# ᴵᴵᴵ·B-GOOD

# Documentation of completion of the 3-tier system of simulation by extension of ApisRAM simulation capability to BE & UK

# Deliverable D5.1

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**B-GOOD**

**Giving Beekeeping Guidance by cOmputatiOnal-assisted Decision making**

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## Preface

This Deliverable (D5.1) focuses on the extension of the ApisRAM simulation capacity to landscapes located in Belgium (BE) and the United Kingdom (UK), with a special focus on 10x10 km landscape windows located around the B-GOOD mini-apiaries run by the Nottingham Trent University (UK) and Ghent University (BE) (see Fig. 1).

ApisRAM is an agent based honey bee colony model for risk assessment developed as a part of the EFSA's MUST-B (MUltiple STressors in Bees) project. ApisRAM has the capacity of integrating impacts of multiple stressors on bees and utilizes the landscape component within the ALMaSS modelling platform (Topping et al., 2003). ALMaSS landscape component is a detailed dynamic model of a landscape capable of providing daily information about temperature, rainfall, wind speed and direction, snow loading, sunrise and sunset, type of land cover / habitat, height and biomass of vegetation, farming operations conducted on agricultural fields etc., for the organisms being modelled. One of the most important information needed for ApisRAM is the amount and quality of floral resources available in the landscape. This information is provided by the phenology models of floral resources (floral resource models) for bees, which is one of the major outputs of WP3 (subtask 3.2.2; see Deliverable D3.3).

Here we first describe how the floral resource models developed in subtask 3.2.2 were implemented in the ALMaSS landscape component and integrated with the ApiSRAM model to be able to provide information on floral resources available for bees in the landscape (section 2). Second, the process of generation of ALMaSS landscapes for BE and UK is presented, together with the description of floral resources curves assigned to landscape element types present in these landscapes (section 3). The last section of the Deliverable (section 4) shows how the generated landscape models with mapped floral resources can be used within ApisRAM to drive the honey bee colony behaviour.

This Deliverable consists of the following components:

1) Report, being the present document, where the methodology and summary of outputs are described;
2) Appendix A: Formal model describing modelling of floral resources in ALMaSS;
3) Appendix B: Report on generation of ALMaSS simulation landscapes for Belgium together with landscape generation Python scripts and ALMaSS input files for the two landscape windows (Merendree and Merelbeke) located around the B-GOOD mini-apiaries (Fig. 1);
4) Appendix C: Report on generation of ALMaSS simulation landscapes for the UK together with landscape generation Python scripts and ALMaSS input files for the landscape window located around the B-GOOD mini-apiary (Fig. 1);
5) Appendix D: ALMaSS input files describing floral resource curves for landscape element types (*habitatALMaSSNectarPollenInput.txt*) and crops / cultivated plants (*tovALMaSSNectarPollenInput.txt*) present in the landscape windows tested in ApisRAM.

Appendices A-D are 'living' documents, thus their most up-to-date versions are stored in a GitLab repository (https://gitlab.com/ALMaSS/b-good-wp5) as open data under the CC-BY-NC license.
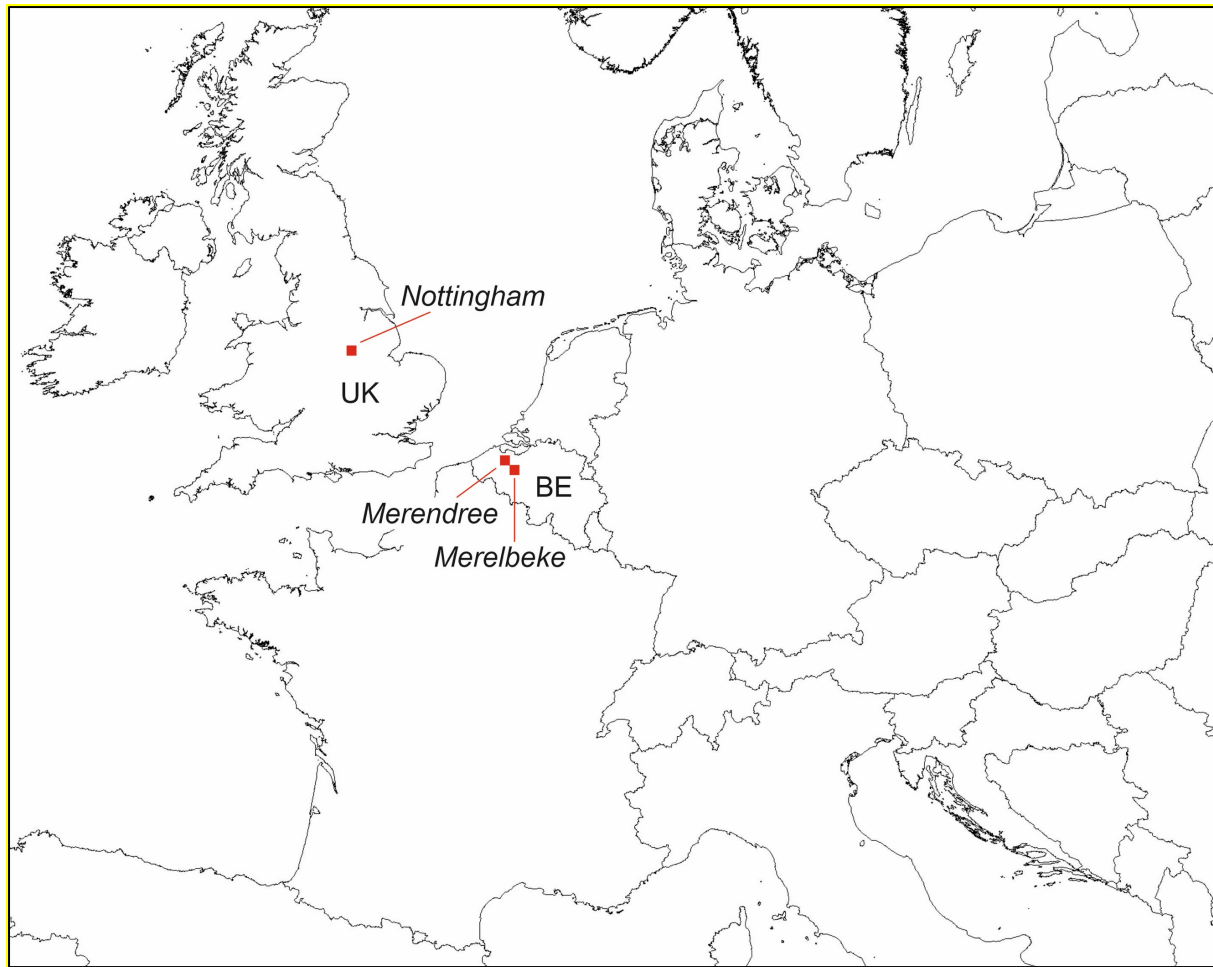
**Figure 1: Location of the three 10x10 km landscape windows located around the B-GOOD mini-apiaries run by the Nottingham Trent University (UK) and Ghent University (BE).**

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# Summary

The overall aim of WP5 is to provide data and analysis, to ultimately establish the relationship between environmental, biological and management drivers and bee health status. These relationships will be incorporated into a holistic predictive simulation model of honey bee colony – the EFSA ApisRAM model. This deliverable is part of the Task 5.2 of which objective is to use and expand on simulation tools developed by EFSA to make holistic assessments of the impacts of multiple stressors and drivers on bees. This requires (1) enhancing the ALMaSS landscape model by allowing modelling of changes of floral resources available to bees in space and time and linking this with the ApisRAM model; and (2) extending the range of landscapes simulated in ALMaSS to Belgium and the UK, and to be able to combine environmental information with bee colony information (gathered in WP1) in ApisRAM at Tier1.

In order to provide information on flower resources available in a landscape to the modelled honey bees during ApisRAM simulation, C++ code was developed in ALMaSS to implement floral resource models as described in Deliverable D3.3 into the ALMaSS landscape component. We had to take into account modelling of floral resources in both agriculturally managed areas (fields with single crops) and habitats consisting of many species of plants. This code was then linked with the ApisRAM model, through the foraging activity.

