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**Advanced BEE-STEWARD Guide: Using BEE-STEWARD with large landscapes and Geographic Information Systems (GIS)**

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This guide is designed to be used in conjunction with a bespoke version of the BEE-STEWARD model - \_\_BEE-STEWARD\_RC\_ColourVersionMB.nlogo, available to download from <https://beehave-model.net/download/>

Citation:

If using this model, please cite the original BEE-STEWARD paper, and this model version.

[Twiston-Davies, G., Becher, M. A., Osborne, J. L. (2021) BEE-STEWARD: a research and decision-support software for effective land management to promote bumblebee populations. Methods Eco Evol, 12: 1809-1815.](https://besjournals.onlinelibrary.wiley.com/doi/epdf/10.1111/2041-210X.13673)

This model version -

Twiston-Davies, G., Shaw, R.F., Comont, R.F., Becher, M.A. (2023) BEE-STEWARDv2.0 Landscape scale and extended habitats. Software tool.  DOI: 10.5281/zenodo.8370020

**See folder ‘1\_BEE-STEW-Modelv2’ for the new BEE-STEWARD model version and its default files. It is recommended that you run your own landscape in a copy of this folder.**

**See folder ‘BBCT\_Advanced\_BEE-STEWARD’ for all the files needed to run the demos;**

* **See folder ‘BBCT\_Advanced\_BEE-STEWARD\_Guide\_1’ for the GIS map files for large landscapes demo and the ‘RC\_BBCT\_Bstew-Model’ version with ‘BehaviorSpace’ experiments for the demos.**
* **See folder ‘BBCT\_Advanced\_BEE-STEWARD\_Guide\_2’ for the files needed to run in R and the R code for the Geographical Information Systems (GIS) demo , and the ‘RC\_BBCT\_Bstew-Model’ version with ‘BehaviorSpace’ experiments for the demos**

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# Using BEE-STEWARD with large landscapes

**See folder ‘BBCT\_Advanced\_BEE-STEWARD\_Guide\_1’ for the GIS map files for large landscapes demo and the ‘RC\_BBCT\_Bstew-Model’ version with ‘BehaviorSpace’ experiments for the demos.**

# Purpose of this report

This report provides guidelines on how to run large landscape maps in the BEE-STEWARD tool. For more information on BEE-STEWARD see [Twiston-Davies *et al.* 2021](https://besjournals.onlinelibrary.wiley.com/doi/10.1111/2041-210X.13673). This guide is designed for users who have some experience with BEE-STEWARD.

BEE-STEWARD can run maps which are 300 by 210 pixels (aka grid cells) in size, this is the BEE-STEWARD ‘world’ and is the maximum size. This means that if you want to run a large landscape, then the resolution (area in real life that an individual pixel represents) needs to be low and therefore, you may miss small or thin areas of habitat. e.g. if you want each BEE-STEWARD pixel to represent a 10m by 10m grid cell on your map then the maximum size of landscape that you can run in BEE-STEWARD will be 3000m by 2100m (3km by 2.1km).

To solve this issue we propose a methodology whereby you split the large landscape into four quarters, run each quarter separately and then combine the results to get an estimate of the whole landscape. This means that you can run each quarter of the landscape at a higher resolution.

# Overview of methodology

**Method 1: apply a generic conversion factor.**

**From the simulations ran and reported in the Appendix, we have calculated a generic conversion factor based on an experiment of the Fowey Valley landscape. You can use this method with the current BEE-STEWARD model version \_\_BEE-STEWARD\_RC\_ColourVersionMB.nlogo.**

**Step 1. Split your landscape into four quarters in your GIS system.**

**Step 2. Run each quarter landscape through BEE-STEWARD as a separate map.**

**Step 3. Combine the results.**

**Step 4. Apply a generic conversion factor.**

**Method 2: apply a bespoke conversion factor. You will need to use our new BEE-STEWARD ‘MapAreaIncluded’ model version.**

**Step 1. Split your landscape into four quarters in your GIS system.**

**Step 2. Run each quarter landscape through BEE-STEWARD as a separate map.**

**Step 3. Combine the results.**

**(Step 4. Apply a generic conversion factor.)**

**Step 5. Create a low-resolution landscape map no larger than 300 by 210 grid cells.**

**Step 6. Run through BEE-STEWARD using the MapAreaIncluded variable.**

**Step 7. Calculate your bespoke conversion factor.**

**Step 8. Apply your bespoke conversion factor.**

# Step-by-step guide

## Method 1 Apply a generic conversion factor

### Step 1. Split your landscape into four quarters in your GIS system.

To create a GIS file that is compatible with BEE-STEWARD, you will need to convert your vector map into a raster map and then convert this raster map into an asci file format.

In QGIS as an example, you can change the VRT to max columns and rows that will fit BEE-STEWARD ‘world’ (300 x and 210 y)

*Hint-* [*How to split a raster into several tiles using QGIS or Python (GDAL) | "How To" in QGIS (wordpress.com)*](https://howtoinqgis.wordpress.com/2016/12/17/how-to-split-a-raster-in-several-tiles-using-qgis-or-python-gdal/)

**In QGIS-**

**(Right-click on the layer) | Export | Save as | (check the box) Create VRT | (select the folder) | (use defaults) | (change the max number of columns and rows in ‘VRT Tiles’) | OK | [ends]**

If your landscape is too large to be split into 4, then consider using Raster | Extraction| Clip Raster by Extent| (draw the area you are most interested in, or consider splitting further).

To create a polygon which you can use to create a maximum area to clip your raster by, calculate the maximum size of your landscape to be divided into 4 based on your resolution. For example, the 25m x 25m resolution Land Cover Map has a maximum landscape size of x = 600 pixels (300 x 2) and y = 420 pixels (210 x 2). This translates to a rectangle 15000m (300 x 25) x 10500m (420 x 25).

Create a polygon shapefile, and use the ‘Add Rectangle’ function to create a polygon of width 14950 and height 10450 (making sure your project is in a projection such as British National Grid which uses metres as the unit (also reduce the size very slightly, by 2 pixels here, otherwise you often end up with a very thin split square). This can then be used to clip the raster using Raster | Extraction| Clip Raster by Mask Layer|

The Virtual Raster (VRT) output by this process will be loaded automatically and will look like a single raster.

