The ALMOPOL Model Description

Overview

The ALMOPOL model is a web-based application which simulates the effects of honeybees or Osmia bees as pollinators for almond orchards. This simulation takes into account the weather-related bloom progression of different cultivars of almonds, the weather-related population dynamic and foraging behavior of pollinating bees, and the movement of the bees across different orchard configurations. ALMOPOL was developed using web-enabled technologies including as Microsoft ASP.NET, the C# programming language, and the MySQL database toolkit.

ALMOPOL is designed to allow users to set up and save their own unique configurations of orchards and simulation data. It can be accessed from any of the popular web browsers

Model Elements

There are a few key modeling elements which contain most of the information for the model: orchards, almond cultivar descriptors, bee colonies, and weather. In addition, there is a model profile which initially contains the default parameters used when the model runs and which can be customized by each user as well as a set of initial conditions that can be saved by the user to recall specific starting points. All these elements will be described in more detail below.

Orchards

Orchards are modeled as a rectangular collection of rows of trees. A single row contains a user-specified number of trees of a single almond cultivar. An orchard can have as many rows as needed, and cultivar types can vary from row to row. When defining a row, the user specifies some information about the tree canopy size and the blossom bud density and the model applies those values to all trees in that row.

Almond Cultivar Descriptors

An almond cultivar descriptor contains information specific to each cultivar which is relevant to the model. This includes information used to determine the bloom progression over time and nut density information. The cultivar descriptors are not intended to be modified by the user. The bloom progression parameters are shown in the following table.

Parameter	Description
Base Temp	The temperature above which degree-days are accumulated. Below this temperature, no degree-days are accumulated
Total DD in Bloom	The span, in degree-days for the entire bloom period
Open Blossom DD	The number of degree-days new blossoms are available
DD Delay	The beginning of blossom for all cultivars other than nonpareil is delayed this many degree-days after nonpareil blossoms.
Xover	The number of degree-days that have elapsed at peak bloom.
Coefficients pre-Xover	A, B, C, D, E, F are coefficients used prior to the Xover point in the equation $B = Ax^3 + Bx^2 + Cx + D + E\,e^x + F\log(x)$ where x is the number of elapse degree-days and B is the proportion of blossoms currently open
Coefficients post-Xover	A, B, C, D, E, F are coefficients used after the Xover point in the equation $B = Ax^3 + Bx^2 + Cx + D + E\,e^x + F\log(x)$ where x is the number of elapse degree-days and B is the proportion of blossoms currently open

Nut set efficiency is influenced by the portion of the entire bloom period that has transpired on each day and by the age of any given blossom. In order to account for that, the model has an aging algorithm for all the blossoms on a row and it divides the bloom period into 10 segments.

Bee Colonies

The initial bee count is specified by the user in terms of colonies per acre and frames per colony for honeybees and by number of females per acre for osmia. Active forager count is the important quantity for the model.

For honeybees, the active forager population algorithm is derived from the description in "ALMOPOL: A Cross-pollination and Nut Set Simulation Model for Almond"[1]. This value is calculated at a given weather condition as follows:

Number of Active Foragers = $(P_{SolarRad} * P_{Temp} * P_{Wind)} *$ Potential Foragers

where

$P_{SolarRad}$ = 0.6 * SolarRadiation between noon and 2:00PM locally and 1.5* (SolarRadiation/(SolarRadiation + 0.5)) for all other times.

P_{Temp} = $\log_{10}$(Temp 8 0.699) – 0.27

[1] DeGrandi-Hoffman, Roth, Loper; Journal of the American Society for Horticultural Science, Vol. 114(1), January 1989.

P_{Wind} = (1 – 0.0249 * Windspeed)

Potential Foragers = 0.92 * Number of colonies * frames per colony * bees per frame

(SolarRadiation in W/m^2, Temp in ^{o}C, Windspeed in m/s)

For Osmia, the active forager population is calculated as follows:

Number of Active Foragers = Number of female osmia * Proportion of Foragers

For the first 15 days of foraging

Proportion of Foragers = 0.844 + (0.0381 * Day) - (0.00205 * Day^2);

For Day 16 through Day 31

Proportion of Foragers = 3.0 - (0.171 * Day) + (0.00234 * Day^2)

Weather

Weather data was collected from a number of CMIS weather sites in California. For each site, multiple years of hourly weather data was collected for the months of January through March. The weather data of interest are time, temperature, windspeed, solar radiation, rainfall. These data are stored as a named set of records, one of which is selected for each simulation run.