ALMaSS landscape models have been so far developed for many countries in the EU, including Denmark and Portugal, where initially the EFSA ApisRAM model has been developed and tested. To be able to utilize information on bee colony and model impacts of multiple stressors on bee colony in landscape windows around the B-GOOD mini-apiaries, it was necessary to extend the landscapes simulated in ALMaSS to those of Belgium and the UK. After generating and testing of ALMaSS landscape models for these countries, types of landscape elements providing floral resources for bees have been identified and linked with floral resource curves describing changes in the amount and quality of floral resources available through time. In the end, preliminary simulations in ApisRAM were conducted to test the landscape models with flower resources in landscape windows located around the B-GOOD mini-apiaries in Belgium and the UK.
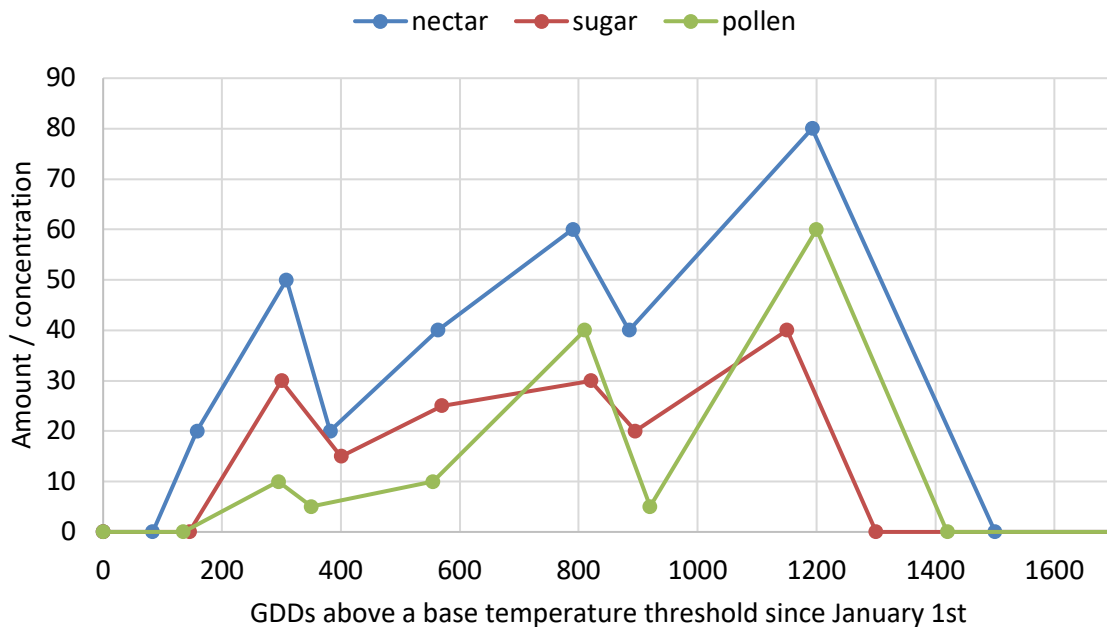
# 1. Introduction

The overall aim of WP5 is to provide data analysis, to ultimately establish the relationship between environmental, biological and management drivers and bee health status. These relationships will be incorporated into a holistic predictive simulation model of honey bee colony – the EFSA ApisRAM model. ApisRAM is an agent based honey bee colony model which can integrate multi-stressors, namely, malnutrition, unfavourable body temperature, infectious agents and effects derived from pesticide exposure. The behaviour of the colony emerges from the decisions and actions taken by individuals in the colony and the interactions between agents. The bees interact with, and react, both to other bees and to the resources in the colony, the hive physical and chemical properties, and the environment outside the colony. The environment is implemented as a dynamic landscape simulation within ALMaSS (the Animal Landscape and Man Simulation System). The ALMaSS landscape model is a spatially and temporally dynamic model which combines detailed land use / land cover mapping with information on farming system and farm practices, weather, plant growth, and flower resource models. The combination of the agent based honey bee model and the dynamic landscape model will allow to translate impacts of multiple stressors, latitudinal and local conditions, and local adaptation to predicted honey bee colony healthy status indicator metrics.

This deliverable is part of the Task 5.2 which is "Stressor interaction analysis using EFSA MUST-B model ApisRAM". The objective of this task is to use and expand on simulation tools developed by EFSA to make holistic assessments of the impacts of multiple stressors and drivers on bees, by integrating colony and environmental information. At Tier1 this will be done using data from BE, UK, and PT. This deliverable describes the implementation of the floral resource models into the ALMaSS landscape component, as well as the process of extension of the ApisRAM simulation capacity to the landscapes located in BE and the UK.

# 2. Integration of flower resource models into ALMaSS

Floral resource models describe pollen, nectar, and sugar production levels and their changes throughout the year and are one of the main major outputs of WP3 (subtask 3.2.2; see Deliverable D3.3; Fig. 2). They can be, however, considered 'living' models and are designed in such a way that they can be easily updated when more/additional data on pollen, nectar or sugar production, phenology of bee-friendly species or plant species composition in landscape elements / habitat units important for bees, are made available. It is the intention that any new data will be added to the database during and also after the project finishes. The most up-to-date version on floral resource models is stored in a GitLab repository (https://gitlab.com/ALMaSS/floral_resource_models) as open data under the CC-BY-NC license.

In this section, the implementation of the flower resource models in ALMaSS is briefly introduced. The detailed implementation can be found in Appendix A.

**Figure 2: Nectar, sugar, and pollen production (y-axis) against day degrees above a base temperature threshold (x-axis). The data for generating these curves are contained in Figure 3. (The data of curve no. 1 in Figure 3).**

## 2.1. Flower resource data input files

There are two input files describing floral resource curves separately for habitats consisting of many species of 'bee-friendly' plants (*habitatALMaSSNectarPollenInput.txt*), and agriculturally managed areas (fields with single crops; *tovALMaSSNectarPollenInput.txt*). The major reason for separating curves for crops was that in this case growing degree days (GDDs) are accumulated starting from the sowing / planting day, while for other habitats consisting of wild plants, GDDs are accumulated starting from the beginning of the year. It is important to highlight that the habitat curves describe the changes in accumulated floral resources from all the plants composing these habitats, i.e. in case of a forest, floral resources from trees, shrubs and plants forming a ground cover, are all taken into account. The composition of a given habitat may be defined by a user (country or landscape specific). Once the composition is defined or changed, the floral resource curves need to be re-calculated (using the *Resources_calculator.ipynb* script available in the GitLab repository https://gitlab.com/ALMaSS/floral_resource_models) to produce input files for ALMaSS.

The structure of files describing curves for habitats and crops is similar. For each habitat and crop type, it is comprised of the x,y pairs from the floral resource model indicating the inflection points describing the amount of nectar, sugar and pollen per day, as well as quality of pollen (separately from the point of view of honey bees, bumble bees and wild bees) available as a function of the number of growing degree days (GDDs) accumulated above a threshold temperature.

An example of a *habitatALMaSSNectarPollenInput.txt* file is provided in Fig. 3. The first number in this file is the number of data sets with floral resource curves (8 in this example). Each set consists of 10 lines of data. The first line in each set contains two numbers, the first

of which is the unique set ID for this data set and the second is the base temperature being a temperature threshold above which GDDs are accumulated. The next nine lines always start with the entry indicating the number of inflection points and refer to:

- Accumulated degree day inflection points for nectar
- Nectar quantity value at the corresponding accumulated degree day inflection point
- Accumulated degree day inflection points for sugar
- Sugar quantity value at the corresponding accumulated degree day inflection point
- Accumulated degree day inflection points for pollen
- Pollen quantity value at the corresponding accumulated degree day inflection point
- Pollen quality at the corresponding accumulated degree day inflection point for honey bees
- Pollen quality at the corresponding accumulated degree day inflection point for bumble bees (*Bombus* spp.)
- Pollen quality at the corresponding accumulated degree day inflection point for wild bees (*Osmia* genus)

As pollen quality data is pollinator specific, the correct curve is selected when the simulation starts for one of these three pollinators.

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habitatALMaSSNectarPollenInput.txt - Notepad                              —    □    ×

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8
1       4
12      -1      0       83      158     308     382     563     790     885     1193    1500    99999
12      0       0       0       20      50      20      40      60      40      80      0       0
11      -1      0       145     300     400     570     820     895     1150    1300    99999
11      0       0       0       30      15      25      30      20      40      0       0
11      -1      0       135     295     350     555     810     920     1200    1420    99999
11      0       0       0       10      5       10      40      5       60      0       0
11      1       1       1       1       1       1       1       1       1       1       1
11      1       1       1       1       1       1       1       1       1       1       1
11      1       1       1       1       1       1       1       1       1       1       1
2       4
11      -1      0       100     233     308     382     660     790     885     1500    99999
11      0       0       0       30      50      80      20      60      40      0       0
11      -1      0       120     250     312     450     650     820     932     1320    99999
11      0       0       0       20      30      40      10      30      20      0       0
10      -1      0       260     350     468     660     790     885     1500    99999
10      0       0       0       10      60      0       40      5       0       0
10      1       1       1       1       1       1       1       1       1       1
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**Figure 3: Example of h*abitatALMaSSNectarPollenInput.txt* file describing floral resource curves for habitats of different type.**

The structure of *tovALMaSSNectarPollenInput.txt* file is similar (see Fig. 4). Besides the heading after the entry indicating the number of data sets with floral resource curves (6 in this example), the specific codes for crops are linked with the curve number. The curve numbers that are greater than 10000 are reserved for crops. In the example provided, code '22' stands for winter rape and the data set describing the floral resource curve for this crop has the number of '10001'.