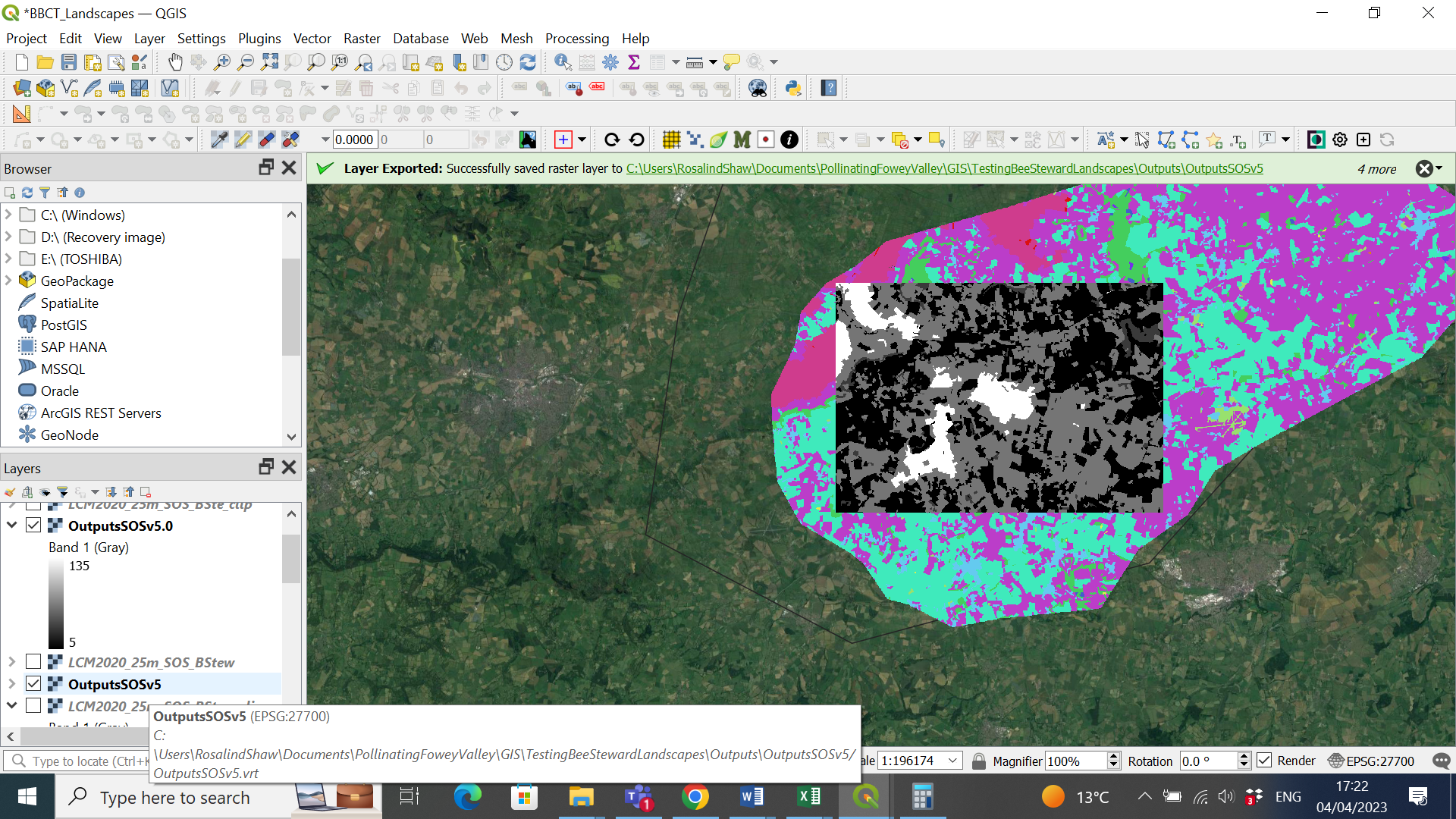


Figure.1 Creating a rectangle to clip your landscape map by- the section you want to run the BEE-STEWARD model on

*NOTE: The functionality of your QGIS program, its version and the plug-ins you have enabled may effect what method you need to use to split your landscape into quarters. Therefore,, you may need to look online for a method that suits you. Ultimately you want 4 quarters of the landscape exported as an asci file.*

To follow the next step, uncheck the VRT, and use Layer |Add Layer | Add Raster Layer to add the four constituent parts of the VRT individually to the project for conversion.

When you are happy with your splits, (ideally we want the landscape split into 4), Convert the raster map to an asci map.

*Hint-* [*25.2.2. Raster conversion — QGIS Documentation documentation*](https://docs.qgis.org/3.22/en/docs/user_manual/processing_algs/gdal/rasterconversion.html)

[*QGIS Export Raster to asc - Tuflow*](https://wiki.tuflow.com/index.php?title=QGIS_Export_Raster_to_asc)

*Hint if your ‘Conversions’ options are not in your menu-* [*qgis - Missing Conversion | Rasterise option in raster menu - Geographic Information Systems Stack Exchange*](https://gis.stackexchange.com/questions/264435/missing-conversion-rasterise-option-in-raster-menu)

**If you don’t have ‘Conversion’ options – In QGIS -**

**Plugins | Manage and Install Plugins | All | (Search for ‘Processing’) | (Check that the box is ticked) | [ends]**

Then you can convert your raster maps to asci.

**In QGIS-**

**Raster | Conversion | Translate (convert format) | (save as .asc) | [ends]**

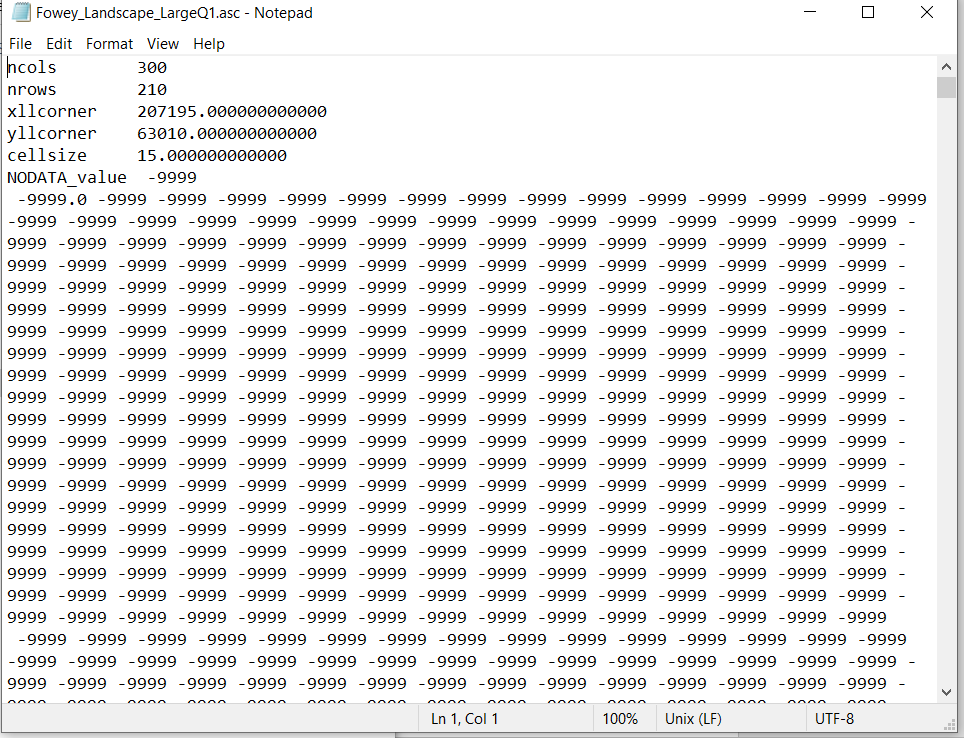


Figure 2. An asci file of a landscape map that can be saved as a text file (.txt).

