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Enhancing Migratory Beekeeping Practice Using Digital Flowering Calendar

Olvija KOMASILOVA, Daniels KOTOVS, Vitalijs KOMASILOVS, Armands KVIESIS, Aleksejs ZACEPINS

Department of Computer Systems, Faculty of Information Technologies, Latvia University of Life Sciences and Technologies, Liela iela 2, Jelgava, LV-3001, Latvia

olvija.komasilova@llu.lv, daniels.kotovs@llu.lv, vitalijs.komasilovs@llu.lv, armands.kviesis@llu.lv, aleksejs.zacepins@llu.lv

Abstract. This research presents an approach to creating and visualising plant flowering calendar. To complete this task, several steps should be taken, starting from the preparation of the flowering data, then selecting the area of interest and converting this area into polygons, which correspond to plant fields and finishing with assigning the plants to target fields. The proposed solution provides flowering simulation, when the fields are encoded by colour, based on flowering information throughout the year. The developed simulation can give an overview of the flowering plants in a specific region and at a certain time. This information can be used in various ways, mainly by the migratory beekeepers, other agricultural specialists and the general public. Python language was used for the simulation and visualisation. Simulation can be extended to use additional factors and parameters to increase the potential application of the outcome. This work is conducted within the Horizon 2020 FET project HIVEOPOLIS (Nr.824069).

Keywords: precision beekeeping, flowering calendar, flowering simulation, nectar foraging, smart beekeeping, HIVEOPOLIS.

1. Introduction

The selection of a good foraging location for bee colonies is an important task for beekeepers, especially for migratory or travelling beekeepers (Komasilova et al., 2021). The optimal location will allow bee colonies to forage a higher amount of resources with minimal energy consumption. To ensure maximum productivity and continuous honey gathering, beekeepers move their beehives closer to the nectar resources (Vlad et al., 2012). When beekeeping is managed on a migratory basis, the bee colony produces honey and provides pollination services at different foraging locations. Foraging locations are competitors if their flowering periods overlap, and they are complementary when plants have different flowering periods (Pilati and Prestamburgo, 2016). In many countries, for example, in the USA (Rucker and Thurman, 2019), Indonesia (Gratzer et al., 2019), Ethiopia (Kumsa et al., 2020), Turkey (Özkirim, 2018), migratory beekeeping is very common, and beekeepers are forced to change the apiary location often to provide food sources for their bees to increase the production rate. Apiculture has gained worldwide interest because of its contribution to economic incomes (Popescu and Popescu, 2019), sustainable environmental conservation (Kass Degu and Regasa Megerssa, 2020; Mudzengi et al., 2020) and, in view of this, migratory beekeeping, as a high-yielding technique, is applied extensively (Ma et al., 2021). Therefore, to make modern beekeeping more profitable and sustainable, migratory apiary management is an important option, not only to enhance overall honey yield, but also to reduce supplementary feeding costs of the colony during food resources scarcity periods.

Migratory beekeepers provide pollination services to the farmers, and nowadays, this function has become of economic importance in main agricultural systems (Allsopp et al., 2008; Hein, 2009). Pollination is an essential ecosystem service, and bees are crucial to the rich diversity of fruits, vegetables, and nuts humans eat (Bolshakova and Niño, 2018). Many of the world's crops are pollinated by bees, and they are often assumed to be the most important pollinators (Rader et al., 2016). As well, beekeepers can move their colonies if the original geographical location lacks foraging resources. Since all crops do not flower simultaneously, the beekeepers can move their bee colonies from one forage site to the next throughout the year. To make the apiary location planning more efficient and predictive, beekeepers can use information about the crop and plant flowering.

Authors define flowering calendar as a digital tool that summarises the data about various crops' flowering periods, including the potential start and end dates of the crops blooming. The selection of forage sites means that timing is a crucial element in the beekeeper's migration over the year. Having information about the potential amount of foraging resources in specific locations, beekeepers can select and plan foraging places (Komasilova, 2020). To make the flowering calendar more user friendly and simplify the application of this tool, it can be combined with spatial information and GIS data. The flowering calendar is a timetable for a beekeeper that indicates the approximate date and duration of the blossoming periods of the important nectar and pollen plants (Bareke and Addi, 2018), basically serving as a guide to migrate the colonies during nectar flow to obtain higher honey production (Cacatian, 2016).

