BeeMapper Users Guide

http://www.umaine.edu/beemapper

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Section 1. Introduction to BeeMapper

BeeMapper was developed to aid Maine wild blueberry growers in making pollination management decisions on their farms. The tool provides maps of wild bee habitat resources and predicted wild bee abundance and allows crop growers to interact with these maps in the landscape surrounding their crop fields. BeeMapper summarizes the information in the maps surrounding each crop field in terms of habitat suitability and wild bee contribution to fruit set from the perspective of small wild bees that fly less than 250 yards as well as large wild bees that can fly up to 1000 yards. This information can be used to aid decisions about the number and placement of rented honey bee hives or installation and location of pollinator plantings to promote wild bee populations.

1.1 Landscape ecology of wild bees

Landscape ecology explores how the composition and arrangement of different types of land across a landscape affects the organisms within that landscape. These landscapes vary in size depending on the organism(s) studied. For example, a wild bee landscape is much smaller than a human landscape (Figure 1).

Colletes inaequalis
Max flight limit: 0.5 mi

Osmia inspergens
Max flight limit: 0.25 mi

Halictus ligatus
Max flight limit: 560 ft

Lasioglossum leucomomum
Max flight limit: 90 ft
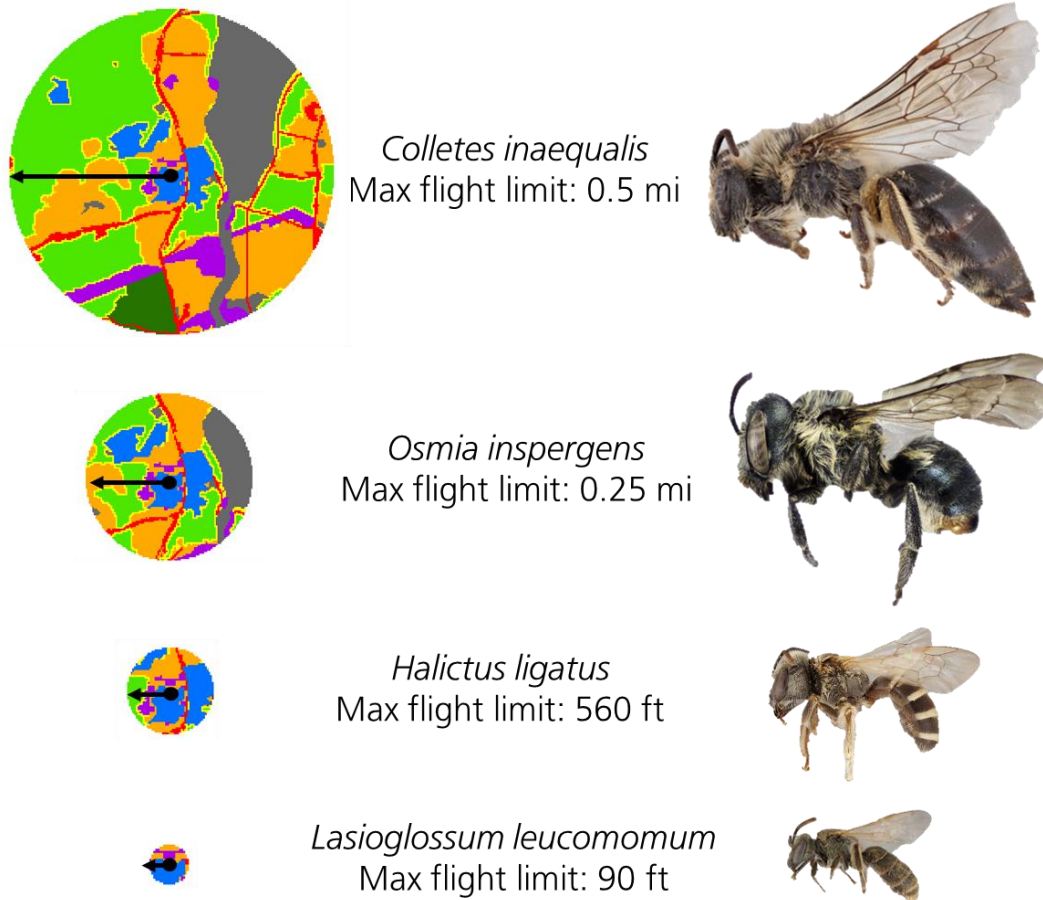
Photos © Laurence Packer 2014 via Discover Life

Figure 1. Landscape size and maximum flight limits of four Maine wild bees.

Bee landscape size is determined using two principles. First, bees are **central place foragers**, meaning they find food, or forage, in the area surrounding their nest and then return to their nest. Second, the **maximum flight limit** of a bee can be estimated by a measure of body size called the intertegular wingspan. This is the distance between the two tegula, the shield-like coverings at the base of a bees wings (Figure 2). Honey bees are the exception to this relationship, however, and have repeatedly demonstrated their ability to fly up to 5 miles to find food. Maximum flight limits for common Maine wild bees can be found in Appendix B.
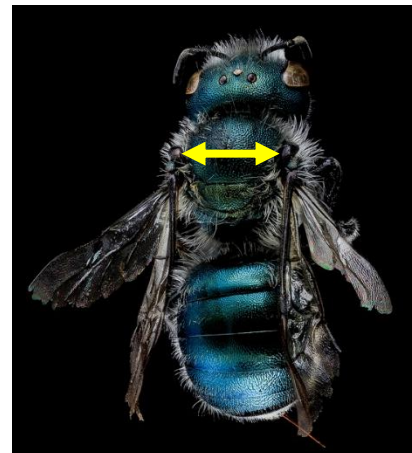
Figure 2. Intertegular wingspan of the wild bee *Osmia atriventris*.