**Figure 4: Example of *tovALMaSSNectarPollenInput.txt* file describing floral resource curves for crops.**

On reading the curve into ALMaSS the slope between two inflection points is used to calculate the amount of resource added/subtracted per day based on the calculated GDDs. This model is driven using the standard ALMaSS weather data based on average daily temperature. This, together with defining the type of floral resource model for each element in the landscape map, allows to track the dynamics in floral resources available to bees in different regions and under different weather patterns.

## 2.2. Implementation of flower resource model in ALMaSS

There are two core classes for the flower resource model, namely *PollenNectarDevelopmentCurveSet* and *PollenNectarDevelopmentData*. The *PollenNectarDevelopmentCurveSet* is designed to load the two pollen and nectar phenological data in the two input files. *PollenNectarDevelopmentData* is designed to implement the pollen and nectar development curves based on the accumulated degree day. Here we take the pollen quantity as an example. Suppose we have two consecutive accumulated degree day inflection points $d_{i-1}$ and $d_i$, the corresponding pollen quantities at these two points are $p_{i-1}$ and $p_i$, the pollen quantity $p(t)$ for any given degree day $d(t)$ between $d_{i-1}$ and $d_i$ can be calculated by equation (1).

$$p(t) = \frac{d(t)-d_{i-1}}{d_i-d_{i-1}} (p_i - p_{i-1}) + p_{i-1} \qquad (1)$$

The floral resources are provided to the model honey bees through the Input/Outputs in the Landscape class in ALMaSS. The quantity and quality of the pollen and nectar for each simulated day can be accessed by polygon or location (1m by 1m area). In ApisRAM, the model bees access the flower resource by polygon. When they do scout, the scouter will choose a direction randomly, with a resolution of one degree, and one of the polygons with flower resource will be chosen and the information of this polygon will be brough back to the colony. This information will be shared with other foraging bees thus allowing them to make decisions about which polygons to visit for foraging.

# 3. Overview of the ALMaSS landscape generation process for BE and UK

In this section we first briefly introduce the landscape representation in ALMaSS, describe the major categories of data needed for generating the ALMaSS landscape model and provide an overview of processing steps of ALMaSS landscape generation. Secondly, we summarize the ALMaSS landscape generation process for BE and the UK and describe how floral resource curves were defined for specific types of landscape elements present in the BE and UK landscapes.

## 3.1. Landscape representation in ALMaSS

In ALMaSS, landscapes are modelled using a detailed, spatio-temporal representation which provides a realistic environment for agent-based simulations of the focal species. In this representation:

- *Spatial landscape heterogeneity* is described by a detailed raster land cover map with complete coverage and spatial resolution of 1 $m^2$. Each unit in the raster land cover map is classified in accordance with its landscape element type (e.g., natural or permanent grassland, field in rotation, built-up area), including detailed structures important for the species under consideration, such as hedgerows or field margins. To account for crop diversity, field boundaries are also added, with each field belonging to a given farm unit (managed by the same farmer). Farm units are classified into different types, e.g., cattle, pig or arable farms, based on the structure of the crops grown and the animals present in the farm. This structure allows for the incorporation of information on farm management to the description of spatial heterogeneity in a given point of time (Topping et al. 2003, 2016).
- *Temporal landscape heterogeneity* includes both crop management throughout a year, described through individually tailored management plans for each crop, and the cropping system understood as a plurennial crop rotation. Associated vegetation growth models for all modelled vegetation types and crops supply vegetation height, green and total biomass on a daily basis, and are fed by weather conditions (mean daily temperature, mean daily wind speed and daily sum of precipitation).

## 3.2. Major categories of input data

The generation of the ALMaSS landscape model is based on the information obtained from different data sources of sufficiently high resolution and quality (Fig. 5).
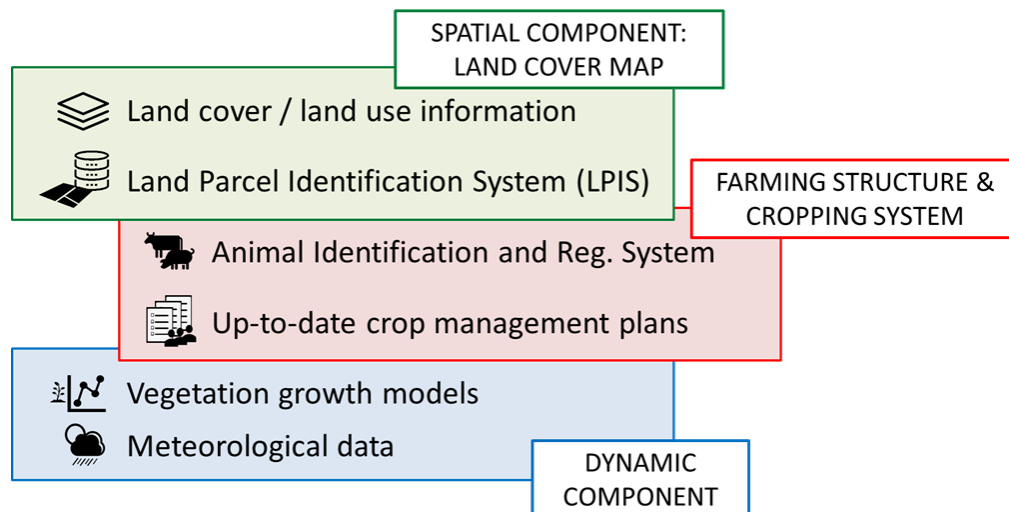
**Figure 5: Main types of input data needed for the generation of the ALMaSS landscape model.**

The following categories of data are necessary:

i.   *Land use/ land cover* information including the map layers presenting natural and/or semi-natural landscape elements (e.g., rivers or streams, lakes, bare sand or rock, steep slopes); natural or semi-natural vegetation (e.g., hedgerows, open vegetation types, forest, isolated trees); infrastructure (e.g., roads, buildings or industry); and protected areas.
     Such information usually comes from different data sources, but in most cases the topographic object databases with level of details corresponding with topographic maps at the scale of 1:5 000 – 1:25 000 are the most important source of land cover/land use information needed for the ALMaSS landscape model generation.

ii.  *Agriculture* (e.g., field boundaries linked to farm management) - Under the Common Agricultural Policy (CAP), if farmers want to apply for the EU subsidies they are obligated to report for each individual reference parcel the crop(s) they grow (with information of area of each crop grown) and the number of livestock they own. The Land-Parcel Identification System (LPIS) has been developed in each of the EU country to support CAP and its stores geographic information on 'reference parcels'. Different types of 'reference parcels' can be used including (i) agricultural parcels, (ii) farmer blocks, (iii) physical blocks, and (iv) cadastral parcels, depending on the country. The data on 'reference parcels' together with agricultural register (related information on type of crops grown and their coverage) needs to be merged with the land use/ land cover information from (i).
     Since the parcel layer is based on subsidy payments from EU, and it is mandatory for farmers claiming subsidy to make the delineation/definition of the parcel(s), this layer has various level of detail depending on the country / region.

iii. *Farm animals data* (Animal Identification and Reg. System) - together with the register of crops this data is used to classify farm units into general farm types.

iv.  *Soil type information* for vegetated landscape elements – as the ALMaSS landscape simulator modifies the actual production on each field based on the dominant soil type. Soil data at the EU level were obtained from the European Soil Database provided by the Joint Research Centre.

v.   *Weather data* – including historical data on mean daily temperatures, wind speed and daily sum of precipitation for at least 10 years. At the EU level these data can be obtained from the European Climate Assessment & Dataset project.

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vi.   *Up-to-date crop management plans* – describing time windows and probabilities of occurrence of all farming operations including soil cultivation practices, as well as fertilizer and pesticide applications.

vii.  *Vegetation growth models* if not already in ALMaSS. Inside the model landscape, all vegetation types and crops have their own seasonal growth models supplying vegetation height, green and total biomass.