The digital flowering calendar can be considered as a tool for precision beekeeping as it integrates information and communication technologies into the beekeeping practices. In general, precision beekeeping is defined as an apiary management strategy based on the remote and real-time monitoring of individual bee colonies to minimise resource consumption and maximise the productivity of bees (Zacepins et al., 2015). Plus, the application of the flowering calendar can directly improve the success of the foraging process, thus increasing the bee colony productivity. Flowering calendar can be combined with other digital tools for the remote detection of the colony parameters, which are increasingly popular among beekeepers. Over the last century, many technical devices have been developed and tested on beehives. Scales, thermometers, microphones and other sensors have been used to monitor bee health (Marchal et al., 2020; Odemer, 2021). Those devices can also provide data that could be used in driving the beekeeper's decisions about timely migration into certain locations.

There are many flowering calendars available in the literature for different locations, but most of them are presented as tables with information, which lacks effective application of this information by end-users. A floral calendar containing the classification, availability and abundance, flowering time and duration is developed for Northwestern Cagayan (Cacatian, 2016). Bee forage plants with their family, habit, flowering period and food source for honeybees is developed for the Gera forest in Ethiopia (Bareke and Addi, 2019). Bee floral calendar of cultivated and wild plants is developed for Chitwan, Nepal (Rijat et al., 2018). A flowering calendar of plant species encountered near a meliponary in Belterra, Pára State, Brazil, also was prepared (De NOVAIS and Navarro, 2012). A bee flora calendar of Nagpur and Wardha regions in India was developed by (Pande and Ramkrushna, 2018). Flowering calendars for Ethiopia and Indonesia were also developed during the SAMS project (Wakjira et al., 2021).

The aim of this study is to describe the approach for digitalisation and visualisation of a flowering calendar and its usage in the beekeeping sector. This work's outcome would mainly allow the beekeepers to predict and plan the potentially high-intensity locations for honey bee colony foraging process, especially useful for migratory beekeepers. As well, when based on real data, this calendar can be used by a variety of specialists from other fields to help solve their specific problems, and, in general, this can serve as educational material for the general public observing the flowering of native plant cultures.

This research is conducted within the Horizon 2020 FET programme project HIVEOPOLIS (https://www.hiveopolis.eu/).

2. Materials and Methods

This section describes a proposed approach for the flowering calendar preparation and visualisation process. Within this research, the authors were not focused on real flowering data collection, but used some examples and data from the literature. This research was not aimed to identify the melliferous plant species and their density in different locations, but the authors' approach can be used for the beekeeping floral calendar development based on existing nectar plants in any geographical location.

2.1. The flowering calendar preparation process

Each nectar producing plant has its own flowering time and duration. Many external environmental parameters can affect the start of flowering. As well, in each geographical and climatic region, spring can come at different times, and this can change the progress of the flowering process. However, it was noticed, that the intervals between the flowering of an individual nectar plant remain almost the same from year to year.

Authors propose two approaches when predicting (evaluating) the start of the flowering period. One method uses the known data of the sowing date and knowing historically after which period it should bloom. The second approach is using the reference plant blooming starting date. In this case, to predict the timing of the flowering of the melliferous plants, it is necessary to choose one plant from those blooming in early spring and, based on the historical records, evaluate the time after which all other melliferous plants begin to bloom. More often, coltsfoot (Tussilágo farfara) or hazel (Córylus avellana) is taken as a reference plant (Mihailova and Litvinova, 2019). The plant blooming duration (period) should be taken from the existing literature (data).

Method 1 example: plant A is planted on day t1, then the start of the blooming is planned on a day t1+45, and the blooming period is 30 days.

Method 2 example: Reference plant (hazel) started to bloom on Day t2, then Plant B will bloom on day t2+30, Plant C bloom on day t2+45 etc.