The small size of wild bee landscapes limits where wild bees can survive. Wild bees need the habitat resources necessary to survive within these landscapes, which include nesting substrate and flowering plants for food. Bee habitat resource availability varies across Maine's wild blueberry production landscape, and therefore some types of land are better suited for wild bee habitat than others. BeeMapper presents eight land cover types in Maine's wild blueberry production landscape that each provide a unique set of habitat resources to wild bees (Figure 3). More information on these land cover types can be found in Appendix C.
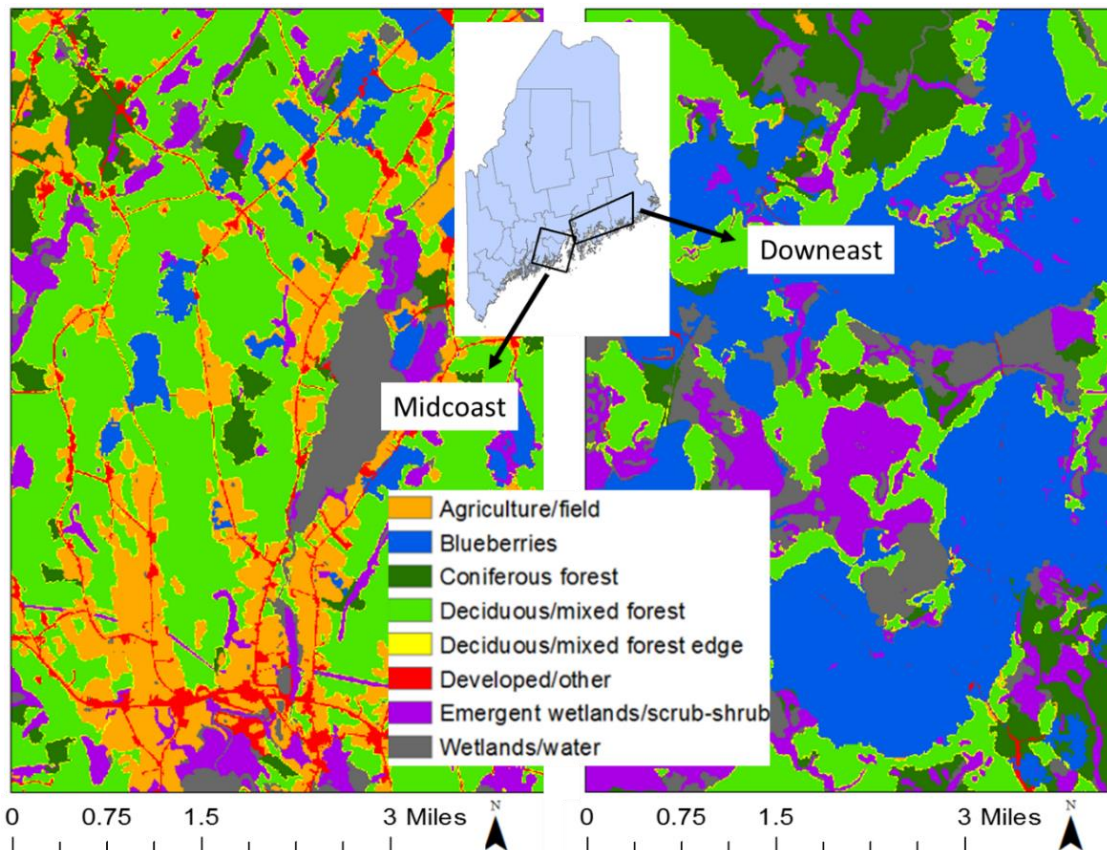
Figure 3. Composition and arrangement of eight land cover types in two growing regions of Maine's wild blueberry production landscape.

1.2 Wild bees and Maine's wild blueberry production landscape

Maine's wild blueberry production landscape differs from most well-studied agricultural landscapes in that it is forest-dominant and contains a large amount of natural habitat for wild bees within forest and crop field edges and forage associated with wetlands, grasslands, and developed areas. Furthermore, there are two blueberry growing regions within Maine that vary in the composition and arrangement of the eight land cover types providing habitat resources to wild bees (Figure 3).

The **Downeast** region covers coastal Hancock and Washington counties and is characterized by large, intensively-managed crop fields surrounded by coniferous forest and emergent wetland. The **Midcoast** region covers Knox County and parts of Lincoln and Waldo counties and is characterized by smaller, more often organically managed crop fields surrounded by deciduous forest and interspersed with other agriculture and urban areas. This dichotomy provides an opportunity to compare the effects of landscape composition and arrangement on wild bee communities. Research suggests that more complex landscapes, such as that of the Midcoast region, harbor bee communities that are more diverse and abundant than simpler landscapes such as the Downeast region. Ongoing bee community surveys in these regions will determine if that is the case.

1.3 Predicting wild bee abundance across agricultural landscapes

Ecosystem services are the economic contributions made by natural phenomena. Crop pollination by wild bees is an ecosystem service, and more than 120 species of wild bee (excluding bumble bees) have been collected in blooming wild blueberry fields in Maine (Bushmann and Drummond 2015). In order to harness wild bee resources more effectively for crop pollination, we need to understand their habitat use outside of crop fields. The **InVEST Crop Pollination model** (Lonsdorf et al. 2009) uses a land cover map along with habitat suitability scores to predict wild bee abundance across agricultural landscapes. We have applied this model to Maine's wild blueberry production landscape (Groff et al. 2016) to produce a map of predicted wild bee abundance. This map highlights areas of high wild bee abundance and indicates areas to improve bee abundance through habitat enhancement. We validated the map predictions using data collected through Maine's wild blueberry production landscape to produce accurate and reliable predictions of wild bee abundance. Appendix D details application of the InVEST Crop Pollination model to Maine wild blueberry.

We developed BeeMapper to share these maps with wild blueberry growers and collaborated with growers throughout the development process. We collected feedback from growers who use a variety of management practices on multiple prototypes of the tool, ultimately leading to a simple, straightforward, interactive interface. This User's Guide describes the features of BeeMapper, demonstrates how to use the tool and interpret the map data, and provides suggestions on pollination management practices to enact given those data.

Section 2: Using BeeMapper

This section is a guide to the use of BeeMapper, the information it provides, and how you can use this information to make pollination management decisions.

2.1: Opening BeeMapper and Exploring Tool Features

To access the web tool, please visit the homepage at http://www.umaine.edu/beemapper. Recommended web browsers for BeeMapper are Google Chrome, Mozilla Firefox, Safari, and Opera. BeeMapper is only compatible with Internet Explorer versions 9.0 or newer. Once at the homepage, launch BeeMapper by clicking on the image of the tool.

