The application of spatial modeling tools to assess the effect of landscape pattern and arrangement on native bee abundance in Maine’s wild blueberries.

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Maine, blueberries and bees

- Country’s largest producer of wild lowbush blueberries
- Wild blueberries, like 75% of the world’s crops (Klein et al. 2007), benefit from animal pollination
- Country’s second largest importer of non-native honeybees
- Decline in honeybees has increased the cost of hive rentals
Native bees are more productive blueberry pollinators than honeybees.
- Native bees have adapted to forage in low light levels and cool temperatures.
- Of the 270 native bee species in Maine, more than 40 species pollinate blueberries.
- Most native bees are solitary species.
USDA - pollination security for fruit and vegetable crops in the northeast

- Collaborative work between economists, anthropologists, biologists, spatial ecologists, and growers
- 5 institutions
- NY – apples, CT – squash and pumpkin, MA – cranberries, ME – wild blueberries
- Develop recommendations for growers to sustainably manage and protect native pollinator diversity in and around their farms
Native bees and the landscape

Suggested as the next step: Does the pattern and arrangement of the habitat influence pollinator abundance?
InVEST Crop Pollination Model

- Relationship between habitat and bee abundance has been incorporated into the InVEST Crop Pollination Model.

- Aim of InVEST: remotely map the relative abundance of pollinators across a landscape using only a landcover layer and user-provided parameters.
Research Questions

1. Does the InVEST Crop Pollination Model provide a good fit for predicting native bee abundance in Maine’s blueberry fields?

2. Is the InVEST model sensitive to the user provided parameters?

3. What are the optimal parameters needed to predict field collected bee abundance data in our area?

4. Is there a relationship between landscape pattern and arrangement, and pollination services?
Research Question 1:

Does the InVEST Crop Pollination Model provide a good fit for predicting native bee abundance in Maine’s blueberry fields?
InVEST Crop Pollination Model

- Aim of InVEST: remotely map the relative abundance of pollinators across a landscape using only a landcover layer and user-provided parameters

<table>
<thead>
<tr>
<th>Landscape</th>
<th>Crop</th>
<th>Predicted Variance (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>California Sunflower, Watermelon</td>
<td>55</td>
<td></td>
</tr>
<tr>
<td>Costa Rica Coffee</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>New Jersey, Pennsylvania Watermelon</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

Question 1: Does InVEST provide a good fit for predicting native bee abundance in Maine?
InVEST Crop Pollination Model

**Question 1:** Does InVEST provide a good fit for predicting native bee abundance in Maine?
InVEST Crop Pollination Model

Bees

Seasonal Activity Level
[0 – 1]
*must sum to 1

Spring

Fall

Summer

Bee Numbers

Osmia

Bombus

Days

April

September

Question 1: Does InVEST provide a good fit for predicting native bee abundance in Maine?
InVEST Crop Pollination Model

Floral Resource Suitability [0 – 1]

Landcover Classes

Deciduous Forest

Meadow

Floral Abundance

April

September

Days

Spring

Fall

Summer

Question 1: Does InVEST provide a good fit for predicting native bee abundance in Maine?
### Input Parameters

<table>
<thead>
<tr>
<th>Species</th>
<th>Ground Nester?</th>
<th>Cavity Nester?</th>
<th>Foraging Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short Dist. Forager (Halictus)</td>
<td>yes</td>
<td>no</td>
<td>100 meters</td>
</tr>
<tr>
<td>Long Dist. Forager (Bombus)</td>
<td>yes</td>
<td>yes</td>
<td>4000 meters</td>
</tr>
</tbody>
</table>

### Nest Suitability

<table>
<thead>
<tr>
<th>Landcover Class</th>
<th>Nest Suitability (Ground)</th>
<th>Nest Suitability (Cavity)</th>
<th>Floral Resource Suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 – 1</td>
<td>0 -1</td>
<td>0 – 1</td>
</tr>
</tbody>
</table>

**Question 1:** Does InVEST provide a good fit for predicting native bee abundance in Maine?
Data Requirement 1 – Landcover Layer

<table>
<thead>
<tr>
<th>Spatial Dataset</th>
<th>Date</th>
<th>Resolution (meters)</th>
<th>Blueberry Class?</th>
<th>Accuracy (%)</th>
<th># of Fields</th>
</tr>
</thead>
<tbody>
<tr>
<td>MELCD</td>
<td>2004</td>
<td>5</td>
<td>Commercial Blueberries</td>
<td>89.7</td>
<td>1,258</td>
</tr>
<tr>
<td>USDA Cropland Dataset</td>
<td>2012</td>
<td>30</td>
<td>Blueberries</td>
<td>80.7</td>
<td>55,676</td>
</tr>
</tbody>
</table>

Major differences between the two, so...