## 3.3. Overview of processing steps

### 3.3.1.   Generation of the ALMaSS landscape map

Generation was done by combining individual layers of land use / land cover information together with information on agricultural fields into a single raster landscape map in a step-by-step process. As layers from different data sources were used, this resulted in inconsistencies related to spatial alignment of features (i.e. overlaps or gaps between features). In addition, some objects were represented as points or lines (dimensionalities of 0 and 1) and had to be first pre-processed in order to change them to be represented in two-dimensional space. However, this process increased the number of inconsistencies in the combined map even more, so a special step-by-step procedure was applied in order to obtain a landscape raster map with no gaps in information and with removal of sliver polygons.

The overall process to generate the ALMaSS landscape map consisted of the following general steps (although some specific processing steps were needed in each country due to the particularity of national / regional data):

i.    Clipping the input layers to the study area extent;

ii.   Converting the input vector data to raster format (with spatial resolution of 1 m), object class by object class;

iii.  Combining individual layers into thematic maps (e.g., transportation theme, built-up theme);

iv.   Stacking of thematic maps to generate raw landscape map (Fig. 6);

v.    Reclassification of large 'background' polygons, and removing of inconsistencies in the landscape raw map (multi-stage process);

vi.   Reclassification and regionalization of resulting landscape map. The landscape map contains more details than are used in ALMaSS. Therefore, to be consistent with landscape element types used in ALMaSS we used simple reclassification based on a text file (separate for each analysed country). All features in the ALMaSS landscape map, consisting both of single and multiple raster cells, have a unique value (polygon ID) that is common to all cells within the feature. This was achieved by regionalizing the raster before exporting the map as a final ASCII file.

vii.  Exporting results;

viii. Generating input files for ALMaSS.
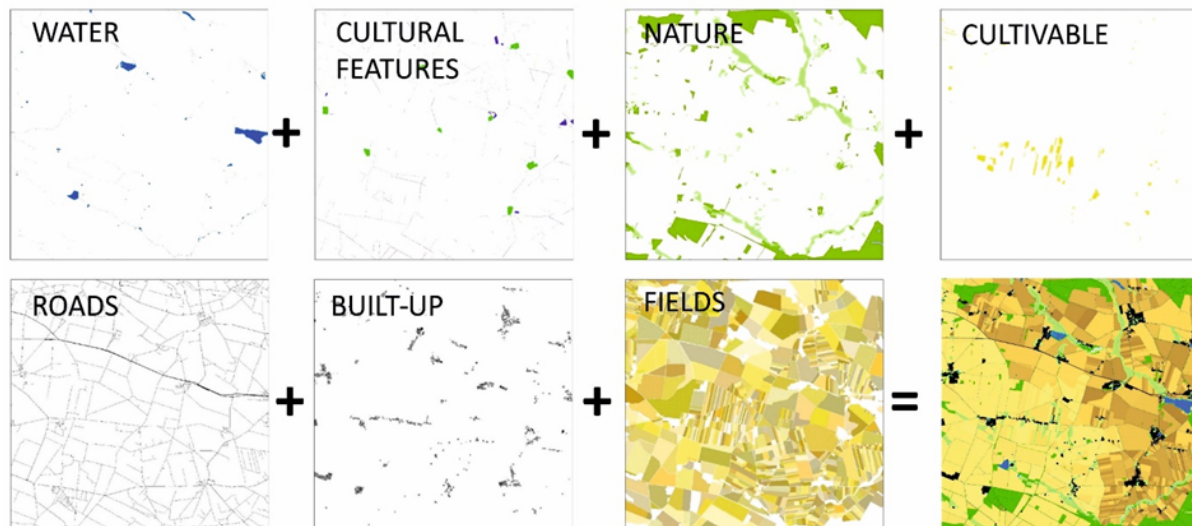
**Figure 6: Stacking of GIS layers.**

### 3.3.2. Farming structure and cropping system

In ALMaSS crop management is applied at the farm level, therefore individual agricultural parcels (fields) have to be grouped into farm units of different types (e.g., conventional cattle, pig or arable farms). Farm classifications were generated for each country / region separately based on LPIS and farm animal data.

Based on proportions of crops cultivated by farms of different types, crop rotation schemes can be generated for each farm type individually. Only crops with more than 1% share of the area of a farm type are considered. In such a case it is assumed that the rotation could be represented by 100 crops (1 crop for each 1%). The order of crops follows typical agronomic practices and issues such as late harvest leading to impossible sowing conditions are controlled by the built-in ALMaSS farm code. The result is a pattern of changing crops on a field that matches the overall crop distribution pattern for that farm type precisely over 100 seasons. If a specific crop, e.g., maize for silage, occurs 13 times out of 100 in the rotation, it will on average occur on 13% of all fields covered by that rotation at any point in time. It is also possible to use pre-defined crop rotation schemes.

### 3.3.3. Incorporation of crop management & vegetation growth

Inside the model landscape, all vegetation types and crops have their own seasonal growth models supplying vegetation height, green and total biomass. The result is a dynamic landscape with all vegetation growing in response to the weather. Crops and other vegetation also respond to management. Crops will grow from sowing and respond to management events such as harvest and cutting, which are programmed into the ALMaSS according to crop management plans provided by farmer advisors or other experts from each analysed country. Non-crop vegetation can also be managed, e.g. roadside verges are mown during summer in the model.

### 3.3.4. Structure of the input files for ALMaSS

Finally, the landscape and farming structure in a landscape is described by three input files for ALMaSS: landscape binary file (.lsb), polygon reference file (.txt) and farm reference file (.txt). The landscape binary file is produced from the landscape ASCII file (see subsection

2.3.1). Each element in the landscape binary file is a 32-bit integer which is the unique polygon ID for a 1m by 1m pixel in the landscape. All additional information on polygons is provided in separate files. The farm reference file is a text file relating farm reference numbers to farm types. The polygon reference file is a text file containing unique IDs on all polygons in the landscape (*PolyRefNum*), with information of their landscape element type (*PolyType*), the number of cells belonging to each polygon (*Area*), a reference number to a farm owner/holding (*FarmRef*), and a set of optional attributes like the soil type of each polygon (*SoilType*) (Table 1).

The last column in the polygon reference file, *PollenNectarCurve*, allows to associate each landscape polygon with an adequate flower resource curve number describing changes in quality and quantity of floral resource produced throughout the year (see subchapter 2.1). There are three specific entries which can be provided in the *PollenNectarCurve* column. If a given landscape polygon belongs to a landscape element type with unknown resources it is assigned a value of '-1' as it is treated in the same way as a landscape polygon not providing resources (with assigned value of '-2', e.g., buildings, rivers, roads). If a given polygon is a field in rotation (*PolyType* = 20), it is assigned a value of '-3'. During the simulation run, when crop type is assigned to a field according to rotation rules for a given farm type, a proper floral resource curve is assigned to this field based on information provided in the heading of *tovALMaSSNectarPollenInput.txt*.

**Table 1: Part of the polygon reference file for Merendre in BE.**

| Poly Type | Poly Ref Num | Area | Farm Ref | UnSprayedM arginRef | SoilT ype | Open ness | Centr oidX | Centr oidY | Eleva tion | Slo pe | Asp ect | PollenNect arCurve |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 0 | 786 | 274 | -1 | 1 | 0 | 32 | 6 | -1 | -1 | -1 | -3 |
| 123 | 1 | 150 | -1 | -1 | -1 | 0 | 2 | 67 | -1 | -1 | -1 | -1 |
| 123 | 2 | 23 | -1 | -1 | -1 | 0 | 78 | 11 | -1 | -1 | -1 | -1 |
| 20 | 3 | 1642 | 276 | -1 | 1 | 0 | 110 | 14 | -1 | -1 | -1 | -3 |
| 60 | 4 | 507 | -1 | -1 | -1 | 0 | 91 | 25 | -1 | -1 | -1 | 5 |