You can open your new asci files in notepad or equivalent to check it looks right (see above). You will just need to save these as a .txt file to read into BEE-STEWARD.

**In Notepad-**

**File | Save as | (save with the same name but .txt) | [ends]**

So we have asci files;

* Fowey\_Landscape\_LargeQ1.asc
* Fowey\_Landscape\_LargeQ2.asc
* Fowey\_Landscape\_LargeQ3.asc
* Fowey\_Landscape\_LargeQ4.asc

And converted these to .txt files;

* Fowey\_Landscape\_LargeQ1.txt
* Fowey\_Landscape\_LargeQ2.txt
* Fowey\_Landscape\_LargeQ3.txt
* Fowey\_Landscape\_LargeQ4.txt

### Step 2. Run each quarter landscape through BEE-STEWARD as a separate map.

We can now load the .txt files into BEE-STEWARD as text maps.

*NOTE: make sure your habitats input and flower species input files are compatible with your new landscapes. The grid cell colours need to relate to the colours allocated to the different habitat types in the habitats input file.*

**In BEE-STEWARD-**

(do this the first time you read in your .txt map, if you have already loaded in your maps and created foodsources files of them you don’t need to do this just load in your map)

**Panel | Maps and Settings | Create Map from Scan or load GIS text file | No (unless you want to) | No | (Select the file of the landscape map) | OK | [ends]**

Do this for each of the 4 quarter landscape maps.

You can now run each quarter separately manually or separately through a BehaviorSpace experiment (Tools | BehaviorSpace).

*NOTE: to run one BehaviorSpace experiment that includes all 4 quarters in it you will need to use the modified BEE-STEWARD model version MapAreaIncluded in method 2 in Appendix. Alternatively, if you want to run one quarter at a time you don’t need to use method 2 in Appendix. If using model version \_BEE-STEWARD\_RC\_ColourVersionMB.nlogo you will need to ‘Save settings’ if you change MapAreaIncluded.*

### Step 3. Combine the results.

Using the results you can then calculate the total number of adult queens, number of colonies and colony density etc. by combining the results of the four quarters using your preferred program (e.g. R or Excel)

To account for the fact that the landscape was split into four, you can either apply a generic conversion factor that we have calculated (Step 4) or you can create your bespoke conversion factor (Step 5).

### Step 4. Apply a generic conversion factor.

Apply a generic conversion factor based on the number of years that the simulation has run (Table 1). We calculated this by running a landscape map through BEE-STEWARD as separate quarters and then as a ‘complete’ landscape. We then calculated the proportional difference between the two results of adding the quarters together and the ‘complete’ landscape. Values of the quarters combined and the ‘complete’ landscape are highly correlated (R2 >0.92). Appendix 1 shows the experiment we have run using the example Fowey landscape in 4 quarters and as ‘complete’.

**Estimation of ‘complete’ landscape = Total of quarters/Conversion factor**

Table 1. Conversion factor to be applied to a result from running simulations of 4 quarters of a landscape based on BEE-STEWARD output and years of simulation. Number of adult queens on the last day of the year (TotalAdultQueens), the maximum number of colonies per km2 (ColonyDensity\_km2) per year and maximum number of colonies (TotalColonies) in the landscape per year.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Year from** | **Year to** | **Conversion factor**  **TotalAdultQueens** | **Conversion factor**  **ColonyDensity\_km2** | **Conversion factor**  **TotalColonies** |
| 0 | 1 | 1.0433 | 0.9211 | 0.9646 |
| 1 | 2 | 1.1598 | 1.1011 | 1.1541 |
| 2 | 3 | 1.2639 | 1.1731 | 1.2304 |
| 3 | 4 | 1.2016 | 1.1569 | 1.2116 |
| 4 | 5 | 1.1852 | 1.2010 | 1.2572 |
| 5 | 6 | 1.1701 | 1.1363 | 1.1902 |
| 6 | 7 | 1.1539 | 1.1285 | 1.1821 |
| 7 | 8 | 1.1386 | 1.0918 | 1.1429 |
| 8 | 9 | 1.0773 | 1.0348 | 1.0829 |
| 9 | 10 | 1.0711 | 1.0024 | 1.0487 |

# Using BEE-STEWARD with large landscapes and Geographic Information Systems (GIS)

**See folder ‘BBCT\_Advanced\_BEE-STEWARD\_Guide\_2’ for the files needed to run in R and the R code for the Geographical Information Systems (GIS) demo , and the ‘RC\_BBCT\_Bstew-Model’ version with ‘BehaviorSpace’ experiments for the demos**

# Purpose of this report

This report provides guidelines on how to create ‘heat’ maps of nectar and pollen visits in the BEE-STEWARD tool. For more information on BEE-STEWARD see [Twiston-Davies *et al.* 2021](https://besjournals.onlinelibrary.wiley.com/doi/10.1111/2041-210X.13673). This guide is designed for users who have some experience with BEE-STEWARD, the BehaviorSpace tool in NetLogo and a good understanding of R.

BEE-STEWARD can run landscape maps and users can visualise nectar and pollen visits in the user interface. However, these maps of nectar and pollen visits to flower patches cannot be extracted from BEE-STEWARD in a format that is compatible with Geographical Information Systems (GIS). We have edited the BEE-STEWARD code, created a new model version and created some R code that translates the bee-steward data on nectar and pollen visits to GIS compatible files.

We demonstrate below the steps to creating GIS compatible nectar and pollen visitation maps.

# Overview of methodology

**Step 1. Using R to read in the BEE-STEWARD output files.**

**Step 2. Extracting nectar and pollen visits per flower patch.**

**Step 3. Calculating new x and y, longitude and latitude coordinates.**

**Step 4. Creating a raster map.**

**Step 5. Plotting and save the raster map.**

**Step 6. Stitching your maps together (If using a landscape split into four quarters).**

## Step-by-step guide

We created a new BEE-STEWARD model version \_\_BEE-STEWARD\_RC\_ColourVersionMB.nlogo that enables the number of nectar and pollen visits per grid cell to be extracted. This means that a GIS raster map can be created.

This new version includes the ability to create two .txt tables as outputs –

1. **\_\_\_\_BBCT\_CellsToPatchesFile**

The BEE-STEWARD ‘world’ consists of 300 by 210 grid cells. This file reports the pxcor and pycor coordinates (x and y) and the flowerpatchid of **every grid cell** in the model before a simulation is run.

* pxcor - x coordinates of BEE-STEWARD grid cell (of bottom left corner)
* pycor - y coordinates of BEE-STEWARD grid cell (of bottom left corner)
* flowerpatchid - a flowerpatchid number is assigned to every grid cell, those grid cells of the **same habitat type** that are touching each other (right, left, top, bottom and diagonally) will receive the same flowerpatchid number as they are considered contiguous and part of the same patch of habitat.
* pcolor - the numeric value for the grid cell colour based on what you’ve defined in the habitats input file e.g. 105 is blue and is “Hedgerow” habitat type.