Now that that tool is open, let's explore the features of the BeeMapper home screen (Figure 4).
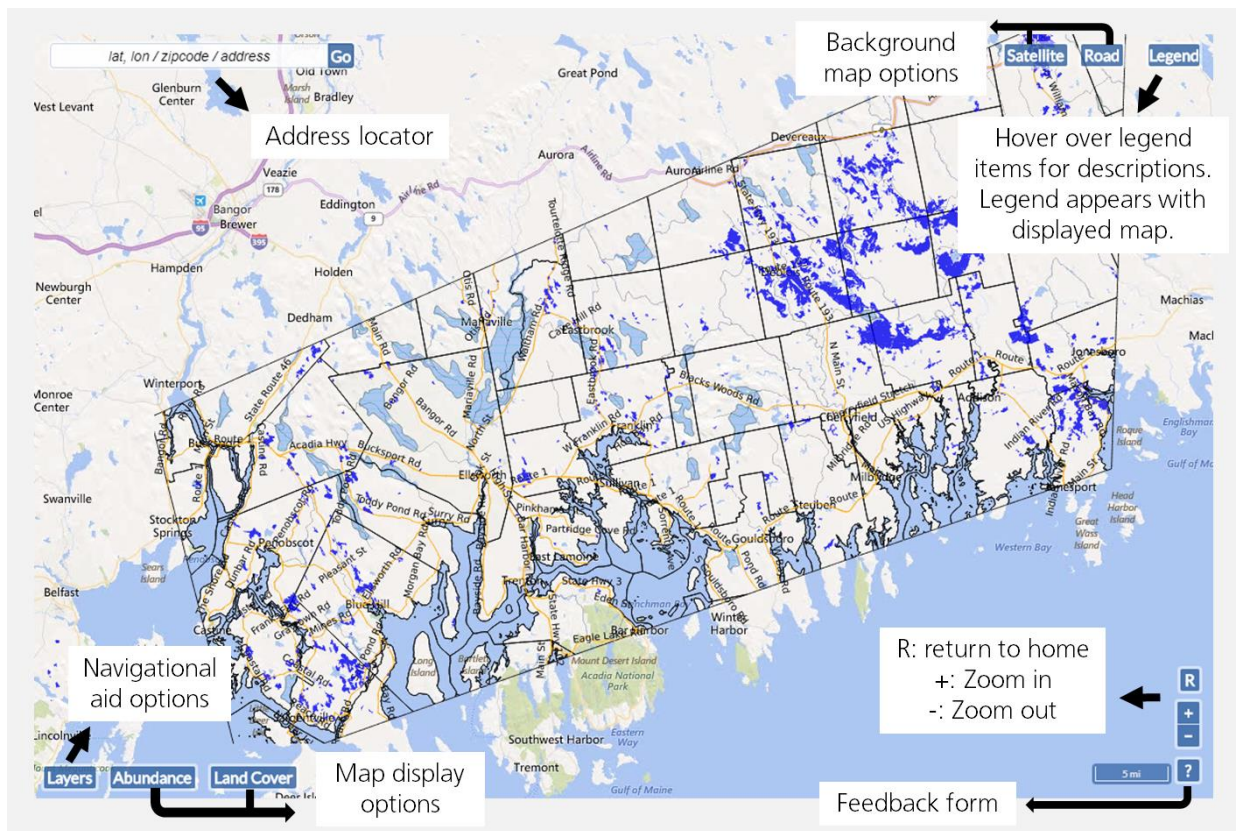

Figure 4. BeeMapper home screen, which appears upon launch of the tool.

Home screen icons:

- The **address locator** is in the top left corner. You can use this to find your field on the map.
- You can choose between two **background map options**: 1) a road map or 2) a satellite image map. Choose a background map using the "Road" and "Satellite" buttons in the top right corner.

- The **legend** button will display the legend for the current map layer. If no map layers are displayed (this is the default setting), no legend will be displayed.
- There are three **map layer buttons** in the bottom left corner (Figure 5):

Figure 5. Navigational aid options found by clicking the Layers button. These maps can be turned off and on using the check boxes next to their names.

- o Layers: this button displays a menu of navigational aids to help locate your field(s). These navigational aids can be turned off and on using the check boxes next to their names. They include: lakes, rivers and streams, town boundaries, roads, and wild blueberry fields.
- o Land Cover: This map displays land cover, or the type of land found across the wild blueberry production landscape. See Section 2.4 for details on this map.
- o Abundance: this map displays the predicted wild bee abundance across the wild blueberry production landscape. See Section 2.4 for details on this map.

- The **tool navigation buttons** in the bottom right corner allow you to zoom in [+], zoom out [-], or return to the entire coverage of the map [R]. There is also a button for a **feedback form** [?] to send questions, comments, or corrections back to the BeeMapper development team. See Appendix A for more information about the feedback form.

2.2: Locating a blueberry field

The first step of using BeeMapper is locating your blueberry field. There are two ways to locate a wild blueberry field:

Method 1: Use the address locator box in the top left corner. Type in the town, street address or latitude-longitude coordinates of a field, and the tool will zoom in on this location.
Method 2: Manually navigate to a field using the roads, rivers, lakes, and town boundaries provided in the tool. Place the cursor over the location of the field and scroll up to zoom in. You can also zoom in using the button in the lower right corner, then click and drag the map to the location of your field.
- a. To click and drag the map: Click on any area in the map and hold down the mouse. Drag the mouse across the screen, and the map will move along with it.

b. If the navigational aids are creating too much clutter on the screen, they can be turned off by clicking the "Layers" button and unchecking the boxes next to the layer names (Figure 5).

2.3: Pollinator habitat assessment

Once at the blueberry field, click on it. Two shaded regions appear around the field, which represent the distance different sized wild bees can fly to access that blueberry field (Figure 6).

- The small circle encloses 250 yards from the edge of the blueberry field. Small wild bees can fly from within this area into your blueberry field for pollination. For more information about small wild bees, see Appendix B.
- The large circle encloses 1000 yards from the edge of the blueberry field. Large wild bees, such as bumblebees, can fly from within this area into your blueberry field for pollination.

These circles are your wild bee source habitat. Wild bees that can contribute to crop pollination in your field have their nests and find forage before and after crop bloom here.
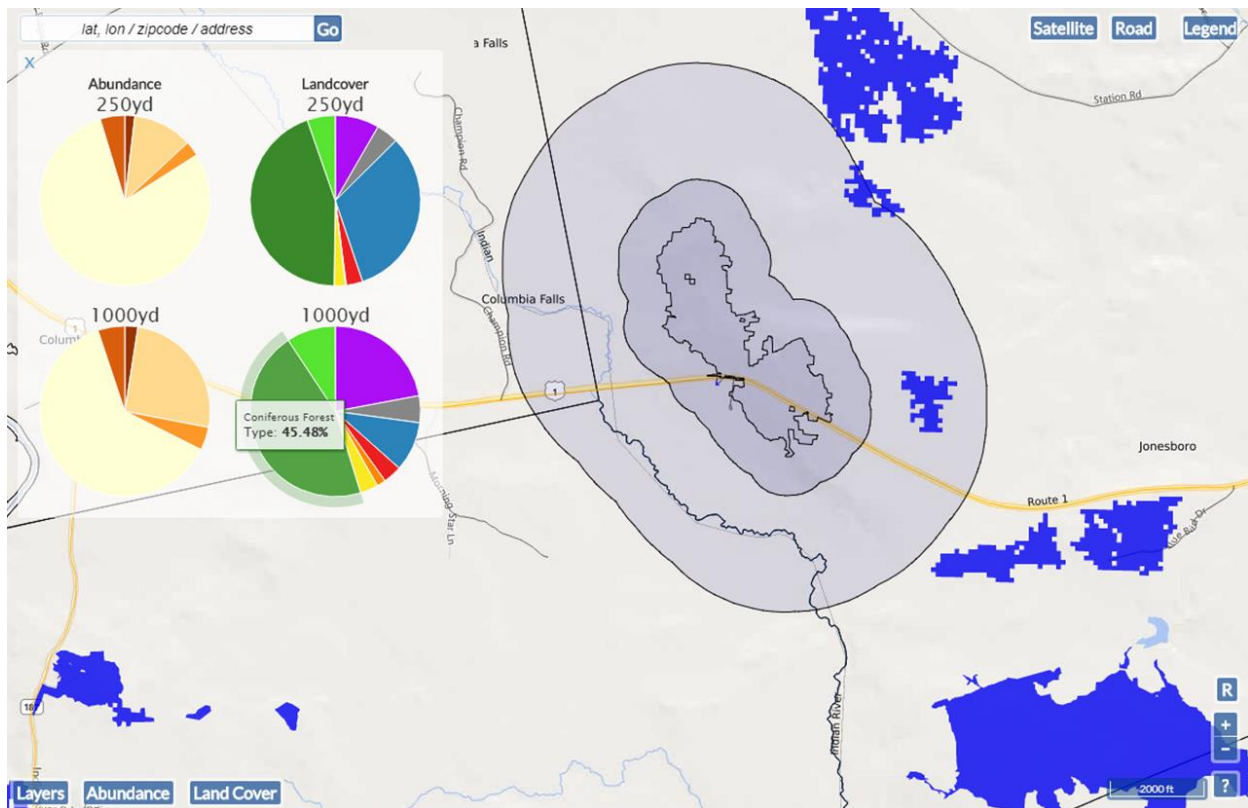
Figure 6. Wild bee source habitat (250 yd for small bees; 1000 yd for large wild bees) and pollinator habitat assessment summary box for a wild blueberry field.