Profile

There are many parameters used by the model that represent observed behavior in the field. In order make it easier to examine sensitivities to these parameters and to allow adaptation of the model based on new observations, each user can modify any or all of these parameters and store it in a profile associated with their login account. The modifiable parameters are listed in the following table.

Parameter	Description
Bees Per Frame	The number of honeybees on a frame
Blossom Visits Per Hr – AM	The number of times a bee visits a blossom in the morning
Blossom Visits Per Her – PM	The number of times a bee visits a blossom in the afternoon
Max Unsatisfying Visits	The number of times a bee will visit a blossom with no nectar before she moves to another row
Max X-Pollinating Visits	The number of blossom visits after arriving on a new row where cross pollination is possible. After this number of visits, no more

	pollen from the previous row is deposited on this row.
X-Pollinating Visits for Nut set	The number of times a blossom must be visited by a cross-pollinating bee in order to achieve nut set
Orchard-Hive Round Trips/Hr	The number of times a bee returns to the hive per hour. This is important because we assume all returns to the hive result the bee picking up pollen from all cultivars for potential cross-pollinating visits
Nut Set Matrix – Bloom Progression	The bloom duration in degree-days is divided into 10 segments. Since nut set is less efficient later in the bloom, the ten entries in this matrix represent the proportion of set blossoms that actually result in set nuts as a function of bloom progression. Total set nuts = Theoretical nut set * Bloom Progression Parameter * Blossom Age Parameter.
Nut Set Matrix – Blossom Age	The blossom age in degree-days is divided into 10 segments. Since nut set is less efficient in older blossoms, the ten entries in this matrix represent the proportion of set blossoms that actually result in set nuts as a function of blossom age. Total set nuts = Theoretical nut set * Bloom Progression Parameter * Blossom Age Parameter.

Initial Conditions

The user can store any number of initial condition sets or start with new initial conditions. The initial conditions define the information the model needs to begin execution and contain the data shown below.

Parameter	Description
Start Date	The simulated start date
Weather	The name of the weather collection
Orchard	The name of the pre-defined orchard to use in the simulation
Honeybees	Selects whether this simulation uses honeybees
Colonies/Acre	Defines the number of honeybee colonies per acre
Frames/Colony	Defines the number of frames per honeybee colony
Blue Orchard Bees	Selects whether this simulation uses Blue Orchard Bees (Osmia)
Bees/Acre	The number of Blue Orchard Bees per acre
Start Date	The date the Blue Orchard Bees are inserted into the orchard

Model Behavior

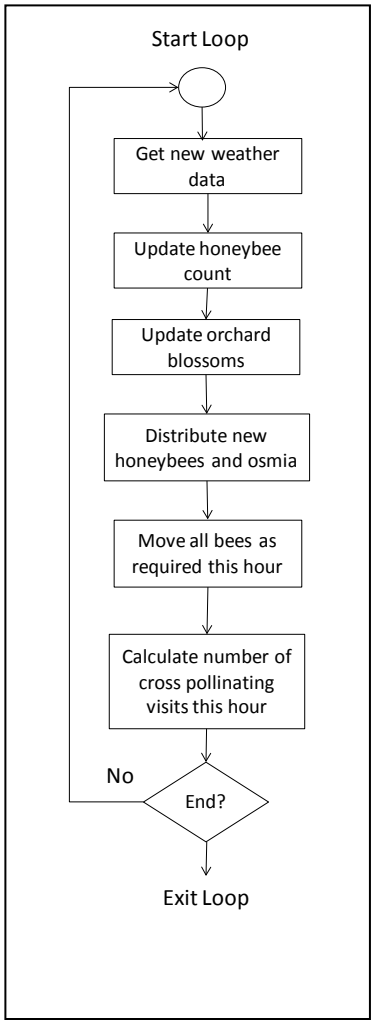
All the information contained in the model elements described above is manipulated sequentially to simulate the hour-by-hour state of the orchard system. After the simulation is complete, the results show the predicted value over time of many of the orchard elements including nut set, bloom progression, and bee distribution.

Model Sequencer

The model sequencer loads all the initial conditions and progresses the model through its steps. Each step through the sequencer moves the state of the model one hour forward beginning with the start date and ending when the weather data ends. The first thing the sequencer does is to load the specified weather data and initial conditions and then initializes the model with these values. From that point the simulation loops through the hour-by-hour steps, once for each hour of data contained in the weather file beginning at midnight on the start date specified in the initial conditions. During these loops, model state data is being saved. When the weather data ends, the sequencer exits the simulation loop and the results are displayed. At that time, the user can evaluate results or change some initial conditions and run the simulation again.