Schematic explanation of the methods is depicted on Figure 1 below:

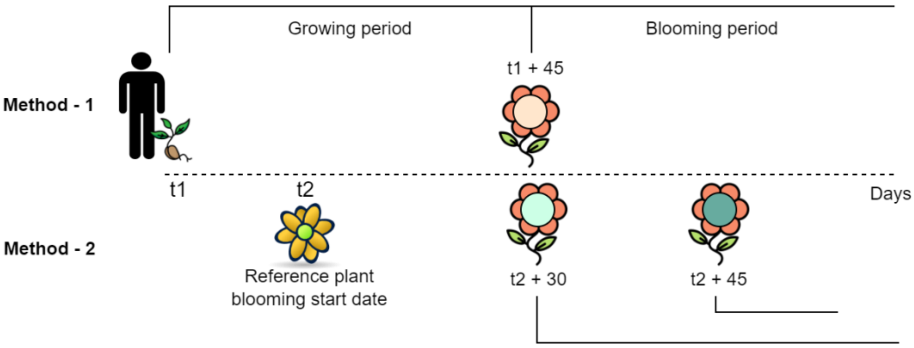

Figure 1. Schematic explanation of two methods

By using different literature sources (Bilash et al., 1999; Liepniece, 2015; Mihailova and Litvinova, 2019) the authors developed an example table of nectar plant flowering phenology. As a reference flowering date, the hazel flowering starting date was used. Then, knowing the reference data, it is possible to calculate the blooming periods for other plants for the current year.

Example record for summarizing the flowering calendar information can be as follows:

- Reference day [Rd] – day of the year, when the reference plant started to bloom
- Plant code (ID) – identifier of the plant
- Plant name – name of the plant
- Days after reference [DaR] – shows the number of days after the blooming start of the reference plant
- Duration [Dur] – duration of the flowering period for this specific plant
- StartDate [Sdate] – calculated start date of the plant blooming / SDate = Rd + DaR
- EndDate [Edate] – calculated end date of the plant blooming / Edate = Sdate + Dur
- StartWeek [Sweek] – calculated start week of the plant blooming / Sweek = ISOWEEKNUM(SDate)
- EndWeek [Eweek] – calculated end week of the plant blooming / Eweek = ISOWEEKNUM(EDate)
- Melliferousness – a parameter which shows the amount of nectar in kg that can be foraged from 1ha field of such a plant. This parameter can be used to evaluate the potential amount of nectar that can be foraged by the bees from those fields in suitable meteorological parameters.

Data step is of importance; it can be considered to use months or weeks, even split the flowering calendar into days. In this example, weeks are used, thus, StartWeek and EndWeek parameters are introduced. Later on, these parameters will be used for visualisation purposes.

Below (Fig. 2) is an example of a fragment of a honey plant flowering table, where April 18, 2022 is taken as the reference date (the beginning of hazel flowering). This date can be considered as a very late date for other environments, thus this date should be adapted for target location.

Plant code	Plant Name	How many days after hazel	Flowering duration (days)	Start date	End date	week_start	week_end	melliferousness
101	*Heracléum*	62	20	19.06.2022	09.07.2022	24	27	300
105	*Calluna*	96	60	23.07.2022	21.09.2022	29	38	200
111	*Lámium álbum*	33	45	21.05.2022	05.07.2022	20	27	100
113	*Fagopýrum esculéntum*	76	30	03.07.2022	02.08.2022	26	31	65
124	*Chamaenérion angustifolium*	65	45	22.06.2022	06.08.2022	25	31	500
126	*Trifolium repens*	56	22	13.06.2022	05.07.2022	24	27	100
132	*Tilia cordáta*	78	14	05.07.2022	19.07.2022	27	29	1000
136	*Pulmonaria officinalis*	5	30	23.04.2022	23.05.2022	16	21	76
145	*Rapeseed (Bráѕsica nápus)*	30	30	18.05.2022	17.06.2022	20	24	65
146	*Sorbus (Sórbus)*	39	10	27.05.2022	06.06.2022	21	23	40
147	*Prunus*	32	10	20.05.2022	30.05.2022	20	22	20
148	*Ribes*	29	10	17.05.2022	27.05.2022	20	21	70
150	*Barbaréa vulgáris*	27	31	15.05.2022	15.06.2022	19	24	42
151	*Phacelia*	42	35	30.05.2022	04.07.2022	22	27	225
152	*Prunus padus*	30	12	18.05.2022	30.05.2022	20	22	20
153	*Vaccinium myrtillus*	33	15	21.05.2022	05.06.2022	20	22	80
154	*Salvia*	47	30	04.06.2022	04.07.2022	22	27	280
155	*Apple tree (Mâlus)*	35	10	23.05.2022	02.06.2022	21	22	25