- SPOT imagery, 2011 – 10 meter, 3,600 km² scene
- Also incorporate ancillary GIS data

Question 1: Does InVEST provide a good fit for predicting native bee abundance in Maine?
Data Requirements 2 & 3 – Bee Data & Landcover Suitability

- Bee foraging/flight distances (Greenleaf et al. 2007)

\[ \log \text{foraging distance} = \log(( -1.643 \pm 0.582 ) + (3.242 \pm 1.218)) \times (\log \text{IT span}) \]

- All other parameter values were developed through an expert opinion survey and available literature

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<table>
<thead>
<tr>
<th>Species</th>
<th>Nest Substrate</th>
<th>Typical Foraging Distance (m)</th>
<th>General Flight Season</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Andrena carlini</em></td>
<td>ground</td>
<td>598</td>
<td>Mar - Aug</td>
</tr>
<tr>
<td><em>Andrena carolina</em></td>
<td>ground</td>
<td>246</td>
<td>Apr - Jul</td>
</tr>
<tr>
<td><em>Andrena vicina</em></td>
<td>ground</td>
<td>569</td>
<td>Mar - Aug</td>
</tr>
<tr>
<td><em>Augochlorella aurata</em></td>
<td>ground</td>
<td>60</td>
<td>Apr - Oct</td>
</tr>
<tr>
<td><em>Colletes inaequalis</em></td>
<td>ground</td>
<td>1091</td>
<td>Mar – Sept</td>
</tr>
<tr>
<td><em>Halictus ligatus</em></td>
<td>ground</td>
<td>148</td>
<td>Mar – Nov</td>
</tr>
<tr>
<td><em>Lasioglossum acuminatum</em></td>
<td>ground</td>
<td>186</td>
<td>Apr – Oct</td>
</tr>
<tr>
<td><em>Lasioglossum cressonii</em></td>
<td>cavity</td>
<td>63</td>
<td>Mar – Oct</td>
</tr>
<tr>
<td><em>Lasioglossum heterognathum</em></td>
<td>ground</td>
<td>16</td>
<td>Apr - Sept</td>
</tr>
<tr>
<td><em>Lasioglossum leucocomum</em></td>
<td>ground</td>
<td>31</td>
<td>Mar – Oct</td>
</tr>
<tr>
<td><em>Lasioglossum pectorale</em></td>
<td>ground</td>
<td>81</td>
<td>Mar – Nov</td>
</tr>
<tr>
<td><em>Lasioglossum versatum</em></td>
<td>ground</td>
<td>79</td>
<td>Mar – Oct</td>
</tr>
<tr>
<td><em>Osmia atriventris</em></td>
<td>cavity</td>
<td>186</td>
<td>Apr – Jul</td>
</tr>
<tr>
<td><em>Osmia inspergens</em></td>
<td>cavity</td>
<td>495</td>
<td>May – June</td>
</tr>
</tbody>
</table>
### Input Parameters – Landcover

<table>
<thead>
<tr>
<th>Landcover Type</th>
<th>Nesting – Ground</th>
<th>Nesting – Cavity</th>
<th>Forage – Spring</th>
<th>Forage – Early Summer</th>
<th>Forage – Late Summer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deciduous/Mixed Forest, edge</td>
<td>0.9</td>
<td>1.0</td>
<td>0.9</td>
<td>0.9</td>
<td>1.0</td>
</tr>
<tr>
<td>Developed/Other</td>
<td>0.9</td>
<td>0.6</td>
<td>1.0</td>
<td>0.9</td>
<td>1.0</td>
</tr>
<tr>
<td>Coniferous Forest</td>
<td>0.5</td>
<td>0.6</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Deciduous/Mixed Forest</td>
<td>0.6</td>
<td>0.9</td>
<td>0.7</td>
<td>0.5</td>
<td>0.4</td>
</tr>
<tr>
<td>Emergent Wetlands/Scrub Shrub</td>
<td>0.2</td>
<td>0.4</td>
<td>0.7</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Wetlands/Water</td>
<td>0.1</td>
<td>0.1</td>
<td>0.3</td>
<td>0.2</td>
<td>0.5</td>
</tr>
<tr>
<td>Agriculture/Field</td>
<td>0.7</td>
<td>0.2</td>
<td>0.9</td>
<td>0.7</td>
<td>0.9</td>
</tr>
<tr>
<td>Blueberries</td>
<td>1.0</td>
<td>0.4</td>
<td>0.4</td>
<td>1.0</td>
<td>0.5</td>
</tr>
</tbody>
</table>

**Question 1:** Does InVEST provide a good fit for predicting native bee abundance in Maine?
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Analysis: InVEST validation