## 3.4. Generation of ALMaSS landscape model with floral resource information for analysed countries
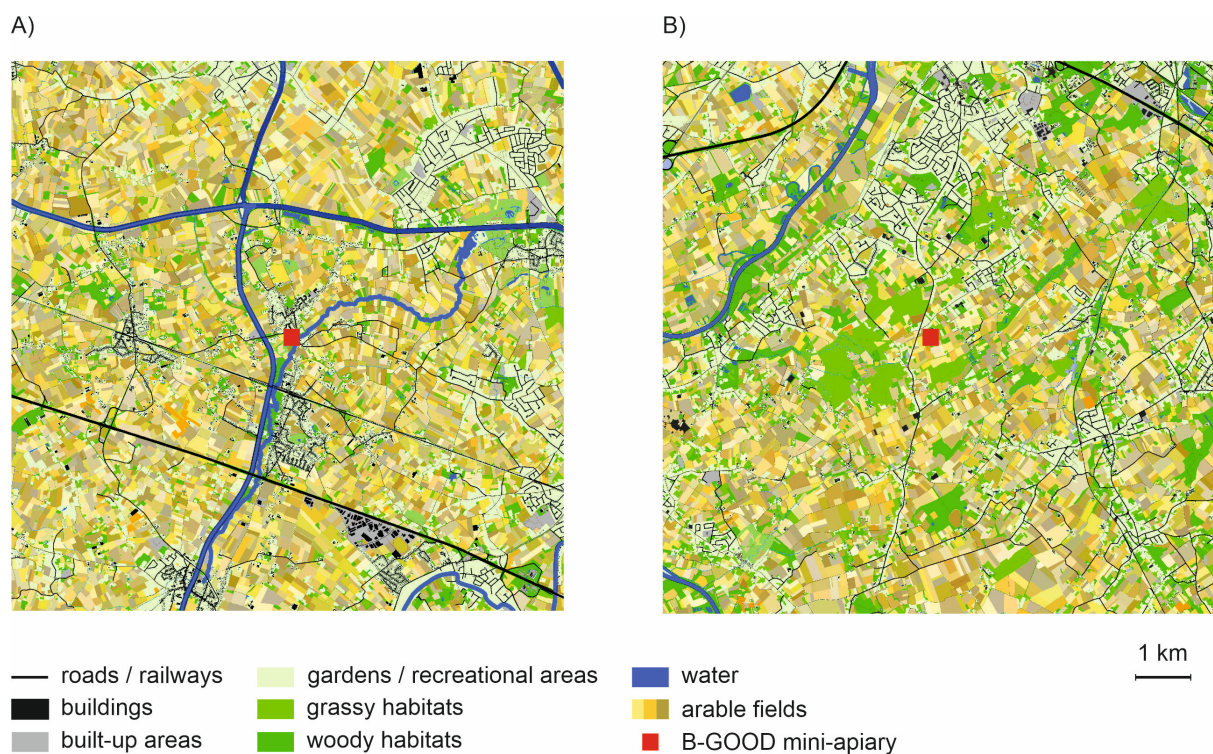
### 3.4.1. Belgium

Here we provide only a short summary of the landscape generation process for Belgium, while the full details are provided in Appendix B.

For generation of simulation landscapes, we used the following datasets:

i.   The Open Street Map (OSM, downloaded from www.openstreetmap.be in November 2019) as a source of topographic information, as the detailed official topographic maps for Belgium are not free of change;

ii.  The Biological Valuation Map (BVM, Biologische waarderingskaart) provided by the Research Institute for Nature and Forestry research (Instituut voor Natuur-en Bosonderzoek), as a source of information on nature reserves and forest types;

iii. LPIS data for 2018 (including field boundaries, area and type of crops cultivated, together with the IDs of agricultural holdings) provided by the Flemish and Walloon Department of Agriculture;

iv.    Crop management plans generated for the most important crops in Belgium based on opinion of tree agricultural advisory agencies (*Proefcentrum Groententeelt*, *Koninklijk Belgisch Instituut tot Verbetering van de Biet* and *Inagro*).

Individual layers of land use / land cover information together with information on agricultural fields were then combined into a single raster landscape map in a step-by-step process described in the subparagraph 2.3.1. The landscape map units were further reclassified to the landscape element types used in ALMaSS (Fig. 7). Landscape map was integrated with information on farming structure to produce input files for ALMaSS. The landscape generation process was coded using Python and R scripts (available in the GitLab repository https://gitlab.com/ALMaSS/b-good-wp5).



A)                                                          B)

| --- roads / railways | gardens / recreational areas | water |
| ■ buildings | grassy habitats | arable fields |
| built-up areas | woody habitats | ■ B-GOOD mini-apiary |

1 km

**Figure 7: Landscape windows (10x10 km) located around B-GOOD mini-apiaries in Belgium: (A) Merendree, (B) Merelbeke. Legend denotes general classes of landscape elements visible on landscape maps. Although spatial resolution is 1 m$^2$, not all features are visible due to the scale used. For the same reason it was impossible to show all the landscape elements classes used in detailed ALMaSS landscape models of the windows.**

For each of landscape element type (*PolyType*) identified in Belgium landscapes, we defined the type of floral resource curve (Table 2) associated with it, and this information was added to the polygon reference file (as described in subchapter 3.3.4). The detailed description of composition of plants, density of flowers and amount of floral resources (nectar, sugar and pollen) produced by each plant is available in Appendix D as well as in the GitLab repository https://gitlab.com/ALMaSS/b-good-wp5). In addition, all the documentation and input files related to the generation of floral resource models can be found in the GitLab repository https://gitlab.com/ALMaSS/floral_resource_models.

**Table 2: Allocation of floral resource curves to landscape element types for BE**

| Poly Type | Landscape element type | Pollen Nectar Curve | Floral resource curve type | Short description | Source of information to define plant composition |
|---|---|---|---|---|---|
| 5 | **tole_Building** | -1 | none | | |
| 8 | **tole_UrbanNoVeg** | -1 | none | | |
| 11 | **tole_Garden** | 29 | GARDEN_BE | Typical garden (one type) | Composition defined based on information provided by David Claeys Boúúaert |
| 17 | **tole_UrbanPark** | 25 | URBAN_PARK_BE | Urban park | Composition defined based on field work (task 3.3) by David Claeys Boúúaert |
| 20 | **tole_Field** | -3 | fields in rotation | Floral resource curve depending on crop | |
| 40 | **tole_DeciduousForest** | 3 | ATL_G1 | Atlantic: Broadleaved deciduous woodland | BIOEUNIS (modified version of Deliverable D3.1) |
| 50 | **tole_ConiferousForest** | 4 | ATL_G3 | Atlantic: Coniferous woodland | BIOEUNIS (modified version of Deliverable D3.1) |
| 56 | **tole_Orchard** | 35 | APPLE_ORCHARD | Apple orchard | |
| 60 | **tole_MixedForest** | 5 | ATL_G4 | Atlantic: Mixed woodland | BIOEUNIS (modified version of Deliverable D3.1) |
| 90 | **tole_Freshwater** | -1 | none | | |
| 94 | **tole_Heath** | 6 | ATL_F4 | Atlantic: Temperate shrub heathland | BIOEUNIS (modified version of Deliverable D3.1) |
| 96 | **tole_River** | -1 | none | | |

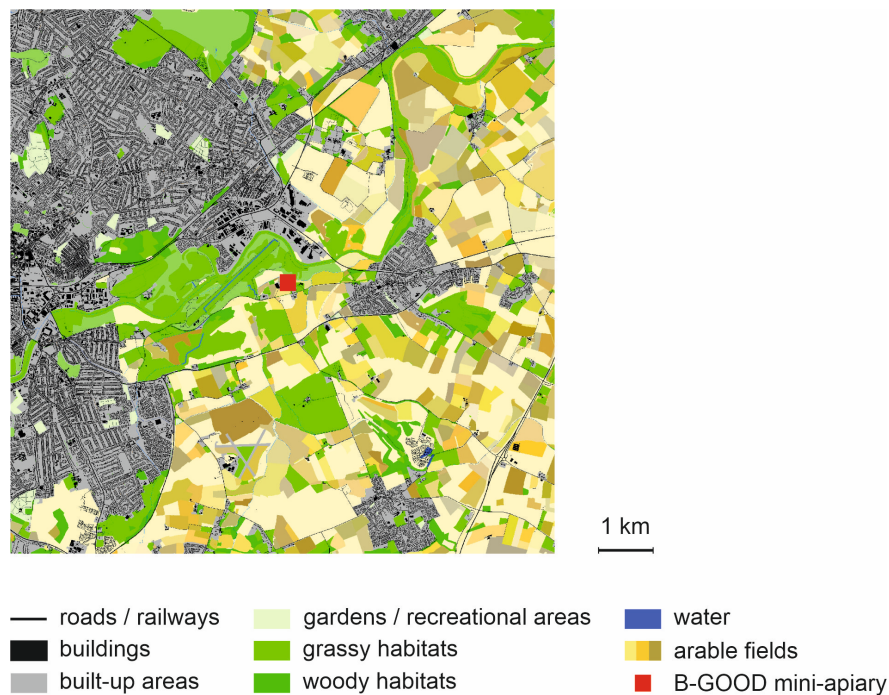| | | | | | |
|---|---|---|---|---|---|
| 98 | **tole_RiversidePlants** | 24 | RIVERSIDE_PLANTS_BE | Riverside plants | Composition defined based on field work (task 3.3.) by David Claeys Boúúaert |
| 118 | **tole_Railway** | -1 | none | | |
| 121 | **tole_LargeRoad** | -1 | none | | |
| 122 | **tole_SmallRoad** | -1 | none | | |
| 123 | **tole_Track** | -1 | none | | |
| 205 | **tole_NaturalGrassWet** | 2 | ATL_E3 | Atlantic: Seasonally wet and wet grasslands | BIOEUNIS (modified version of Deliverable D3.1) |
| 207 | **tole_Stream** | -1 | none | | |
| 213 | **tole_IndividualTree** | 30 / 31 / 32 / 33 / 34 | | Castanea sativa; Tilia platyphyllos; Fagus silvatica; Quercus robur / rubra; Robinia pseudoacacia | Composition defined based on information provided by David Claeys Boúúaert |
| 222 | **tole_DrainageDitch** | -1 | none | | |
| 223 | **tole_Canal** | -1 | none | | |