Figure 2. Fragment of honey plants flowering table

Some additional parameters can be added if necessary. In this research, authors do not split the flowering period by the intensity of the flowering, as plant productivity can potentially vary during the flowering period.

Input data is prepared as MS Excel spreadsheet, and then, a data matrix is generated to be used with Python programming language for data visualisation. The data matrix is defined as a table, where for each plant the value 0 or 1 is calculated for each week of the year, based on the flowering information. The data matrix can be supplemented by additional parameters.

Example of the data matrix can be seen below in Figure 3:

FlowerCode	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0
101	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
102	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
103	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
104	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0
105	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

FlowerCode	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	Melliferousness
100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
101	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	300
102	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15
103	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	194
104	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
105	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	200

Figure 3. Example of a data matrix

2.2. The flowering calendar visualisation process

This section describes a proposed flowering calendar visualisation process. This process can be divided into two main steps. In the first step, the aerial image of the region of interest is annotated with polygons for the plant fields. As the result, authors obtain a semantically annotated map, which can be used for further visualisation of flowering information. Based on this semantic map, in the second step, a simulation of a plant flowering is made. Several predefined parameters can be used for additional calculations and evaluations.

1. Getting the map of the geographical location of interest

At the first stage, it is essential to choose the geographical location of interest for the flowering calendar visualisation (see Fig.4a). The authors used Google Maps for the image selection. The used part of the map (10 km x 10 km) can be seen here:

Figure 4. Selected region for the flowering calendar visualisation.
(A) Selected region. (B) Annotated region.

2. Definition of plant fields

Currently, only agricultural fields and territories with mono cultures are marked (see Fig. 4b). In the future, also individual gardens, parks and other locations can be used for marking and visualisation. Agricultural fields are represented by different polygons and it is necessary to mark all of them. At this moment, this task is completed manually using the authors' developed web interface. Users mark all the vertices of each polygon (field), and the tool will extract their coordinates. Then, a digitised map of the region is created (see Fig. 5).

In the example, there are 201 polygons defined within the selected region of interest.

1. Assigning the plants to the marked fields

Then, all fields are linked to the specific plants, which are growing there. At the moment, authors randomly assigned plants to fields for demonstration purposes. The parameter "Melliferousness" is visually coded as the brightness of a field, light (lower number) to dark (higher number). Values for "Melliferousness" are taken from the literature.

Figure 5. Generated digitised map of the region of interest with plant fields

2. Calculating the crop diversity and equitability indexes

Sometimes it is important to know the environment crop diversity for the specific region, especially when beekeepers want to produce monofloral honey. For this research, the authors selected the Shannon Diversity Index (sometimes called the Shannon-Wiener Index) to measure the diversity of species in a geographical location (Nolan and Callahan, 2006).

Denoted as H, this diversity index is calculated as:

$$H = - \Sigma(p_i * \ln(p_i)), \tag{1}$$

where: p_i: the proportion of the entire community made up of species i.

The higher the value of H, the higher the diversity of species is in a particular location. The lower the value of H, the lower the diversity. A value of H = 0 indicates that only one species is present.

In addition to the diversity index, also equitability Index can be calculated. Equitability is a way to measure the evenness of species in a location. The term “evenness” simply refers to how similar the abundances of different species are in the community. Its value ranges between 0 and 1, with being complete evenness.

Denoted as EH, the Shannon’s equitability index is calculated as:

$$EH = H / In(S), \tag{2}$$

where H is Shannon’s diversity index and S is the number of species encountered in a region.