When you click on a field, a summary box with four pie charts appears in the top left corner (Figs. 6 and 7). These pie charts summarize the land cover and predicted wild bee abundance maps for the small wild bee source habitat (250 yd) and large wild bee source habitat (1000 yd) surrounding a

field. Hover over each wedge for a category label and percent total value. To close the summary box, click the X in the top left corner.
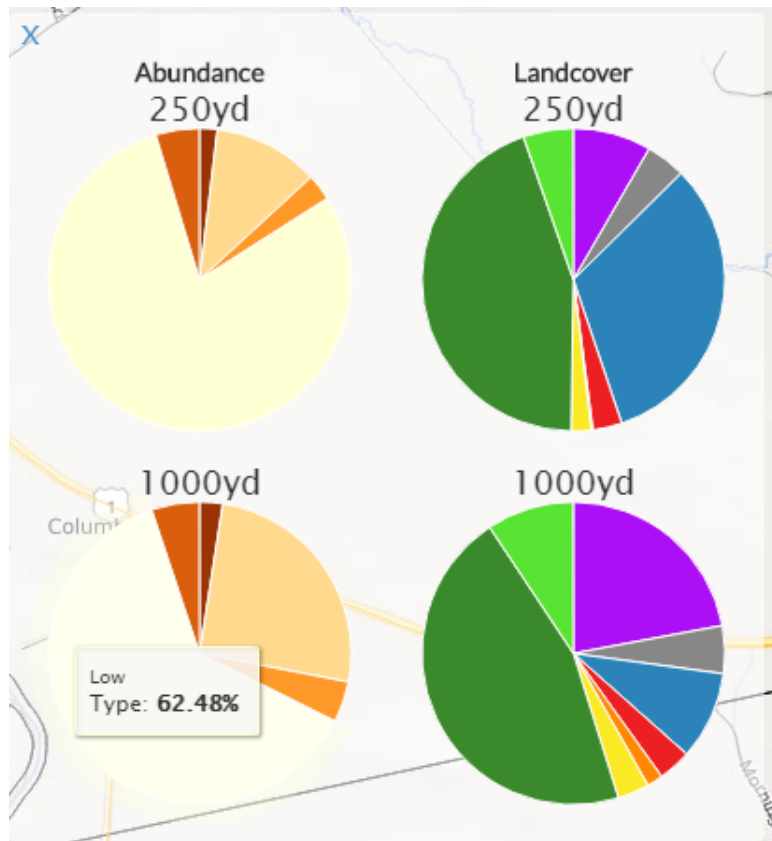
Figure 7. Pollinator habitat assessment summary charts.

2.4. Understanding the maps

BeeMapper is based on two maps:
- The **land cover map** displays eight land cover types that each offer a unique set of habitat resources to wild bees (Figure 8). For more information on these land cover types, see Appendix C.
- The **predicted wild bee abundance map** displays our prediction of wild bee abundance across the Maine wild blueberry production landscape (Figure 9). For more information on how this map was generated, see Appendix D.

To display the **land cover map**, click the "Land Cover" button in the bottom left corner. When the map appears, a corresponding legend appears under the "Legend" button in the top right corner (Figure 8). Hover over each land cover type in the legend for a short description. The legend can be turned off and on by clicking the "Legend" button.
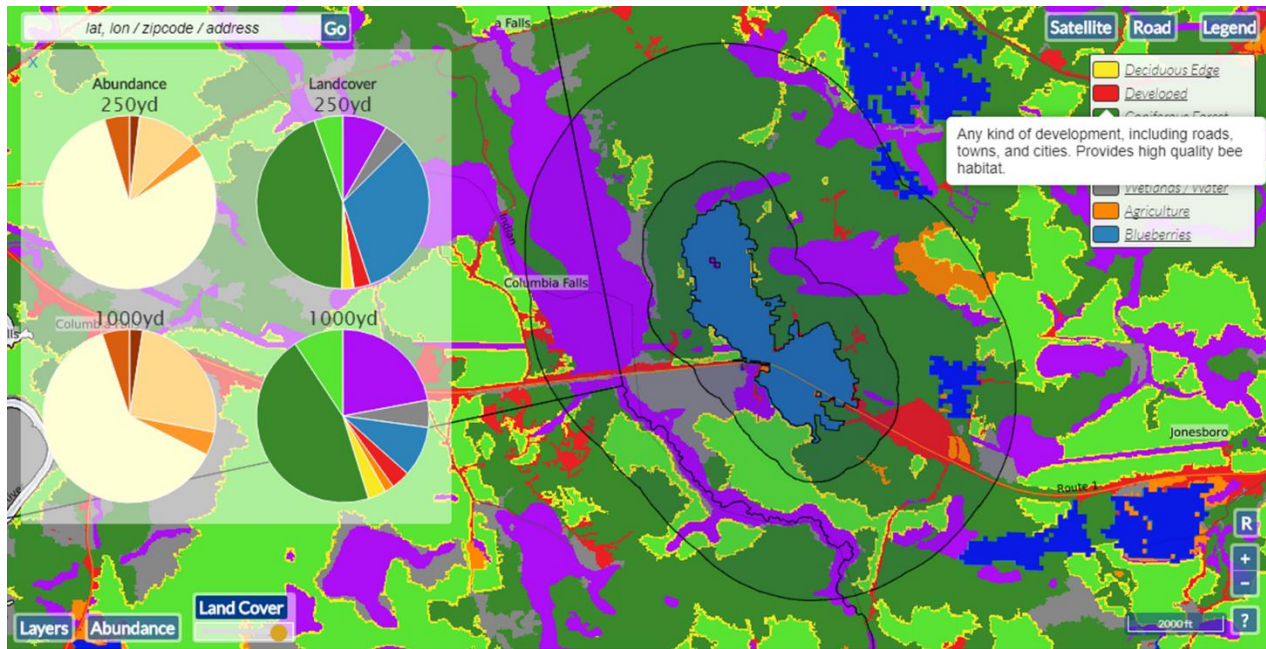
Figure 8. Land cover map and legend.