### 3.4.2.  UK

Here we provide only a short summary of the landscape generation process for the UK, while the full details are provided in Appendix C.

For generation of simulation landscapes, we used the following datasets:

i.   Topographic data from Ordnance Survey available for use on the Edina Digimap service (https://digimap.edina.ac.uk/roam/download/os). The data available included river and watercourses, roads, railways, greenspaces including cemeteries and sport spaces, and buildings;

ii.  Land cover map from the Centre of Ecology and Hydrology (CEH) available for use on the Edina Digimap service (https://digimap.edina.ac.uk/roam/download/environment) to obtain information on woodland and grassland types;

iii. LPIS data for 2021 (including field boundaries, area and type of crops cultivated, together with the IDs of agricultural holdings) provided by the Rural Payment Agency (https://www.gov.uk/government/organisations/rural-payments-agency);

iv.  Crop management plans generated for the most important crops in UK based on information gathered from farmer advisors.

Individual layers of land use / land cover information together with information on agricultural fields were then combined into a single raster landscape map in a step-by-step process described in the subchapter 2.3.1. The landscape map units were further reclassified to the landscape element types used in ALMaSS (Fig. 8). The landscape map was integrated with information on farming structure to produce input files for ALMaSS. The landscape generation process was coded using Python and R scripts (available in the GitLab repository https://gitlab.com/ALMaSS/b-good-wp5).



| | | |
|---|---|---|
| — roads / railways | gardens / recreational areas | water |
| buildings | grassy habitats | arable fields |
| built-up areas | woody habitats | B-GOOD mini-apiary |

**Figure 8: Landscape window (10x10 km) located around B-GOOD mini-apiary in UK. Legend denotes general classes of landscape elements visible on landscape maps. Although spatial resolution is 1 m², not all features are visible due to the scale used. For the same reason it was impossible to show all the landscape elements classes used in detailed ALMaSS landscape models of the windows.**

For each of landscape element type (*PolyType*) identified in UK landscapes, we defined type of floral resource curve (Table 3) associated with it, and this information was added to the polygon reference file (as described in subchapter 3.3.4). The detailed description of composition of plants, density of flowers and amount of floral resources (nectar, sugar and pollen) produced by each plant is available in Appendix D available in the GitLab repository https://gitlab.com/ALMaSS/b-good-wp5). In addition, all the documentation and input files related to the generation of floral resource models can be found in the GitLab repository https://gitlab.com/ALMaSS/floral_resource_models.

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**Table 3: Allocation of floral resource curves to landscape element types for the UK**

| Poly Type | Landscape element type | Pollen Nectar Curve | Floral resource curve type | Short description | Source of information to define plant composition |
|---|---|---|---|---|---|
| 5 | **tole_Building;** | -1 | none | | |
| 8 | **tole_UrbanNoVeg;** | -1 | none | | |
| 12 | **tole_AmenityGrass;** | -1 | none | | |
| 17 | **tole_UrbanPark** | 26 | URBAN_PARK_UK | Urban park | Composition defined based on field work (task 3.3.) by Adam Mcveigh |
| 20 | **tole_Field** | -3 | fields in rotation | Floral resource curve depending on crop | |
| 40 | **tole_DeciduousForest** | 3 | ATL_G1 | Atlantic: Broadleaved deciduous woodland | BIOEUNIS (modified version of Deliverable D3.1) |
| 50 | **tole_ConiferousForest** | 4 | ATL_G3 | Atlantic: Coniferous woodland | BIOEUNIS (modified version of Deliverable D3.1) |
| 90 | **tole_Freshwater** | -1 | none | | |
| 96 | **tole_River** | -1 | none | | |
| 110 | **tole_NaturalGrassDry;** | 1 | ALT_E1 | Atlantic: Dry grassland | BIOEUNIS (modified version of Deliverable D3.1) |
| 118 | **tole_Railway** | -1 | none | | |
| 121 | **tole_LargeRoad** | -1 | none | | |
| 122 | **tole_SmallRoad** | -1 | none | | |
| 123 | **tole_Track** | -1 | none | | |
| 130 | **tole_Hedges;** | 27 | HEDGES_UK | Hedges | Composition defined based on field work (task 3.3.) by Adam Mcveigh |
| 204 | **tole_Churchyard;** | -1 | none | | |
| 205 | **tole_NaturalGrassWet** | 2 | ATL_E3 | Atlantic: Seasonally | BIOEUNIS (modified version of |

| | | | | wet and wet grasslands | Deliverable D3.1) |
|---|---|---|---|---|---|
| 209 | **tole_Wasteland;** | 23 | FALLOWS3-5YRS_PL | Fallows not cultivated in the last 3-5 years | Personal information provided by Jacek Jachuła |
| 221 | **tole_RiverBed** | -1 | none | | |
| 223 | **tole_Canal** | -1 | none | | |
| 222 | **tole_DrainageDitch** | -1 | none | | |
| 223 | **tole_Canal** | -1 | none | | |

# 4. Testing of ApisRAM for BE and UK

The main purpose of this deliverable is to create the landscape model for BE and the UK and integrate the flower resource model into ALMaSS. After these two steps were done, the final step was to test whether ApisRAM could run on these landscapes and was able to access the flower resource in order to provide the basis for the further development of ApisRAM in the B-GOOD project. Below we show, for illustration, ApisRAM simulations running on one landscape per country. At this point we can only demonstrate that ApisRAM now functions in the landscapes together with the modelled nectar and pollen in Belgium and UK. The next step will be to use the apiary data to calibrate ApisRAM for the various countries in B-GOOD and provide a much more realistic colony growth model.

## 4.1. Testing result in BE

Fig. 9 shows an ALMaSS landscape generated using the method described in Section 3 for the location of the Gent B-GOOD mini-apiary in Belgium. The ApisRAM colony is in the centre of the landscape. The simulation started on the Jan. 1st. When the simulation started, there was one queen and ca. 16 thousand worker bees, and no brood. There were frames and cells randomly assigned with pollen and nectar for the colony. In Fig. 10 and 11, the available amount of pollen and nectar in the landscape for a given day is displayed as a heat map, where dark means the absence of resources, and brighter corresponding to more resource. When the bees start foraging, they will choose locations with flower resources, initially randomly but later based on communicating their knowledge of the resources to other bees in hive.