Grid cells which are defined as ‘nodata’ from a text file or of a habitat type that does not contain flowers are given a flowerpatchid value of -1.

1. **\_\_\_\_BBCT\_NPvisits**

This file reports the id, patchtype, flowerspecies, masterpatchid, xcor, ycor, size\_sqm, nectarVisits and pollenVisits extracted across the **‘foodsources’** in the landscape after a simulation has run. ‘Foodsources’ are created from habitat patches and are displayed as a circle, with its centre in the centre of the habitat patch, its size relates to the area of the habitat patch.

* id - is the individual identification number (‘who’ in NetLogo terms) of a foodsource.
* patchtype – is the habitat type of the foodsource.
* flowerspecies – the name of the flower species assigned to that foodsource.
* masterpatchid – multiple foodsources may share the same masterpatchid when they are all located in the same habitat patch.
* xcor - pxcor of the centre of the foodsource (3dp).
* ycor – pycor of the centre of the foodsource (3dp).
* size\_sqm – size of the foodsource in square metres.
* nectarVistits – the cumulative number of visits to that foodsource for nectar.
* Pollen Visits - the cumulative number of visits to that foodsource for pollen.

*Note: although the names are similar, flowerpatchid and masterpatchid are not the same or directly linked in the model (the same grid cell will belong to a different flowerpatchID and masterpacthid in the two output files). This is dealt with using the R code in Step 1 below. Flowerpatchid relates to a contiguous patch of habitat of the same type but is not related to foodsources that are created from the different habitat patches. Foodsources are the specific nectar and pollen resources and each habitat patch and each flower in that patch is its own foodsources. The masterpatchid is the umbrella patch for a list of foodsources that are in the same patch of habitat.*

Grid cells all the same habitat type denoted by their colour and connected to one another

Foodsources all at the sharing the same habitat patch location

Flowerpatchid = 1

Flowerpatchid = 2

Who = 1

Who = 2

Who = 3

**Grid cells**

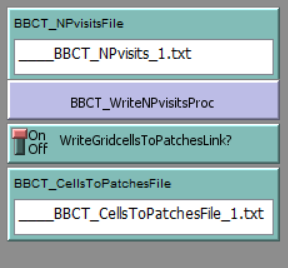
**Foodsources**

flowerspecies = bramble

flowerspecies = buttercup

flowerspecies = bugle

Figure 3. Diagram of flowerpatchid vs masterpatchid.

  
Figure 4. New interface options in BEE-STEWARD found at the very bottom of the BEE-STEWARD interface (scroll down the interface).

*NOTE: the BBCT\_NPvisitsFile (see Figure 1) is created automatically based on your input map name and the random seed you run your simulation on. This means that you can get the outputs from multiple maps and multiple rand seed runs in BehaviourSapce. HOWEVER, the BBCT\_CellsToPatchesFile is defined by user input. You will need to change this to the desired name ideally relating to the map that you want to extract the cell to patches information from BEFORE loading the map in, otherwise when you load in the map your file will be called whatever is already in the BBCT\_CellsToPatchesFile box. E.g. in Figure 1 your file will be called \_\_BBCT\_CellsToPatchesFile\_1.txt.*

To create the **\_\_\_\_BBCT\_CellsToPatchesFile** file, you need to read in a new text map.

*NOTE: make sure the “WriteGridCellsToPatchesLink?” Switch is “On”!*

In BEE-STEWARD-

(To create the output files you need to read in the text map for the first time)

**Panel | Maps and Settings | Create Map from Scan or load GIS text file | Yes | (Select habitats input file) | No |(Select ‘Fowey\_Landscape\_LargeQ1.txt’) | [ends]**

This will create your foodsources, image and parameters files. It should also automatically create the BBCT\_CellsToPatchesFile which in this example is-

“\_\_\_\_BBCT\_CellsToPatchesFile\_1.txt”

You can check in the folder if you have a new “\_\_\_\_BBCT\_CellsToPatchesFile”.

To create the second output which gives you the nectar and pollen visits per foodsource you need to use the new BBCT\_WriteNPvisitsProc procedure, as explained below. The procedure is engaged when you press or call the BBCT\_WriteNPvisitsProc. You want to call this after you have run your simulation otherwise there will be no nectar and pollen visits.

Test by manually running your landscape for 1 year.

In BEE-STEWARD-

**Period | 1 year | Run for period | (Ends)**

Remember that the output file name will be created automatically.

In BEE-STEWARD-

**BBCT\_WriteNPvisitsProc | (ends)**

This gives you the number of nectar and pollen visits to each flower species, in each masterpatch

*Note: If running more than one landscape, remember to change the filename in the BBCT\_CellsToPatchesFile box before loading the next text map,\_\_\_BBCT\_NPvisits will change automatically when you press the BBCT\_WriteNPvisitsProc button.*

We have also set up a BehaviorSpace experiment where you can run multiple random seeds of a landscape and get an output for each (Figure 5). You can also set up a BehaviorSpace experiment to run multiple maps and multiple random seeds- with the new procedure the output will automatically have the file name ending in the name of the map and the random seed.

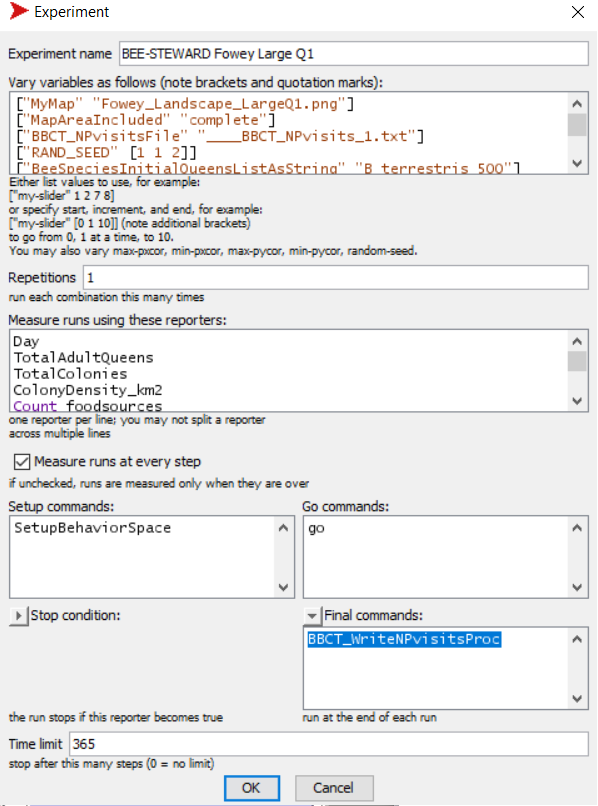


Figure 5. BehaviorSpace experiment set up to get nectar and pollen visits for multiple random seeds (1:2).