See Section 3.1 for more information on land cover type and pollinator habitat suitability.

To display the **predicted wild bee abundance map**, click the "Abundance" button in the bottom left corner. A light to dark brown shaded map appears with a corresponding legend, displaying predicted wild bee abundance across the landscape (Figure 9).

Figure 9. Predicted wild bee abundance map and legend.

The abundance map is categorized into 5 classes. Hover over each category in the legend for a brief description. Predicted wild bee abundance is typically low across the Maine wild blueberry production landscape (Groff et al. 2016). The predictions used to make this map are a combination of the land cover type and habitat suitability for wild bees (see Appendix D for more information). 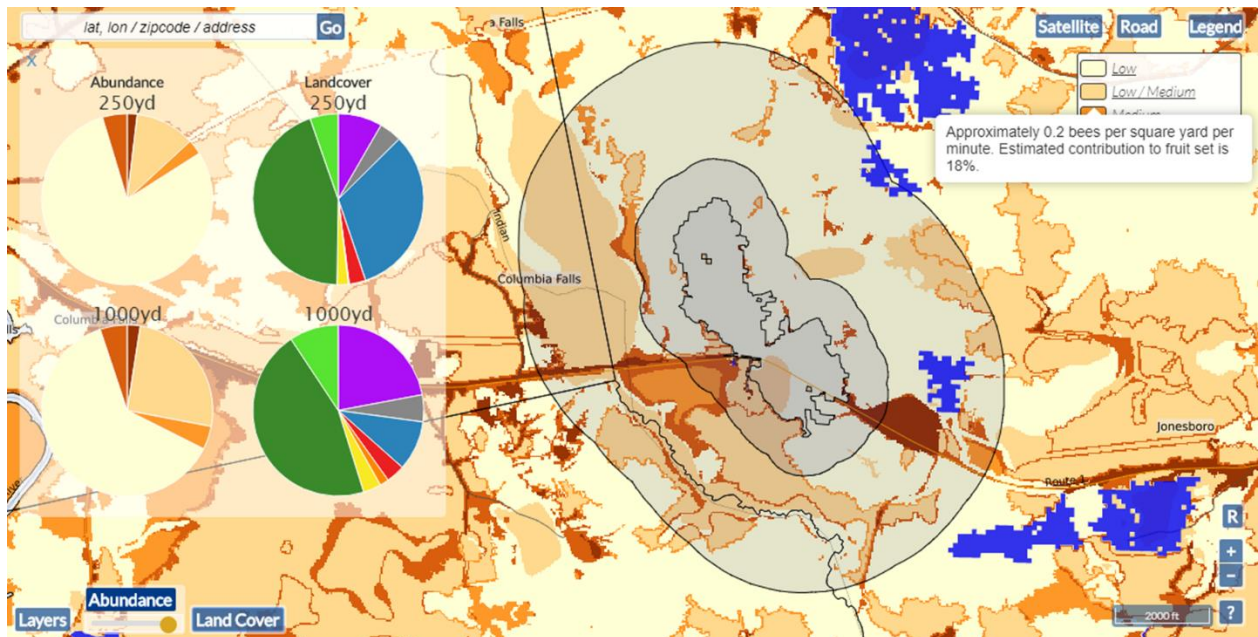The estimates for number of bees and contribution to fruit set are based off of a large data set on wild bee density collected by Dr. Frank Drummond at the University of Maine:

- Low: Approximately 0.1 bees per square yard per minute (1 bee per clone every 10 minutes). Estimated contribution to fruit set is 12%.
- Low-Medium: Approximately 0.2 bees per square yard per minute (2 bees per clone every 10 minutes). Estimated contribution to fruit set is 18%.
- Medium: Approximately 0.3 bees per square yard per minute (3 bees per clone every 10 minutes). Estimated contribution to fruit set is 20%.
- Medium-High: Approximately 0.4 bees per square yard per minute (4 bees per clone every 10 minutes). Estimated contribution to fruit set is 25%.
- High: Approximately 0.5-1.0 bees per square yard per minute (5-10 bees per clone every 10 minutes). Estimated contribution to fruit set is 30%.

Section 3. Interpreting BeeMapper information

BeeMapper illustrates the connection between land cover type and wild bee habitat resources. The types of land surrounding wild blueberry fields play a very strong role in determining the wild bee community present. Working with the landscape surrounding your crop fields can affect your wild bee pollination resource.

3.1 Land cover type and pollinator habitat suitability

Wild bees prefer habitat that has a variety of wildflowers for collecting pollen and nectar, ample sun exposure for warmth and easy flying, and dead wood or open, sandy soils for building nests. Using this information, experts predict that deciduous/mixed forest edge and urban/developed land cover types will provide good bee habitat. Other land cover types can provide more wildflowers (emergent wetlands, agriculture) or better nesting areas (blueberries, deciduous/mixed forest). Coniferous forest and wetlands/water provide less wild bee habitat resources than the other land cover types.

Look at the land cover map within the shaded regions surrounding your fields.
- What is the most common land cover within these buffers?
- What do you think this could mean for bees?
    - Does this land cover provide high quality or poor quality bee habitat?

With this information in mind, look at the predicted wild bee abundance around your blueberry fields. Compare the abundance map to the land cover map.
- Can you see how the land cover affects the predicted wild bee abundance?
    - What types of land correspond with high bee abundance? With low bee abundance?
- What is the predicted bee abundance around your blueberry fields? Why?

3.2. Making pollination management decisions

Areas with high wild bee abundance can provide up to 30% of fruit set to a nearby wild blueberry field. If these patches are found around your field, you might strategically place rented honey bee hives or purchased bumblebee quads away from these areas. You can concentrate managed pollinators in areas of your crop field that are not surrounded by high quality wild bee habitat. Additionally, conserving areas with high wild bee abundance ensures that wild bees will continue to pollinate your crop. If your crop field is surrounded by poor quality wild bee habitat with low predicted wild bee abundance, you may consider habitat enhancement to promote wild bee populations around your crop field. See Appendix E for additional resources on pollination management.

3.3 Wild bee conservation

Wild bees are an important part of crop pollination because they are more efficient wild blueberry pollinators than honey bees. The wild blueberry landscape often can be harsh for wild bees, but there are actions you can take to manage, promote, and conserve wild bee populations around your blueberry fields. See Appendix E for additional resources on wild bee conservation.

- Installing bee pasture will provide ample forage resources for wild bees. Instructions on bee pasture installation are provided by the University of Maine Cooperative Extension. To create similar resources with less effort, you may consider leaving fallow areas near your fields to flower or allowing wildflowers along field edges to bloom.
- Provide nesting resources for wild bees by installing nesting boxes for cavity nesting bees or leave open patches of sandy soil available for ground nesting bees. Allowing woody shrubs near crop fields also provides nesting resources for cavity nesting bees.
- Reduce pesticide applications, and aim to use pesticides with low toxicity to wild bees.