3. Results and discussion

The developed tool shows the nectar availability, in terms of spatially and temporally for a given landscape which could be really important for migratory beekeeping to 1) Provide the pollination ecosystem service for crops that rely on honeybees and 2) To maintain profitable honeybee operations. However, honeybees also need to collect pollen (which may not necessarily be collected from the same sources as nectar) and this is not considered in the current tool.

As a result of the work, a simulation of flowering is prepared, which can be demonstrated for a selected geographical region. The simulation contains 53 steps, which correspond to weeks of the year, where an individual simulation step is equal to a one-week step. Maximum number of weeks for the year is equal to 53, thus this number is taken for the simulation. The simulation is prepared as a .gif file compiling individual image files.

Images below (Fig. 6 and Fig. 7) show simulations for weeks: 17 and 31.

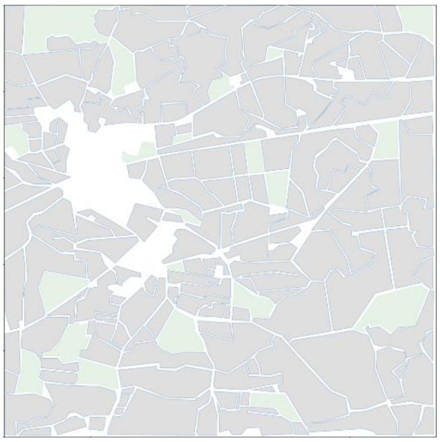

Figure 6. Simulation outcome for week 17

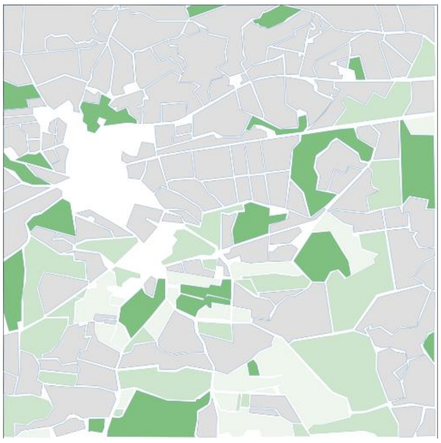

Figure 7. Simulation outcome for week 31

Using this simulation, migratory beekeepers can see when specific plants would be blooming and which geographical location would be more beneficial for placing bee colonies. The flowering calendar is an important tool for determining various beekeeping management operations, such as when to add or reduce supplementary feed and honeybee colony migration time.

More details on how to select the best apiary location are described in other authors' publications (Komasilova et al., 2020, 2021). There are also several methods and algorithms present on how to sequence the movements of the bee apiaries (Pilati and Fontana, 2018).

As an additional feature of the developed simulation, there is an option to select a specific date of the year (for example, 05.07.2022), and an output image of the flowering calendar to that specific week would be presented. To ease the detection of a crop, ID (plant code) numbers can be shown on the outcome image, see Fig. 8 below:

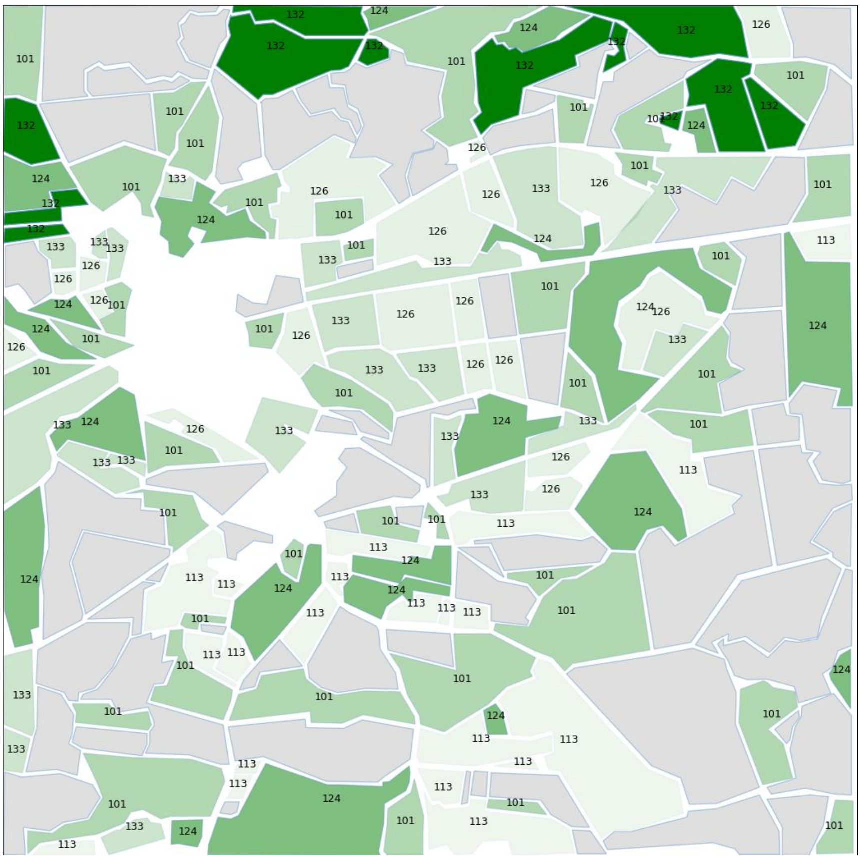

Figure 8. Simulation outcome for a specific date with crop IDs on a field

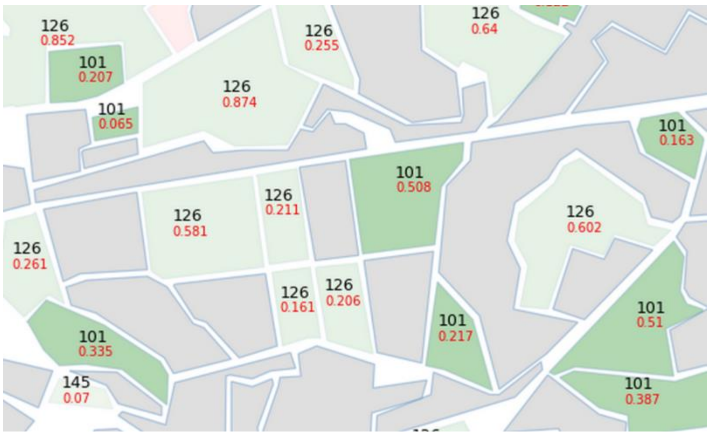

Figure 9. Example of the outcome with the field area,
showing plant ID (black) and field area in km2 (red)

For better usage of the calendar by the beekeepers, it is also possible to show the area (km2) of the fields on the image (see Fig. 9), then, taking into account nectar production rates (“Melliferousness”), the potential amount of nectar available for foraging can be evaluated.

This simulation also can be used by agricultural specialists and farmers for planning activities. As well, it can serve as educational tool for the general public.

Also, it is possible to use the crop sowing date for the specific field to calculate the potential flowering date and its period. For example, buckweat (*Fagopýrum esculéntum*), code 113 in the authors’ example, will bloom on the 37th day after sowing, and rapeseed (*Brássica nápus*) code 145 will bloom on the 55th day after sowing.

Authors developed an option to visualise these individual fields, for which the sowing information is known. This data is entered in a separate table combined with the calendar, which is optimised considering this data. Visually, these fields are coloured in red. Fig. 10 shows a combined visualisation of fields for which sowing date is known and for fields which uses the reference crop. In addition, the Shannon’s diversity index and equitability index are calculated. For this week H=1.0255 and EH=0.9334.