Simulation Loop

The top-level of the simulation loop is shown here. When the simulation loop is entered, the first step is to get the new weather data for the current hour and day. The weather data are used to cause the honeybee colony active forager count to be updated. Also, the blossoms in the orchard are updated by progressing their age forward by the appropriate number of degree-days.



Generally, the active forager count for the honeybees changes hour to hour so the correct number are distributed or removed from the orchard. The number of honeybee foragers distributed is constrained to not exceed the number that can visit all the blossoms in the hour. Osmia all forage at the beginning of the day so they are distributed once. In order to forage, it must meet the conditions of a foraging day.

The next step is to move all the bees based on the number of times a bee visits blossoms per hour. Finally, the number of cross pollinating visits is calculated along with the number of nuts set. This bee movement and nut set rules are fairly complex so it will be described in more detail below.

At the end of the loop, the model checks to see if the weather data has ended and if not, returns to the top of the sequence again. When the weather data for all hours of every day have been processed, the simulation loop is complete.

Honeybee Movement

As part of the execution of the main simulation loop, all the bees are moved multiple times per hour. This number is the value contained in parameters *Blossom Visits Per Hour – AM* and *Blossom Visits Per Hour –PM* in the Profile mentioned earlier. The default values for these parameters are 23 and 100 respectively.
The movement is done row by row as follows. First the bees on each row are moved. During this move, the model keeps track of the number of blossoms visited by any bee, the number of blossoms visited by a cross-pollinating bee and the number of unsatisfying visits (a blossom previously visited this hour).

When all the bees have been moved once on each row, we distribute some of the bees on each row to adjacent rows based on a proportion of blossoms on each of the left, right, and current rows. This models the attraction differences to different rows when

the cultivars in adjacent rows have different blossom progression. Bees that have had a number of unsatisfying visits as high as the value contained in *Max Unsatisfying Visits* are the candidates to move to a new row. Bees that move to a new row can cross pollinate on that row (if the cultivars on both rows cross pollinate) for the number of visits contained in *Max X-Pollinating Visits* parameter contained in the Profile. The default value for this is 3. After that, if the bee stays on the new row, it doesn't generate any more cross pollinating moves.

When blossoms are visited by cross pollinating bees, the visit counts towards nut set. The number of this type of visit required to actually cause nut set is contained in the Profile parameter *X-Pollinating Visits for Nut set* and the default is 2;

The foraging honeybees return to the hive throughout the day. When they emerge, they have picked up pollen from all cultivars in the orchard. This behavior is modeled by making all bees cross pollinators several times per simulated hour. The number of times per hour this happens is contained the Profile parameter *Orchard-Hive Round Trips/Hr* which has a default value of 2.

Osmia Movement

Osmia forage is modeled differently than honeybees and the way we calculate osmia cross pollination per hour is different than that of honeybees but the nut set approach is the same. The first available foraging trip of the day is the first case where foraging weather is present in the morning. At this time, all the foraging osmia are distributed across the orchard rows. After 5 hours of foraging, the osmia return to the nest. For each pass through the simulation loop, the number of osmia cross pollinating visits is given by:

OsmiaXPolVisits = QuantityOsmia * 6.25 * ProbXPol * *Max X-Pollinating Visits*

Where ProbXPol is 1.0 if both adjacent rows contain cross pollinating cultivars, 0.5 if only one adjacent row has a cross pollinating cultivar and 0 if no cross pollinating from adjacent rows.

Nut set Calculations

The number of potential set nuts is tracked as the bees move. Younger blossoms are more efficient at setting nuts and the entire bloom period is more efficient earlier in bloom. The Nut Set Matrix found in the Profile is used to model that behavior. At the end of each hour, the actual nut set is given by:

$$\text{Actual Nut Set} = \text{Potential Nut Set} * P_{BlossomAge} * P_{BloomPeriod}$$

Where

$P_{BlossomAge}$ is the value contained in the applicable cell in the Blossom Age Nut Set Matrix in Profile and

$P_{BloomPeriod}$ is the value contained in the applicable cell in the Bloom Progression Nut Set Matrix in Profile.

These two matrices effectively divide the blossom age span and the bloom period, in degree-days, into 10 equally sized segments. The value applied is based on how far along we are with the bloom period and the distribution of blossom ages. The default values for both matricies range between 0.99 for the first 10% of the periods to 0.1 when 90% through the periods.