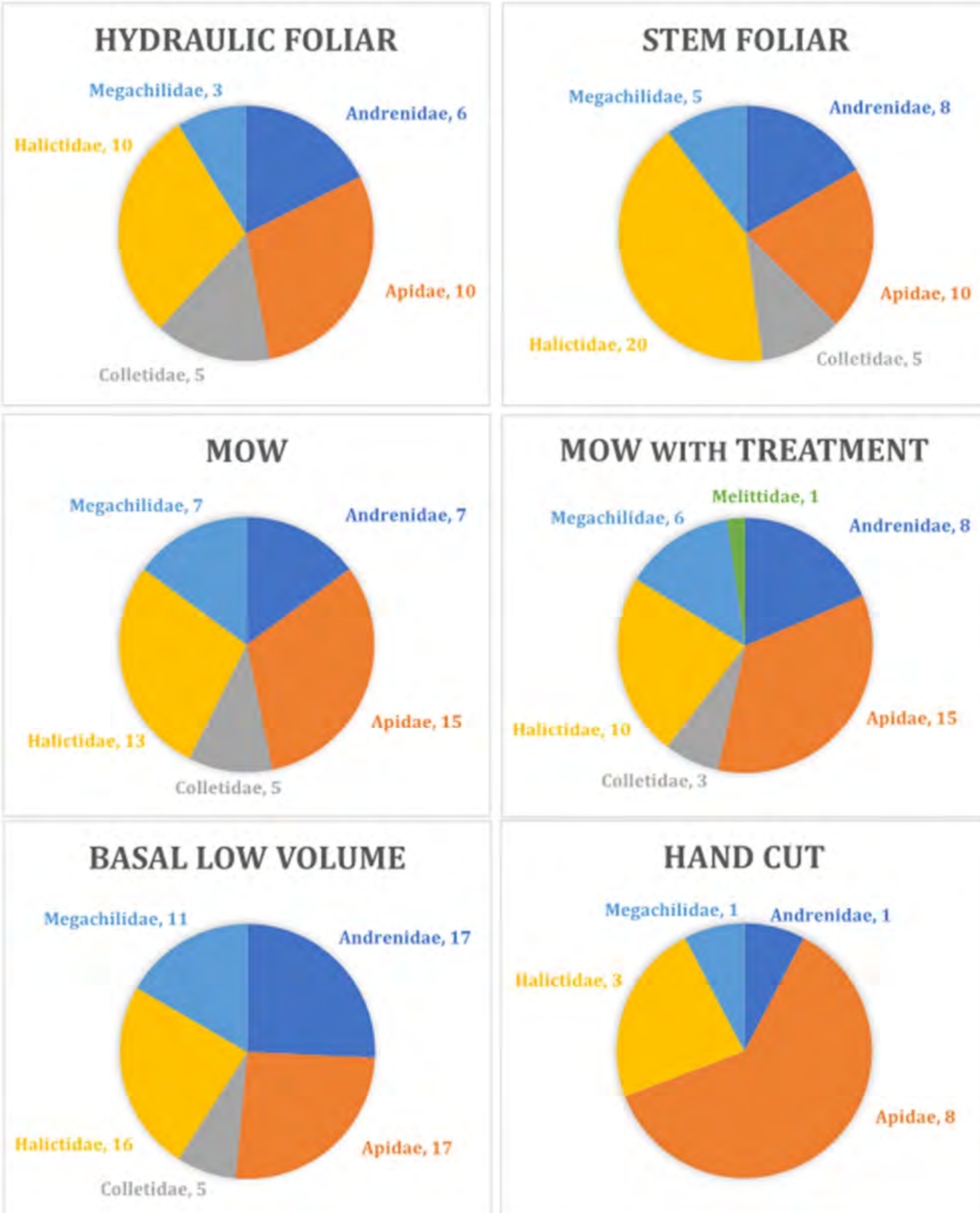
BEE FAMILY DENSITY AND TAXA RICHNESS PER TREATMENT

BEE FAMILY DENSITY PER TREATMENT

(FAMILY, NUMBER OF ***INDIVIDUALS*** PER FAMILY)



BEE FAMILY TAXA RICHNESS PER TREATMENT
(FAMILY, NUMBER OF ***TAXA*** PER FAMILY)



European honey bee *(Apis mellifera)* on *Prunus* flowers. (Photo: K. Engstrom)