<table>
<thead>
<tr>
<th>Run</th>
<th>Extent</th>
<th>Number of Species Modeled</th>
<th>Landcover Dataset</th>
<th>Validation Dataset</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td># 1</td>
<td>9 total</td>
<td>updated landcover, no SPOT, no soils</td>
<td>7 sites</td>
<td>0.77</td>
</tr>
<tr>
<td>2</td>
<td># 1</td>
<td>9 total</td>
<td>updated landcover, no SPOT, with soils</td>
<td>7 sites</td>
<td>0.76</td>
</tr>
<tr>
<td>3</td>
<td># 1</td>
<td>9 total</td>
<td>updated landcover, with SPOT, no soils</td>
<td>7 sites</td>
<td>0.77</td>
</tr>
<tr>
<td>4</td>
<td># 1</td>
<td>6 total</td>
<td>updated landcover, no SPOT, no soils</td>
<td>7 sites</td>
<td>0.86</td>
</tr>
<tr>
<td>5</td>
<td># 3</td>
<td>9 total</td>
<td>updated landcover, no SPOT, no soils</td>
<td>40 sites</td>
<td>0.36</td>
</tr>
<tr>
<td>6</td>
<td># 3</td>
<td>14 total</td>
<td>updated landcover, no SPOT, no soils</td>
<td>40 sites</td>
<td>0.32</td>
</tr>
</tbody>
</table>

Question 1: Does InVEST provide a good fit for predicting native bee abundance in Maine?
Research Question 2:
Is the InVEST model sensitive to the user-provided parameters?
Sensitivity Analysis

• Study of how the uncertainty in the output of a model can be apportioned to different sources of uncertainty in its inputs.

• Goal is to calculate how variation in each parameter affects estimates of a parcel's pollinator abundance, independent of all other parameters in the model (Lonsdorf et al. 2009)

Question 2: Is the InVEST model sensitive to the user-provided parameters?
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>Max</th>
<th>Min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forage Suitability - Spring</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deciduous/Mixed Forest, edge</td>
<td>0.9</td>
<td>1</td>
<td>0.8</td>
</tr>
<tr>
<td>Developed/Other</td>
<td>1</td>
<td>1</td>
<td>0.9</td>
</tr>
<tr>
<td>Coniferous Forest</td>
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<td>0.5</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Question 2: Is the InVEST model sensitive to the user-provided parameters?
Research Question 3:
What are the optimal parameter values needed to predict field collected bee abundance data in our area?
Model Optimization

- Simulated annealing
- Compare results of expert opinion survey to optimized results

Question 3: What are the optimal parameter values needed to predict bee abundance data in our area?
Research Question 4:

Is there a relationship between landscape pattern and arrangement, and pollination services?
Neutral Landscape Models (NLMs)

1. Determine the extent that some properties of a landscape deviate from random

2. Predict how ecological processes are affected by the landscape structure

Question 4: Is there a relationship between landscape pattern and pollination services?
Neutral Landscape Models (NLMs)

Question 4: Is there a relationship between landscape pattern and pollination services?

King and With, 2002
InVEST -> Neutral Landscape Models

1. Create fractal NLMs using QRULE

2. Re-run InVEST Crop Pollination Model on simulated NLMs

3. Regress changes in InVEST model output of bee abundance to landscape metrics (i.e. # of patches, average patch size, and patch compactness).

Question 4: Is there a relationship between landscape pattern and pollination services?
model bee abundance with InVEST

devlop NLMs with QRULE

real landscapes

simulated landscapes (NLMs)

compare model-predicted vs. field-observed bee abundance

sensitivity analysis on parameters

parameter optimization

compare model-predicted bee abundance vs. landscape metrics
**Models**

model bee abundance with InVEST

devolve NLMs with QRULE

**Landscape**

real landscapes

**Research Questions**

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parameter optimization

compare model-predicted bee abundance vs. landscape metrics
32

Simulated landscapes (NLMs)

- Model bee abundance with InVEST

- Develop NLMs with QRULE

Landscape

Real landscapes

- Compare model-predicted vs. field-observed bee abundance

- Sensitivity analysis on parameters

- Parameter optimization

Research Questions

- Compare model-predicted bee abundance vs. landscape metrics
model bee abundance with InVEST

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real landscapes

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**Models**

- Model bee abundance with InVEST
- Develop NLMs with QRULE

**Landscape**

- Simulated landscapes (NLMs)
- Real landscapes

**Research Questions**

1. Compare model-predicted vs. field-observed bee abundance
2. Sensitivity analysis on parameters
3. Parameter optimization
4. Compare model-predicted bee abundance vs. landscape metrics
My contributions

• **Economists:** Are growers more likely to experience lower profits in areas with lower native bee abundance (as predicted by the InVEST model)?

• **Anthropologists:** Are growers more likely to adopt practices to enhance native bee habitat if they live in an area with higher native bee abundance (as predicted by the InVEST model)?

• **Growers/Land Managers:** If I provide native bee habitat, does the location and arrangement matter for bees? (as predicted by the NLMs in the InVEST model)
Acknowledgments

Committee: Cyndy Loftin, co-advisor; Frank Drummond, co-advisor; Brian McGill

Funding: USDA, University of Maine, USGS Maine CFWRU, OFWIM

Data: Sara Bushmann, Frank Drummond

Advice: Pollination Team, Spatial Ecology Lab Group

Photos: AirPhoto - Jim Wark, Maine ACF, Bangor Daily News, Amy Campbell

Questions, Comments, Suggestions?