*NOTE: make sure you type BBCT\_WriteNPVisitsProc in the Final commands: box!*

Select Run options|Table output and save the outputs where wanted (defaults to model folder)

### Step 1. Using R to read in the BEE-STEWARD output files.

Once you have at least one \_\_\_\_BBCT\_CellsToPatchesFile and one \_\_\_\_BBCT\_NPvisits file you can follow the steps below which are covered in the associated R code file.

Open the following file in R studio-

**BBCT\_Creating\_GIS\_Maps\_with\_BEE-STEWARD\_Quarters\_Rand\_Seed\_August\_2023.rmd**

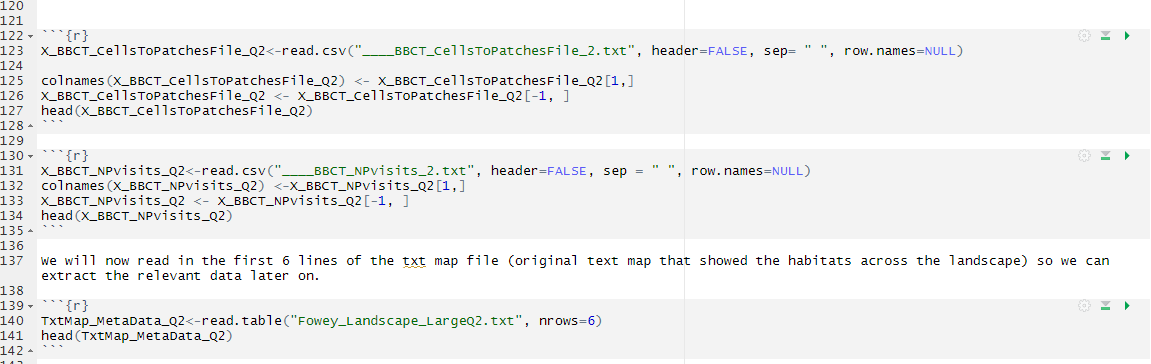
You can run the code using the ‘Run all Chunk Above’ and ‘Run Current Chunk’ tabs shown in Figure 3. 

Figure 6. R code and explanation in R studio, you can run the ‘chunks’ of code using the green arrows.

*NOTE: make sure you change the working directory and make sure you have installed the relevant packages. Also some systems may not let you have certain length file names etc, you may need to adjust the R code so then it will read in your table names.*

Use the R code to read in the files you want to create nectar and pollen maps from, this may be one landscape map, your four quarters or a large landscape and/or multiple random seeds.

If you have multiple random seeds you will need to use R or another tool to calculate the average nectar and pollen visits **per id** before creating your GIS compatible files in R. You will only have the one “\_\_\_\_BBCT\_CellsToPatchesFile” for your landscape. We do not include the code for that.

### Step 2. Extracting nectar and pollen visits per flower patch.

Each grid cell in both files has a NetLogo x-coordinate and a y-coordinate (pxcor, pycor in the CellsToPatchesFile and xcor, ycor in the BBCT\_NPvisits file). We can use this by extracting the xcor and ycor of a foodsource, knowing that that same grid cell will also have an allocated flowerpatchid in the CellsToPatchesFile. We also know that grid cells with the same flowerpatchid form the same contiguous patch of habitat. Therefore, that contiguous patch of habitat will have a uniform number of nectar or pollen visits across it as it would have formed the foodsources which share the same masterpatchid

Once you have these files loaded in R you will extract the nectar and pollen visits per foodsource, then **average** the total value of visits per masterpatchid. Finally, you will cross reference the grid cell x and y coordinates of the centre of the foodsource in the BEE-STEWARD ‘World’ with the corresponding flowerpatchid for those same grid cells in the cells to patches file. Once we know the flowerpatchid we know that all other grid cells with the same flowerpatch id will get the same nectar and pollen visit values. In rare occasions there can be a bug which we have fixed, details are in Appendix 2.

1, 5

2, 5

1, 4

2, 4

All grid cells with the same flowerpatchid will therefore, share the 100 nectar visits

The xcor and ycor of the centre of the foodsource can be linked to the flowerpatchid

Flowerpatchid = 1

Flowerpatchid = 2

Who = 1

Who = 2

Who = 3

**Foodsources**

**Grid cells**

flowerspecies = bramble

flowerspecies = buttercup

flowerspecies = bugle

Centre of foodsource

pxcor = 2, pycor = 4

Nectar visits = 100

Grid cell

Xcor = 2, Ycor = 4

Therefore, grid cell 2, 4 and all others with the same flowerpatchid have Nectar visits = 100

Figure 7. How coordinates of grid cells and foodsources are linked.

### Step 3. Calculating new x and y, longitude and latitude coordinates.

Using the original text map that you used to run your simulations in BEE-STEWARD, you will extract the X and Y longitude and latitude and the cell size and calculate the new ‘real life’ coordinates of your map.

### Step 4. Creating a raster map.

Using R you will create a raster map of nectar and of pollen visits.

### Step 5. Plotting and save the raster map.

Using R you can then plot and save these maps which can be read into a GIS like ArcMap or QGIS. You can edit the symbology as you like but we include a colour palette that you can use.

### Step 6. Stitching your maps together (If using a landscape split into four quarters).

If you have four quarters of a large landscape you will then stitch these maps together to create one large map.

*BUG: when using the four quarters map and creating an R nectar and pollen map there is a gap between Q1 and Q2 as well as a gap between Q3 and Q4 of cells. We have included a solution in the code.*

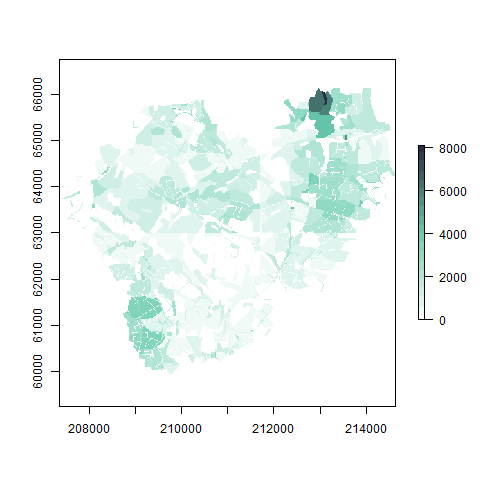
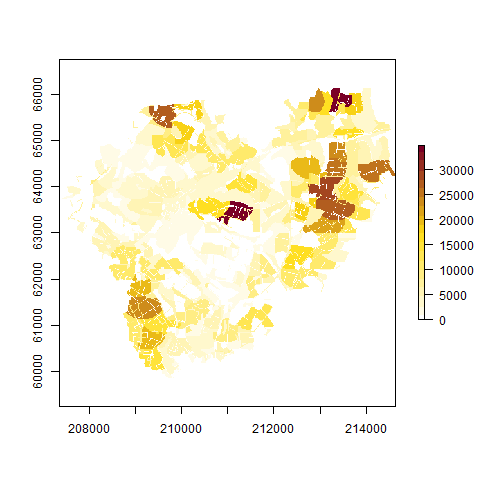
**

Figure 8. Nectar (top) and Pollen (bottom), visits (mean per habitat patch) ‘heat maps’ for the example landscape. These are also saved as raster maps that can be read into your GIS system, we use QGIS.