3.4 Limitations

The land cover map displayed in BeeMapper is based on the 2004 Maine Land Cover Dataset (MeLCD, http://www.maine.gov/megis/catalog/metadata/melcd.html). Any change in land use since 2004 will not be accounted for in this map. In Maine, this generally means missing forest harvest, which may or may not lead to land cover change. Research in Maine is developing and ongoing as to the pollinator habitat suitability of recently harvested forest, information that may be of critical importance for wild blueberry growers.

The map is static and does not support user-generated modifications, such as the effects of installing a pollinator planting on wild bee abundance. BeeMapper provides a baseline pollinator habitat assessment for Maine wild blueberry growers to inform pollination management decisions.

We have discovered that wild bee abundance is difficult to predict accurately in blueberry fields that are small or irregularly-shaped. Model predicted bee abundance is lower, but more accurate in large, square-shaped fields with simple edges and is often overpredicted in small, elongated fields with complex edges. This does not affect predictions in other land cover types, which we have found to be accurate owing to the large amount of these other cover types in comparison to wild blueberry.

Appendix A: Using the BeeMapper feedback form

We welcome comments, suggestions, and corrections to BeeMapper through the feedback form, which is accessed by clicking the button with the question mark [?] in the bottom right corner of the tool window (Figure 10). The feedback form will appear in the top left corner of the window.
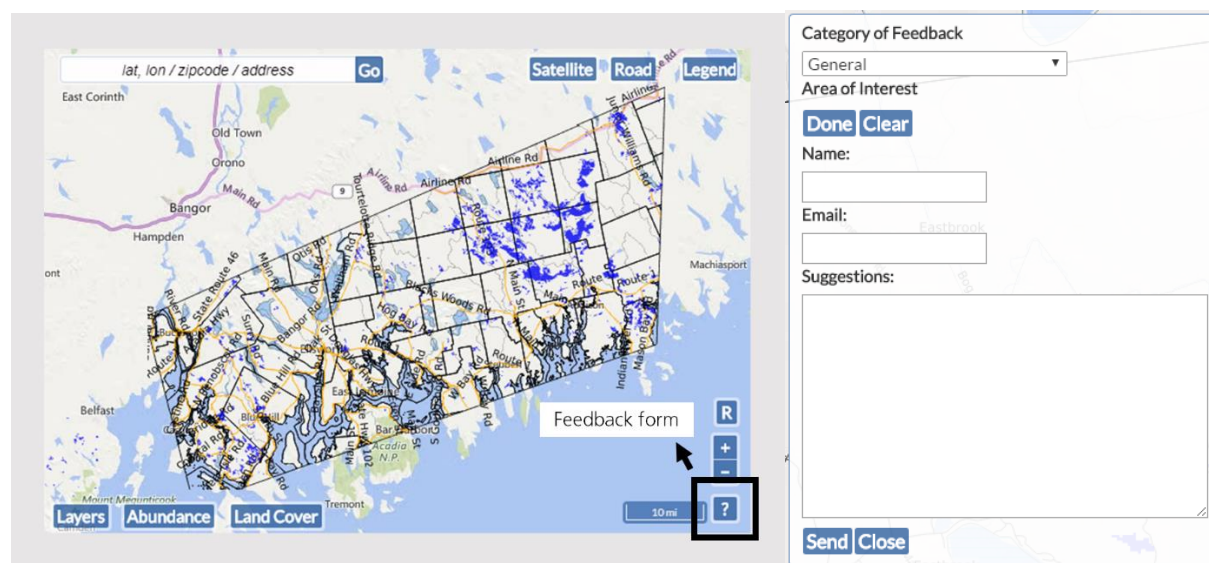
Figure 10. Location of the feedback form button in the BeeMapper home screen and the feedback form, which appears in the top left corner of the tool window.

All feedback goes to the BeeMapper technical development team, who will work to address any problems and answer any questions.

There are three categories of feedback:
1. General: Any questions or comments beyond data inaccuracies or website problems can be submitted under this category.
2. Map is inaccurate: If your blueberry field is not classified as blueberry in BeeMapper, please let us know through this category on the feedback form. You also can alert us to other data inaccuracies, such as an agricultural area classified as a forest, etc. Please provide a street address or lat/long coordinates so we can locate the area and make the corrections.
   a. You can also send us a picture of the inaccurate area using the "Area of Interest" menu on the feedback form. To do this, click "Select," then draw the area that is incorrect. When finished, click "Done." If you need to re-draw the area, click the "Clear" button and try again. See Appendix A.2 for more details on this process.
3. Technical troubles with website: If buttons aren't working, the maps take too long to load, or if the summary box is not displaying correctly, please let us know using this category of feedback.

Please provide your name and email address or other contact information to allow the development team to contact you with any questions. Provide feedback within the "Suggestions" box, then click "Send" to send your comments. The "Close" button will close the feedback form.

A.2: Submitting feedback for inaccurate data

When submitting feedback regarding inaccurate map data, you may delineate the inaccurate area using the **Area of interest** function of the feedback form. To provide an area of interest, first click the "Select" button on the feedback form. This turns the cursor into a drawing tool. Begin drawing a shape around the inaccurate area on the map (Figure 11).

Figure 11. Drawing an area of interest around an inaccurate data area of the Land Cover map.

To complete the shape, double click and the shape border will turn orange (Figure 12). You may select multiple areas of interest to submit. To clear the area(s) of interest, click the "Clear" button on the feedback form. To finish delineating areas of interest, click the "Done" button on the feedback form.

Figure 12. Completed area of interest and additional comments in the BeeMapper feedback form.

Appendix B: Common wild bees in Maine wild blueberry fields

We collected information on nesting preference, flight season, and foraging distance for these 14 wild bee species commonly found in blooming wild blueberry fields (Bushmann and Drummond 2015) from published scientific literature and expert opinion. This information was input into the InVEST Crop Pollination Model (Appendix D) applied to Maine's wild blueberry production landscape.