Using these recourses, the ApisRAM colony could persist in this landscape. The number of worker bees at different life stages for one simulated year can be seen in Fig. 12. As noted above, this is for illustration only. Now that the models are working together properly calibration of the models can start.
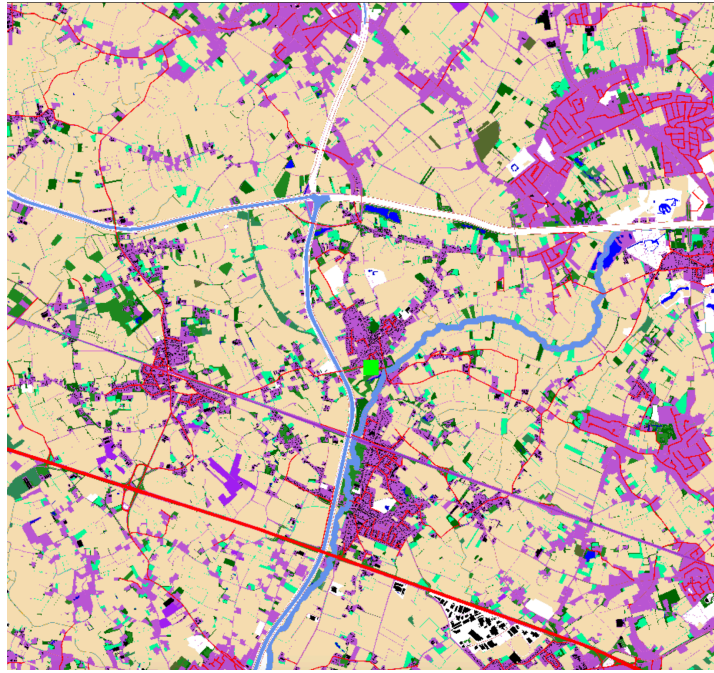
**Figure 9: ALMaSS landscape map (view from ALMaSS GUI) around the B-GOOD mini-apiary in the Merendree landscape window in BE. The green rectangle is the ApisRAM colony.**
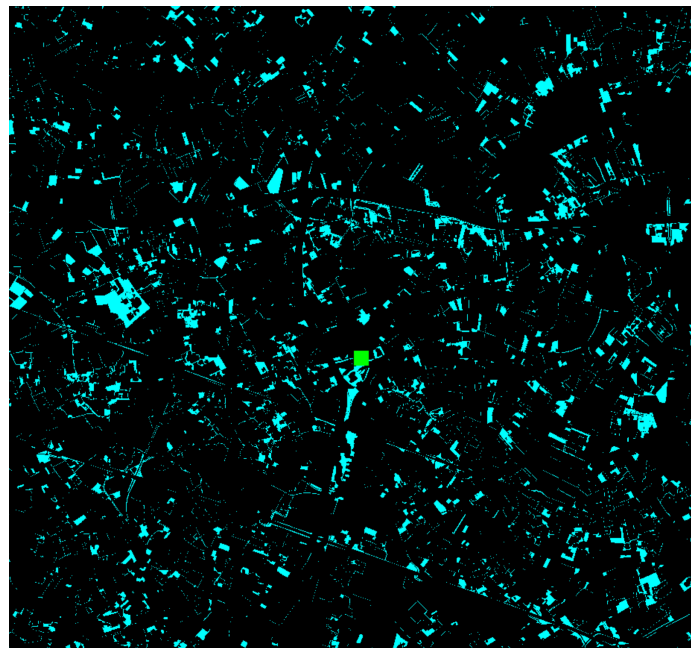


**Figure 10: The status of pollen in the Merendree landscape window on Feb. 14 in a simulated year. The dark areas are with little or no pollen while the brighter ones show high pollen availability. The green rectangle represents the ApisRAM colony.**
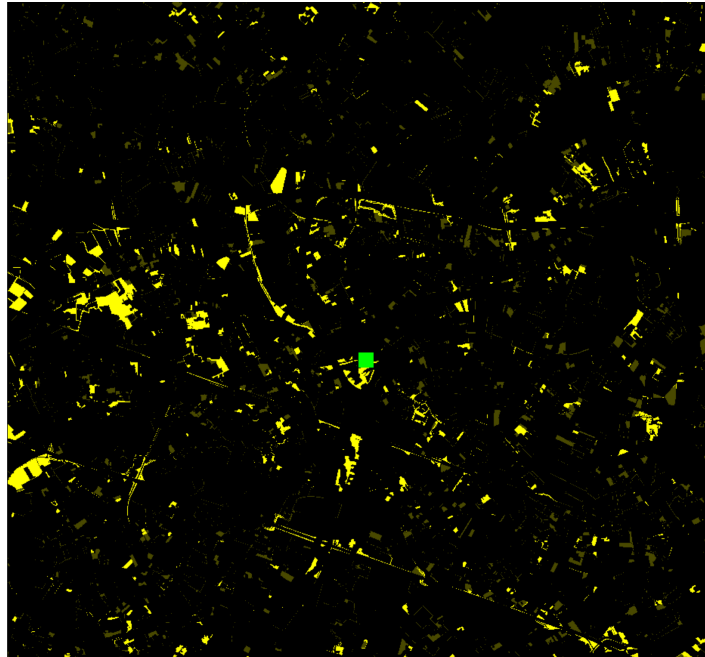
**Figure 11: The status of nectar in the Merendree landscape window on Feb. 14 in a simulated year. The dark areas are with little or no nectar while the brighter ones show high nectar availability. The green rectangle represents the ApisRAM colony.**
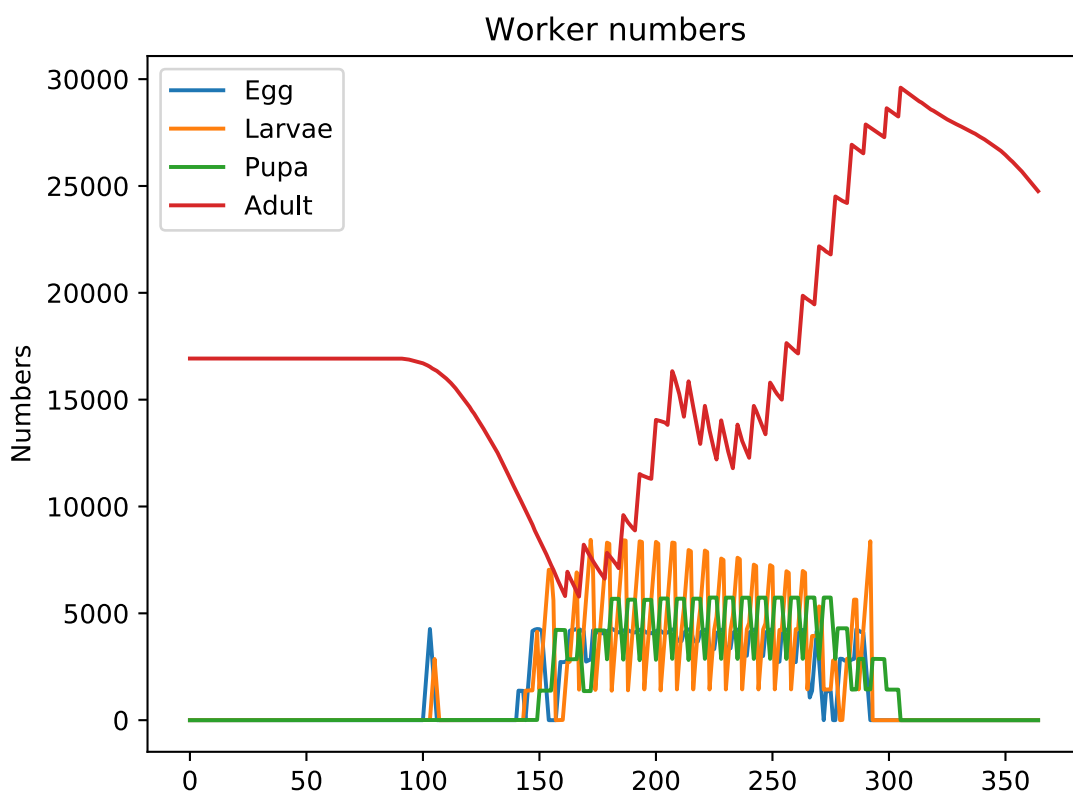


**Figure 12: Population dynamics of worker bees in one simulation year in the Merendree landscape window in BE.**

## 4.2. Testing result in UK

To test the UK landscape, we used a similar approach to that for the Belgian landscape. The landscape itself was centred on the Nottingham B-GOOD mini-apiary (Fig. 13). The simulation started with one queen and ca. 16 thousand workers and no brood. Honey and pollen were randomly assigned to cells in the frames to provide starting resources.