# Appendix 1

Results from BehaviorSpace experiments:

* BEE-STEWARD MapAreaIncluded Fowey quarters

"LCM\_plus\_Hedge\_20m\_BS\_small.png” each quarter run for 10 years, 3650 steps, 10 random seeds with 125 starting queens. Figure 3 in the main report).

* BEE-STEWARD MapAreaIncluded Fowey complete 1-5
* BEE-STEWARD MapAreaIncluded Fowey complete 6-8
* BEE-STEWARD MapAreaIncluded Fowey complete 9-10

Separated as the simulations take a long time. "LCM\_plus\_Hedge\_20m\_BS\_small.png” ‘complete’ landscape run for 10 years, 3650 steps, 10 random seeds with 500 starting queens.

‘Reporters’ (outputs) :

* Day
* Ticks
* TotalColonies
* ColonyDensity\_km2
* TotalAdultQueens

We calculated the mean per ‘Ticks’ (day number 0-3650) and then we calculated per year of simulation the number of adult queens on the last day of the year, the maximum colony density per km2 and the maximum number of colonies.

Table A1. Conversion factor based on output and years of simulation.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Year from** | **Year to** | **TotalAdultQueens** | **ColonyDensity\_km2** | **TotalColonies** |
| 0 | 1 | 1.0433 | 0.9211 | 0.9646 |
| 1 | 2 | 1.1598 | 1.1011 | 1.1541 |
| 2 | 3 | 1.2639 | 1.1731 | 1.2304 |
| 3 | 4 | 1.2016 | 1.1569 | 1.2116 |
| 4 | 5 | 1.1852 | 1.2010 | 1.2572 |
| 5 | 6 | 1.1701 | 1.1363 | 1.1902 |
| 6 | 7 | 1.1539 | 1.1285 | 1.1821 |
| 7 | 8 | 1.1386 | 1.0918 | 1.1429 |
| 8 | 9 | 1.0773 | 1.0348 | 1.0829 |
| 9 | 10 | 1.0711 | 1.0024 | 1.0487 |

Figure A1. Results from the experiment comparing the results from four quarters of the landscape combined (Total of quarters) and the complete landscape (“complete”) of a)TotalAdultQueens (on the last day of the year), b) Colony\_density\_km2 (max in the year), and c) ColonyDensity (max in the year) over 10 years for 10 random seeds. i) results from over 10 years and ii) correlation between the four quarters combined and the “complete” landscape.

## Method 2 – Apply a bespoke conversion factor

### Follow steps 1 to 3.

### Step 5. Create a low-resolution landscape map no larger than 300 by 210 grid cells.

In your GIS system create a low-resolution map that fits into the BEE-STEWARD ‘world’ which is 300 by 210 grid cells.

To create a low resolution version in QGIS use -

Raster| Warp (Reproject)

Alter the resampling type to Mode (“mode resampling, selects the value which appears most often of all the sampled points. In the case of ties, the first value identified as the mode will be selected.”)

Currently, QGIS does not offer the option of setting the height and width of the raster, so you will need to calculate the pixel size from the dimensions. If you need to reduce the height and width of the raster by half, then double the size of the pixels. In the example below the original pixel size was 25m by 25m, now changed to 50m x 50m.

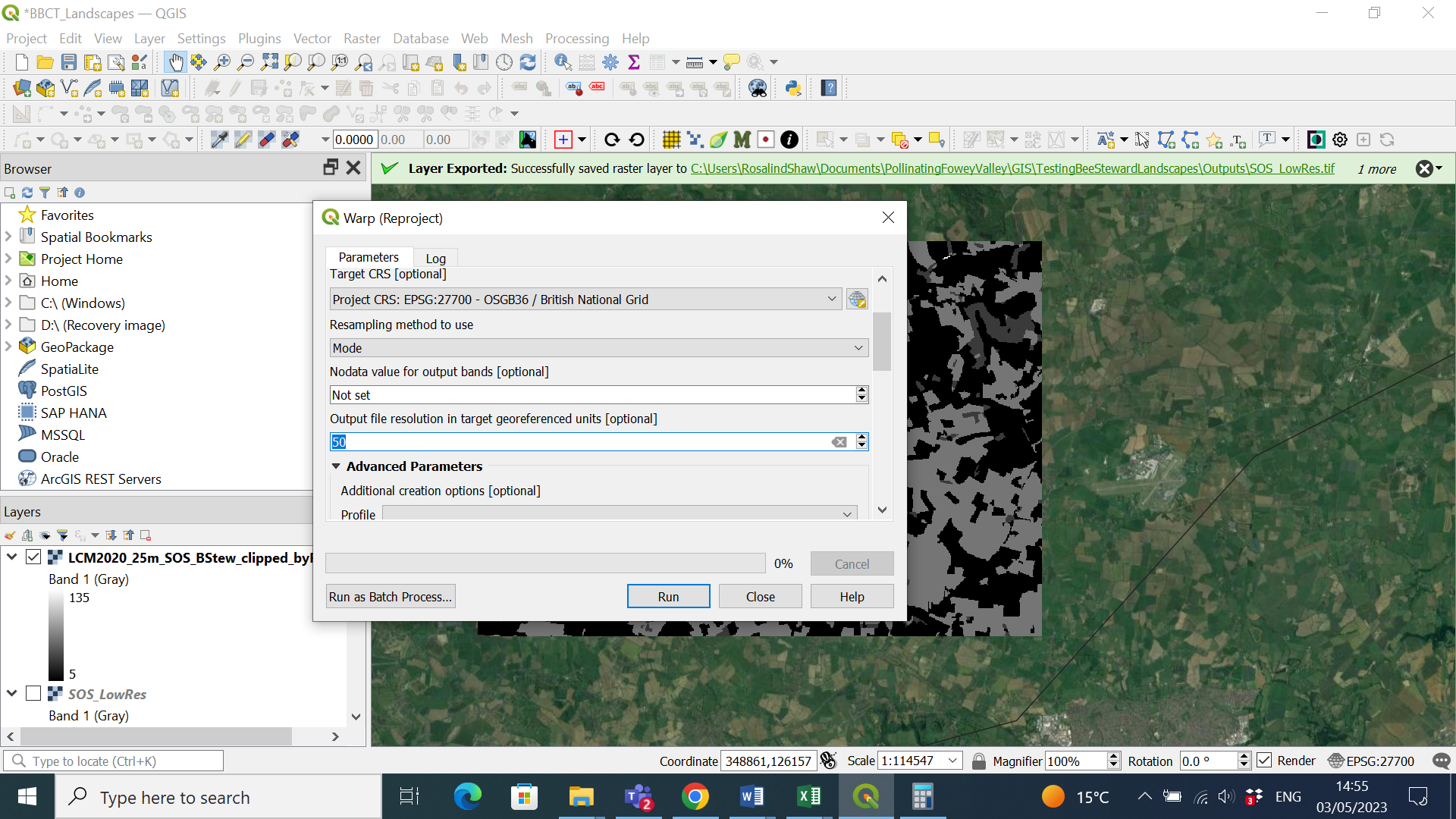


Figure A2. Repoject in QGIS.