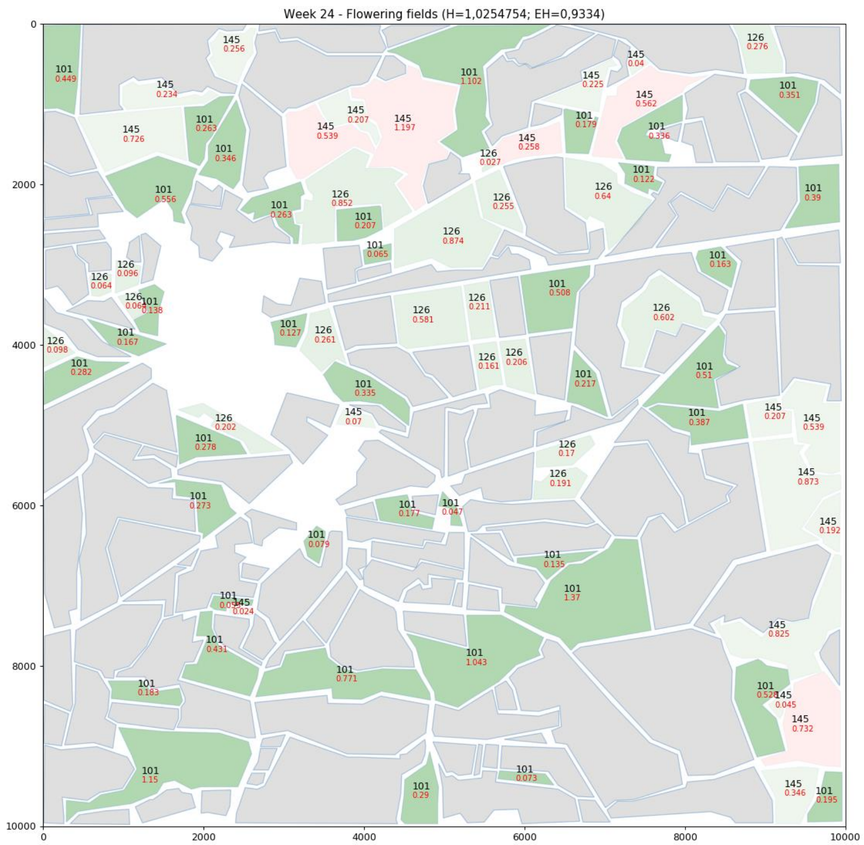

Figure 10. Example of visualisation for combination of crops

Diversity and equitability indexes are calculated for all simulation steps (weeks). Calculated diversity and equitability indexes are calculated for the whole simulated area which is 10 km x 10 km. For example, for the 3rd week, when three crops are flowering, diversity index is 0,837 and equitability index is 0,762.

Within this research, authors are not considering meteorological factors and their effect on crop blooming and duration. These factors affect nectar production and the blooming process. Flowering phenology is mediated by the interaction of internal factors with external environmental signals such as temperature, day length or drought (Christopher, 2020). For instance, higher environment temperatures condense the bloom period, and lower temperatures extend it (Rucker and Thurman, 2019). Rainfall variability plays an important role in the start and length of flowering phenology (Christopher, 2020). Rain can wash away the nectar and pollen, decreasing the foraging activity (Vorobjeva, 2015; Gaeva, 2015). Drought is one of the most limiting factors for vegetative growth and flower development (Borchert, 1983).

It is not possible for the migratory beekeepers to passively follow the same fields each year because of changes over the years in crop planting calendars and the result of climate change which is shifting the onset of the crop flowering period (Fitter and Fitter, 2002). Climate change is one of the most important problems the beekeepers are presently coping with. Under that condition, both the period and intensity of nectar flows have become unpredictable (Patruica et al., 2021; Vercelli et al., 2021).

To provide the highest value from the flowering calendar, it should be constantly updated based on actual climatic conditions, which are affecting the start and duration of the crop flowering.

Additionally, the honeybee model BEEHAVE (Becher et al., 2014) with the landscape model BEESCOUT (Becher et al., 2016) can combine and display temporal and spatial resource availability. But, the models mentioned, require the use of the freeware program Netlogo by the stakeholders which may be an obstacle to some users.

4. Conclusions

In this study, we propose a python simulation model which can be used by beekeepers and the general public to visualise the plant flowering calendar in a specific geographical location.

Non-simultaneous crop flowering motivates the allocation and re-allocation of bee colonies to different foraging locations. Developed tool and approach shows a promising way to visualise nectar production in a given landscape and enable stakeholders interested in this to make decision on when and where to take their honeybee migratory colonies

The simulation model can have additional parameters to extend its potential applications.

The proposed simulation is implemented in Python language, but data preparation is done in MS Excel.

For future work, we plan to automate the map-to-polygon transformation, to facilitate the user data pre-processing for the simulation model. As well, the authors are planning to link the flowering calendar data with the GIS system, where fields are pre-defined with meta-data and make a simulation on real field data.

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