Andrena carlini:

Family	Andrenidae
Nesting preference	Ground nesting
Flight season	March-August
Foraging distance	653 yd

Andrena carolina:

Family	Andrenidae
Nesting preference	Ground nesting
Flight season	April-July
Foraging distance	270 yd

Andrena vicina:

Family	Andrenidae
Nesting preference	Ground nesting
Flight season	March-August
Foraging distance	622 yd

Augochlorella aurata:

Family	Halictidae
Nesting preference	Ground nesting
Flight season	April-October
Foraging distance	65 yd

Colletes inaequalis:

Family	Colletidae
Nesting preference	Ground nesting
Flight season	March-September
Foraging distance	1193 yd

Halictus ligatus:

Family	Halictidae
Nesting preference	Ground nesting
Flight season	March-November
Foraging distance	161 yd

Lasioglossum acuminatum:

Family	Halictidae
Nesting preference	Ground nesting
Flight season	April-October
Foraging distance	203 yd

Lasioglossum cressonii:

Family	Halictidae
Nesting preference	Cavity nesting
Flight season	March-October
Foraging distance	68 yd

Lasioglossum heterognathum:

Family	Halictidae
Nesting preference	Ground nesting
Flight season	April-September
Foraging distance	17 yd

Lasioglossum leucomomum:

Family	Halictidae
Nesting preference	Ground nesting
Flight season	March-October
Foraging distance	34 yd

Lasioglossum pectorale:

Family	Halictidae
Nesting preference	Ground nesting
Flight season	March-November
Foraging distance	88 yd

Lasioglossum versatum:

Family	Halictidae
Nesting preference	Ground nesting
Flight season	March-October
Foraging distance	86 yd

Osmia atriventris:

Family	Megachilidae
Nesting preference	Cavity nesting
Flight season	April-July
Foraging distance	203 yd

Osmia inspergens:

Family	Megachilidae
Nesting preference	Cavity nesting
Flight season	May-June
Foraging distance	541 yd

While not incorporated into the InVEST Crop Pollination model, bumble bees are very important wild blueberry pollinators. Bumble bee queens, which are the only caste of bumble bee present during wild blueberry bloom, are much larger than the solitary wild bees featured here. Therefore, bumble bee queens can fly much longer distances than solitary wild bees.

Bombus species:

Family	Apidae
Nesting preference	Ground and cavity nesting
Flight season	Queens: May Workers: June-September
Foraging distance	Queens: 4.7 miles Workers: 1.3 miles

Pictured: orange banded bumble bee (*Bombus ternarius*)
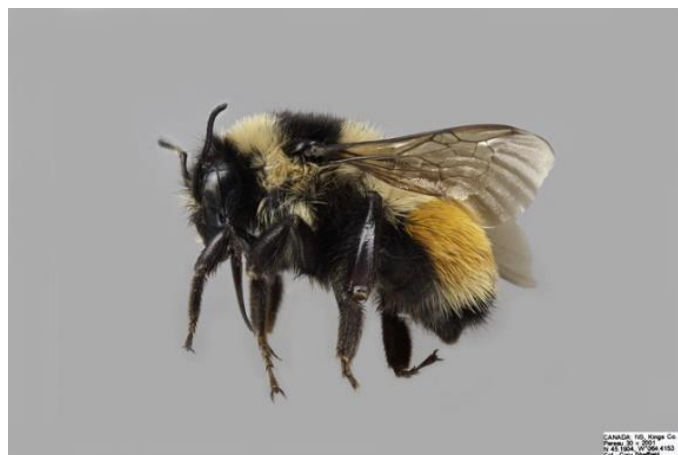
All photos are © Laurence Packer via Discover Life.

Appendix C: Land cover types and wild bee habitat resources

We summarized land cover in Maine's wild blueberry production landscape into eight land cover types relevant to wild bees. Each of these cover types offers a unique set of habitat resources to wild bees. Wild bee habitat resources include nesting substrate and flowering plants for food. Nesting substrate can be bare patches of sandy soil for ground nesting bees or hollow twigs and downed woody debris for cavity nesting bees. Flowering plants should be abundant and diverse throughout the growing season to provide ample and nutritious food for wild bee populations.

Coniferous forest: Consists of softwood trees. Coniferous forest is poor bee habitat. Although it provides some ground and ample cavity nesting resources, the lack of light in the understory does not allow many flowering plants to grow. Furthermore, the density of trees in coniferous forest is difficult for wild bees to fly through, making coniferous forest a potential barrier to accessing nearby patches of abundant floral resources. However, recently harvested patches of coniferous forest may provide high quality bee habitat for a few years until trees become dominant again.

Deciduous/mixed forest: Consists of hardwood or a mixture of hardwood and softwood trees. Deciduous/mixed forest is moderate quality bee habitat, providing some ground nesting resources and ample cavity nesting resources. Sunlight through the tree canopy allows some wildflowers and flowering shrubs to provide pollen and nectar for wild bees throughout the growing season. Flowering trees, particularly maple, are a crucial pollen and nectar source in the early spring and provision many wild blueberry pollinating wild bees.

Deciduous/mixed forest edge: The transition between forests with hardwood or a mixture of hardwood and softwood trees and another land cover type. This is very high quality bee habitat, with excellent ground and cavity nesting resources. Woody shrubs provide hollow twigs, and bare patches of sandy soil are common. There are also plenty of wildflowers and flowering shrubs and trees to provide pollen and nectar throughout the growing season. Wild bee communities in edge habitat are very diverse and abundant owing to these ample resources. Forest edge along wild blueberry fields makes great habitat for wild bees.

Emergent wetland: Emergent wetland is wetland habitat that is not consistently submerged throughout the growing season. It provides moderate quality bee habitat. Ground nesting resources are limited owing to wet soils, but cavity nesting resources are plentiful among the abundant woody shrubs and hollow flower stems. Emergent wetland provides a unique set of blooming plants to wild bees, including woody shrubs, bog plants and close relatives of wild blueberry. They are a good source of pollen and nectar throughout the growing season. Their proximity to blueberry fields in the Downeast region is important for wild bee population survival.

Wetlands/water: This cover type consists of either submerged wetlands or open water. These areas typically are poor bee habitat—owing to the dominance of open water, they provide almost no ground nesting and few cavity nesting resources. Furthermore, they offer little pollen and nectar throughout the growing season as few flowering plants can establish in the wet soils. Submerged wetlands can offer cavity nesting resources in standing dead wood or hollow twigs and stems and may have flowering plants available at the water's edge.

Agriculture/Grassland: Either non-blueberry agriculture or open, grass-dominated fields. These areas provide moderate quality bee habitat. Agricultural and grassland areas provide ground nesting resources via exposed patches of soil if the soil is not compacted from heavy farm machinery, but a lack of woody shrubs and woody debris means they provide few cavity nesting resources. Abundant flowering plants can provide ample pollen and nectar to wild bees throughout the growing season, especially on small, diversified farms and grassy fields with constant wildflower bloom.

Urban/Developed: Any kind of development, including roads, towns, and cities. Urban/developed areas provide high quality bee habitat. They have excellent ground nesting resources in exposed sandy soils found along roadsides and in gardens, parks, and yards. Cavity nesting resources are also abundant in woody shrubs used for landscaping. Flowering plants are also abundant throughout the growing season from gardens, landscaping in public and residential areas, and fallow strips along roadsides. Reduced lawn mowing and pesticide applications are encouraged in urban/developed areas to promote wild bee populations.

Blueberries: Blueberry fields that may be managed or unmanaged. Blueberry fields provide moderate quality bee habitat. There are excellent ground nesting resources owing to patches of exposed, sandy soils, but few cavity nesting resources within blueberry fields. The crop bloom in late spring provides an incredible source of food for wild bees, but there is little pollen and nectar throughout the rest of the growing season. Wild bees rely on nearby habitat to sustain their populations after crop bloom, therefore it is crucial to have ample floral resources nearby. Unsprayed field edges and installed pollinator plantings can promote wild bee habitat in blueberry fields.