Convert this to a text file (see Step 1 for the method).

### Step 6. Run through BEE-STEWARD using the MapAreaIncluded variable.

BEE-STEWARD has a function where you can split your landscape into quarters and then run a simulation on each quarter. In the new BEE-STEWARD MapAreaIncluded version this function has been moved from the code to the user interface.

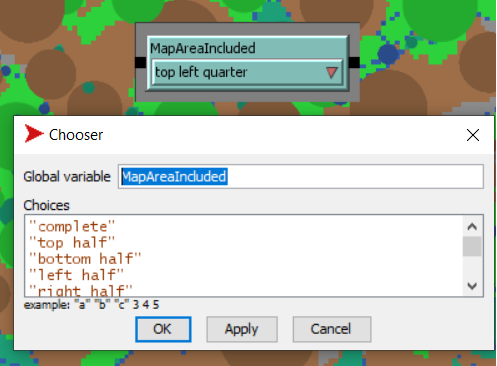


Figure A3. The new MapAreaIncluded chooser on the user interface. (This is located at the bottom of the BEE-STEWARD ‘world’)

To test this manually, you need to select which part of the landscape you want to run your simulation on before you hit SETUP.

Using the interface you can manually change parameters -

* MapAreaIncluded = "top left quarter"
* MapAreaIncluded = "top right quarter"
* MapAreaIncluded = "bottom left quarter"
* MapAreaIncluded = "bottom right quarter"
* MapAreaIncluded = "top half"
* MapAreaIncluded = "bottom half"
* MapAreaIncluded = "left half"
* MapAreaIncluded = "right half"

The default value is

* MapAreaIncluded = "complete"

As an example:

Load in the example Fowey map, and rename it so you can edit the parameters without affecting the original map (you’ll change the parameters of your original map if you don’t rename it to do this test on)

*Tip: when manipulating maps and parameter files save under a new map name so you don’t accidently change imprint parameters in your original maps.*

**Panel | Maps and Settings | Create Map from Scan or load GIS text file | Yes | (Select habitats input file) | No |(Select ‘LCM\_plus\_Hedge\_20m\_BS\_small.txt’) | [ends]**

Or if you have already created a BEE-STEWARD map from this –

**Panel | Maps and Settings |Load Existing Map | OK | (Select LCM\_plus\_Hedge\_20m\_BS\_small.png) | [ends]**

**Panel | Modify Maps | Button 7 Update current Map | ( type in “LCM\_plus\_Hedge\_20m\_BS\_small”) | OK | No | OK | [ends]**

This is to name each quarter based on what quarter is represents etc……

**Test to see that it has worked by running the maps manually -**

**MapAreaIncluded | "top right quarter" | \*Panel | \*Maps and Settings | \*Set Panel | Save Settings | Period | 1 year | Run for Period | [ends]**

You don’t need to update the maps or store them with separate names, as this will be done in the Behaviour space experiment.

\* This is only needed if you are using model version *\_BEE-STEWARD\_RC\_ColourVersionMB.nlogo*, if you are using the advanced version you don’t need to save settings as there is no parameter for *MapAreaIncluded.*

*NOTE: for this new MapAreaIncluded model version the parameters file has been changed, this no longer includes the MapAreaIncluded and its default value. Check that BEE-STEWARD is using the correct parameters file that doesn’t include MapAreaIncluded as a parameter. You do this by navigating to the model folder (not via the model interface) and looking for the \_SYSTEM\_parameters.csv file, which can be opened in Excel. There SHOULD NOT be a column called MapAreaIncluded in the csv file. If you are using the standard model version \_BEE-STEWARD\_RC\_ColourVersionMB.nlogo or if this parameter is present in your parameters file then just delete this column from the parameters file.*

Then when you are happy with how it’s working, you can set up a BehaviorSpace experiment to run the map on each quarter.

There are example experiments set up that you can edit and use. The default number of starting queens in the model is 500, to run the 4 quarters this needs to be reduced to 125 (so then when you combine each quarter you have started with the same number of queens i.e. 500).

BehaviorSpace Experiments:

* BEE-STEWARD MapAreaIncluded Fowey quarters
* BEE-STEWARD MapAreaIncluded Fowey complete