When the model is run in landscape view the status of the nectar and pollen can be seen on a daily basis. Fig. 14 and 15 show the nectar and pollen quantities for June 1$^{st}$ and May 31$^{st}$ respectively. Using these resources the ApisRAM colony could persist and grow in this landscape, and the population dynamics for one year is shown in Fig. 16. Like the Belgian example this is for illustration only since the calibration of the model and resources together is the next step.
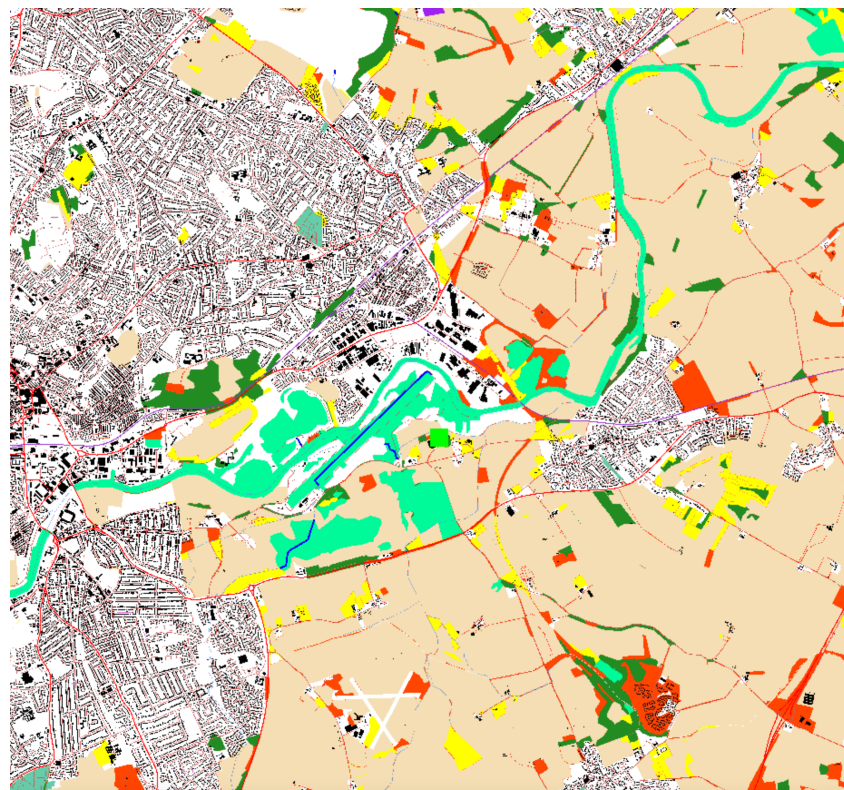


**Figure 13: ALMaSS landscape map (view from ALMaSS GUI) around the B-GOOD mini-apiary in the Nottingham landscape window in UK. The green rectangle is the ApisRAM colony.**
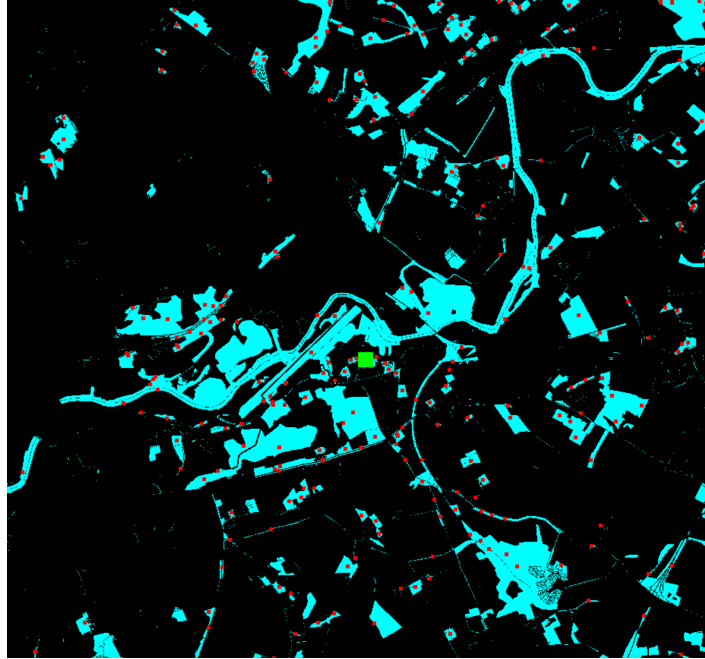
**Figure 14: The status of pollen in the Nottingham landscape window on June 1 in a simulated year. The dark areas are with little or no pollen while the brighter ones show high pollen availability. If there is a red dot, it means there are foragers in that polygon at that moment in time. The green rectangle represents the ApisRAM colony.**
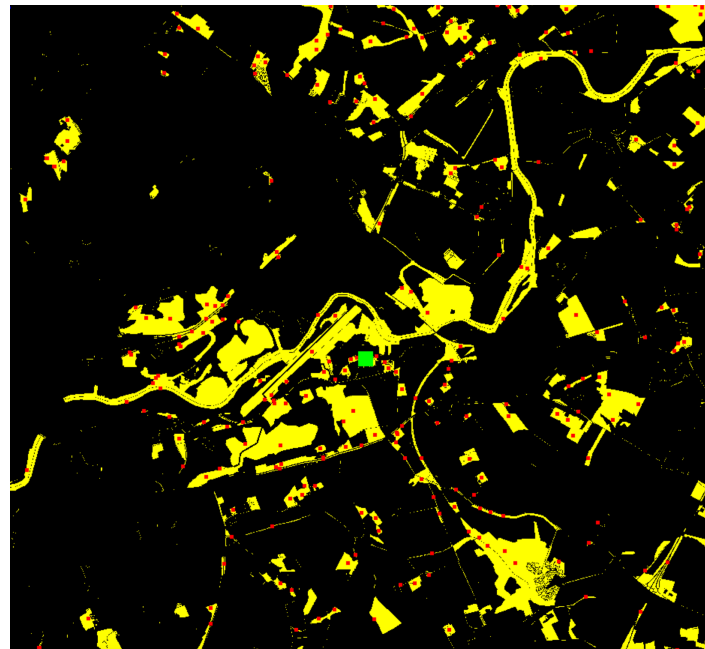


**Figure 15: The status of nectar in the Nottingham landscape window on May 31 in a simulated year. The dark areas are with little or no nectar while the brighter ones show high nectar availability. The red dot represents that there are forager(s) in that polygon. The green rectangle represents the ApisRAM colony.**
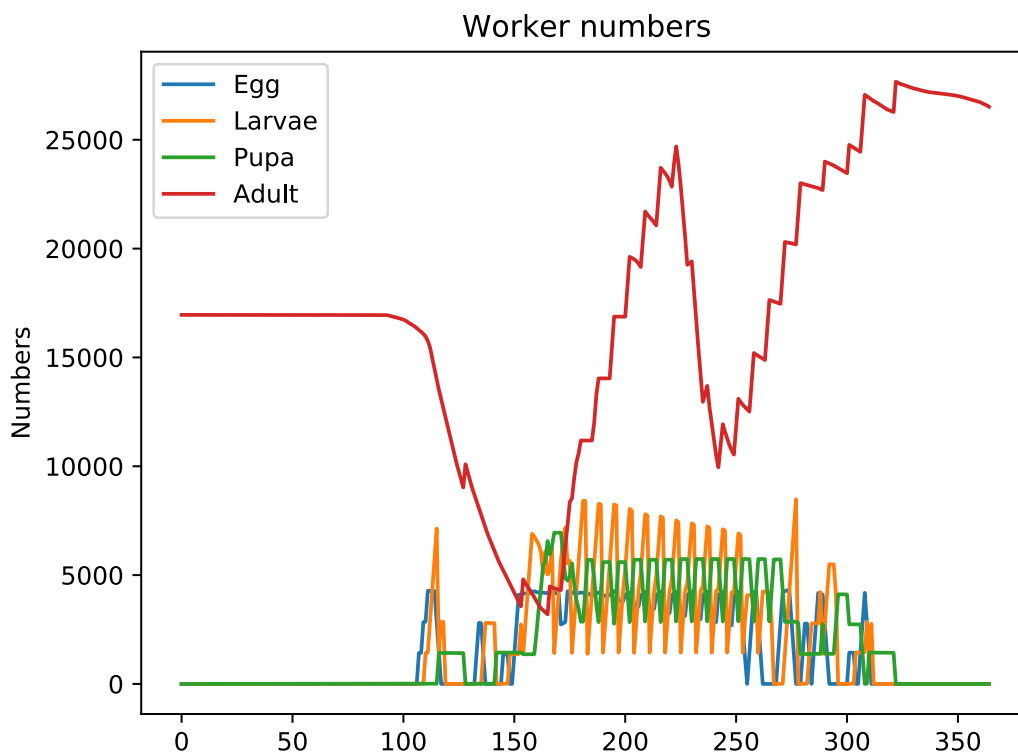
**Figure 16: Population dynamics of worker bees in one simulation year in the Nottingham landscape window in UK.**

# 5. Acknowledgements

We would like to thank Luna Kondrup Marcussen for testing the crop code in ALMaSS for BE and UK, David Claeys Bouuaert for developing the ALMaSS landscape model for BE, and Adam McVeigh for developing the ALMaSS landscape model for the UK.

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