Appendix D. BeeMapper map development

Here, we describe the development of the two maps presented in BeeMapper: a land cover map and a predicted wild bee abundance map.

D.1: Land cover map

The land cover map is based on the 2004 Maine Landcover Dataset (MeLCD), which is freely available from the Maine Office of GIS (Landcover – MELCD 2004, http://www.maine.gov/megis/catalog/). This dataset has 5m spatial resolution, which captures landscape variation that is important to wild bees. We classified the original map into 8 land cover classes that each provide a unique set of resources for wild bees (Appendix C). We further modified this map to include roads and railroads, enhance wetland diversity, and provide the most extensive wild blueberry coverage. Additional data sources used for the land cover map are:

- Roads: MEDOTPUBRDS, http://www.maine.gov/megis/catalog/
- Railroads: RAILROUTESYS, http://www.maine.gov/megis/catalog/
- Wetlands: National Wetlands Inventory, http://www.fws.gov/wetlands/NWI/Index.html
- USDA Croplands Dataset: CDL; http://nassgeodata.gmu.edu/CropScape/

D.2: Predicted wild bee abundance map

The abundance map is output from the **InVEST Crop Pollination Model** (Lonsdorf et al. 2009) applied to Maine's wild blueberry production landscape. The InVEST Crop Pollination Model requires three components to predict bee abundance across a landscape:

1) A **land cover map**. The land cover map presented in BeeMapper and described in section D.1 is the same land cover map we used to predict wild bee abundance with the InVEST Crop Pollination Model. We resampled this map to 10m spatial resolution for computational efficiency, with no measurable loss in model performance.

2) **Habitat suitability values** for wild bees within each land cover type within the land cover map. These values were provided by expert opinion. We asked 12 experts to rank eight land cover types for their ability to provide:
   - Ground nesting resources (open soil, gravel)
   - Cavity nesting resources (rotting logs, dead shrubs with hollow branches)
   - Forage resources (pollen and nectar from blooming flowers) in the early, middle, and late summer (3 separate scores). Assessing forage resources throughout the growing season accounts for seasonal variability in the abundance and diversity of blooming flowers and leads to more accurate model predictions.

   Expert opinion-derived habitat suitability parameters are listed in Table 1. Each land cover type is ranked on a scale of 0 to 1, with 1 being most suitable habitat for wild bees.

3) **Bee life history traits** for wild bees associated with the focal crop. We collected information for nesting preference, foraging distance, and flight season of 14 wild bee species found in blooming wild blueberry fields (Appendix B). Due to model constraints, we did not incorporate bumble bees (*Bombus* species), an important blueberry pollinator, into the model.

Table 1. Expert-opinion derived parameters for the InVEST Crop Pollination Model applied to Maine wild blueberry.

Land cover type	Ground nesting	Cavity nesting	Late spring forage	Early summer forage	Late summer forage
Agriculture/grass	0.7	0.2	0.9	0.7	0.9
Blueberries	1.0	0.4	0.4	1.0	0.5
Coniferous forest	0.5	0.6	0.1	0.1	0.1
Deciduous/mixed forest	0.6	0.9	0.7	0.5	0.4
Deciduous/mixed forest edge	0.9	1.0	0.9	0.9	1.0
Emergent Wetland	0.2	0.4	0.7	0.6	0.6
Urban/developed	0.9	0.6	1.0	0.9	1.0
Wetlands/water	0.1	0.1	0.3	0.2	0.5

The InVEST Crop Pollination Model predicts bee abundance at each point across the input land cover map for each bee species using bee foraging distance and flight season in tandem with the resources offered by each land cover type throughout the growing season. These maps are then summed to create the model output, an overall predicted wild bee abundance map. Each point in this map is given an index value between 0 and 1, with 1 representing the highest wild bee abundance. We classified this index into five abundance classes for clearer interpretation.

For more details on the InVEST Crop Pollination model, please visit
http://data.naturalcapitalproject.org/invest-releases/3.3.3/userguide/croppollination.html

Full details of the development of the land cover map and application of the InVEST Crop Pollination Model to the Downeast wild blueberry growing region can be found in Groff et al. (2016) and Chapin (2014). Additional details regarding application of the InVEST Crop Pollination model to the Midcoast wild blueberry region and model accuracy in non-blueberry cover types are forthcoming.

Appendix E: Additional Resources

The wild blueberry web page of the University of Maine Cooperative Extension has many resources on pollinator management and conservation. Recommending reading includes:

- Fact Sheet 301: Field Conservation Management of Native Leafcutting and Mason Osmia Bees
- Fact Sheet 630: Wild Bee Conservation for Wild Blueberry Fields
- Farming for Bees: Guidelines for Providing Native Bee Habitat on Farms
- Enhancing Wild Bees for Crop Pollination: Sowing Bee Pasture for New England's Wild Lowbush Blueberry

You can find these resources and additional information on wild bees by visiting the Cooperative Extension wild blueberry web page: https://extension.umaine.edu/blueberries/factsheets/bees/

A series of YouTube videos details multiple aspects of wild bee management and conservation in Maine wild blueberry:

- Dr. Frank Drummond demonstrates how to count wild bees in wild blueberry fields: https://www.youtube.com/watch?v=rgVav2byI8o
- Hear why the landscape is important for pollination management: https://www.youtube.com/watch?time_continue=120&v=aY9GKAH231I
- Learn more about pollinator plantings: https://www.youtube.com/watch?v=J1kFxmiYncA

Academic references:

Bushmann, S., and F. Drummond. 2015. Abundance and Diversity of Wild Bees (Hymenoptera: Apoidea) Found in Lowbush Blueberry Growing Regions of Downeast Maine. Environmental Entomology 44(4): 975-989. https://doi.org/10.1093/ee/nvv082

Chapin, S.J. 2014. The application of spatial modeling tools to predict native bee abundance in Maine's lowbush blueberries. M.S. Thesis, Ecology and Environmental Sciences, University of Maine, Orono, 44 pp. http://digitalcommons.library.umaine.edu/etd/2112/

Groff, S.C., Loftin, C.S., Drummond, F.A., Bushmann, S., and B. McGill. 2016. Parameterization of the InVEST Crop Pollination Model to spatially predict abundance of wild blueberry (Vaccinium angustifolium Aiton) native bee pollinators in Maine, USA. Environmental Modelling and Software 79:1-9. https://doi.org/10.1016/j.envsoft.2016.01.003

Lonsdorf, E., Kremen, C., Ricketts, T., Winfree, R., Williams, N, and S. Greenleaf. 2009. Modelling pollination services across agricultural landscapes. Annals of Botany 103(9): 1589-1600. https://doi.org/10.1093/aob/mcp06