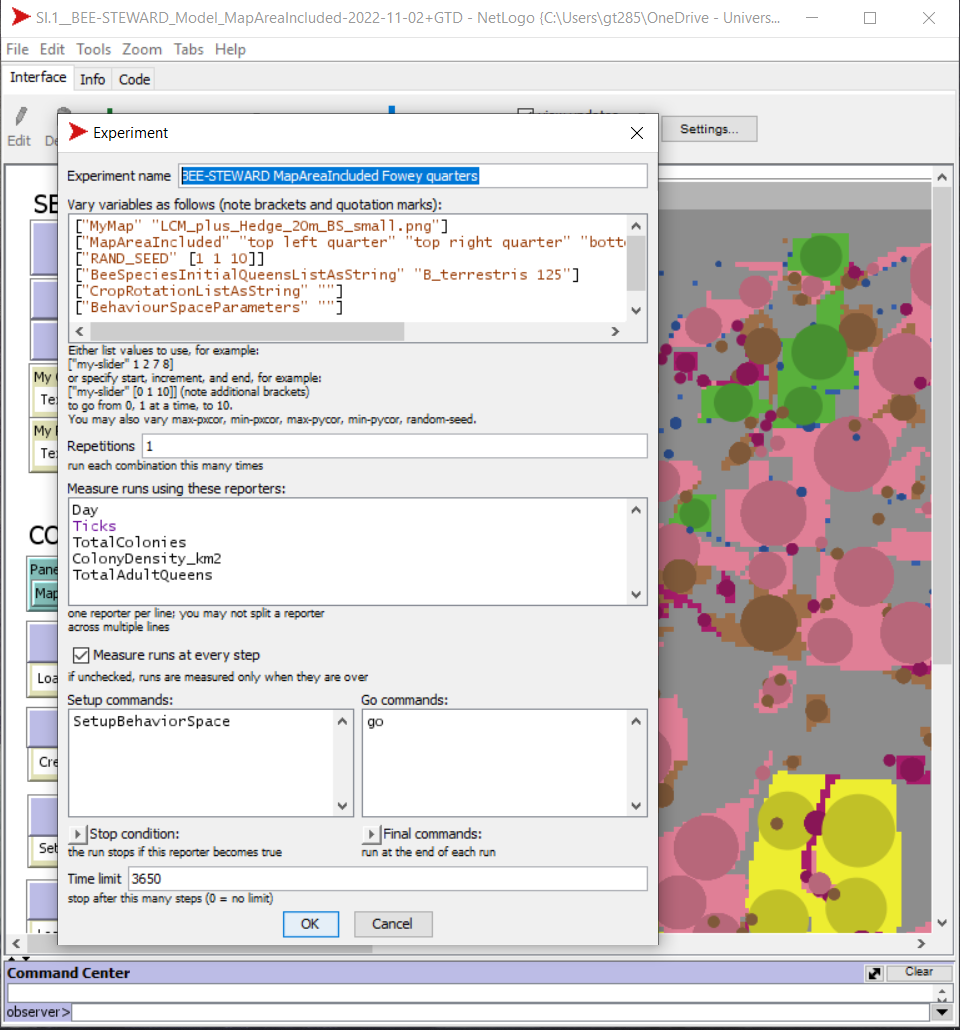


Figure A4. A BehaviorSpace experiment to run four simulations based on each quarter of the landscape.

*NOTE: Tick ‘Measure runs at every step’.*

*NOTE: before running for multiple years and multiple random seeds test out the BehaviorSpace experiment with 1 or 2 random seeds and 365 days to make sure it is running and the results make sense.*

Repeat the BehaviorSpace experiment for MapAreaIncluded for the ‘complete’ map with 500 starting queens - e.g. BEE-STEWARD MapAreaIncluded Fowey complete

### Step 7. Calculate your bespoke conversion factor.

Use the results of the four-quartered landscape combined and compare that to the ‘compete’ landscape to calculate your conversion factor.

**Conversion factor = Total of four quarters/’complete’ landscape**

*NOTE: for the total of four quarters for colony density per km2 divide your result by 4. This is because it is giving you the density for the quarter it’s run on rather than the whole landscape.*

### Step 8. Apply your bespoke conversion factor.

Apply your bespoke calculated conversion factor to the results you got for your high-resolution map split into four from Steps 1, 2 and 3.

**Estimation of ‘complete’ landscape = Total of quarters/Conversion factor**

# Appendix 2

### The new BEE-STEWARD procedures

In BEE-STEWARD we have edited the code below to include two new procedures to create the two new output files-

to BBCT\_WriteNPvisitsProc ; \*\*\*MB\*\*\* BBCT 2022-02-25

set BBCT\_NPvisitsFile (word "\_\_\_\_BBCT\_" remove ".png" MyMap "\_" Rand\_seed ".txt"); \*\*\*GTD\*\*\* 12-12-2 need a way of creating output for each rand seed in behaviourspace

if file-exists? BBCT\_NPvisitsFile [ file-delete BBCT\_NPvisitsFile ]

file-open BBCT\_NPvisitsFile ; file-open creates a new file, if it doesn't exist yet!

file-print "id patchType flowerSpecies masterpatchID xcor ycor size\_sqm nectarVisits pollenVisits"

foreach sort foodsources

[

ask ? ; now the actual data for each food patch are written in the file:

[

file-type (who - count habitats) file-type " " ; number of habitat-turtles subtracted, to make sure, ID listed in foodsource text file is identical to "who" of that foodsource

file-type "\""

file-type patchType

file-type "\""

file-type " "

file-type "\""

file-type item 0 flowerspecies\_relativeAbundanceList

file-type "\""

file-type " "

file-type masterpatchID file-type " "

file-type precision xcor 3 file-type " "

file-type precision ycor 3 file-type " "

file-type area\_sqm file-type " "

file-type cumulNectarVisits file-type " "

file-type cumulPollenVisits file-type " "

file-print (" ")

]

]

file-close

end

; \*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

to BBCT\_WriteGridcellsToPatchesProc ;\*\*\*MB\*\*\* BBCT 2022-02-25

if file-exists? BBCT\_CellsToPatchesFile [ file-delete BBCT\_CellsToPatchesFile ]

file-open BBCT\_CellsToPatchesFile ; file-open creates a new file, if it doesn't exist yet!

file-print "pxcor pycor pcolor flowerpatchID" ;

foreach sort patches

[

ask ? ; now the actual data for each food patch are written in the file:

[

file-type pxcor file-type " "

file-type pycor file-type " "

file-type pcolorSave file-type " " ; \*\*\*GTD\*\*\* added 2003-08-29

file-type flowerpatchID file-type " "

file-print (" ")

]

]

file-close

end

; \*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

### Bug with extracting nectar and pollen visits data using Foodsource xcor and ycor

When we create our nectar and pollen visits maps from BEE-STEWARD BBCT\_NPvisits output file, there can be a rare bug. This is because a foodsource contains its xcor and ycor location to determine where it is located in the NetLogo world, this is calculated from the min and max xcor (min + max xcor / 2) and the min and max ycor (min + max ycor / 2), if this coordinate doesn’t fall on a grid cell of the same habitat type as the foodsource then it finds the nearest grid cell of the correct habitat type and it is located there. So this means that a foodsource can have decimal xcor and ycor. We therefore, need to round the xcor and ycor of the foodsources output file so then when we read it into R to cross reference it with the pxcor and pycor of the grid cells in the CellsToPatchesFile we can find a match. In a very rare occasion this can cause a bug – see diagram below.

To fix this we have added R code whereby the grid cell will only extract the the nectar or pollen visits of the foodsource that shares the same pxcor and pycor if it is the same habitat type. If it is not it does not transfer the visits data. So in a rare occasion the nectar or pollen visits data will not be transferred and therefore we may get false negatives but never false positives. This is mostly affecting habitat patches that are thin and long like hedgerows.

Two hedgerow habitat patch scenarios (blue cells are hedgerow, grey cells are no data “NA”), both the same size overall with the same xcor and ycor for the centre of their resulting foodsource but with slightly different configuration…

xcor

xcor

ycor

1 2 3 4

1 2 3 4

Foodsource centre

pxcor = 1 + 4 / 2 = 2.5

pycor = 1 + 3 / 2 = 1.5

Round the Foodsource centre

pxcor = 3, pycor = 2

Corresponding Grid cell = “Hedgerow”

Grid cell gets the correct visits data from the Foodsource

Scenario 1

Scenario 2

1

2

3

Foodsource centre

pxcor = 1 + 4 / 2 = 2.5

pycor = 1 + 3 / 2 = 1.5

All grid cells have integer xcor and ycor so to find the grid cell that this foodsource corresponds to we need xcor and ycor to be an integer so we round….

Round the Foodsource centre

pxcor = 3, pycor = 2

Corresponding Grid cell = “NA”

Grid cell gets the incorrect visits data from the Foodsource!

**!!!**

Figure A5. Diagram of how a rare bug may arise from foodsources xcor and ycor.

****

Report for the Bumblebee Conservation Trust

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