EcoServ-GIS v3.3

Technical Report: "Pollination Service"

1. Ecosystem Service Definition and Description

<u>Short definition</u>:

Areas where pollinators contribute to crop yield or stability in allotments, orchards and agricultural land

<u>Long definition</u>:

Allotments, orchards and areas of agricultural land where pollinators may contribute to crop yield and stability. Capacity for pollination is mapped based on likelihood of pollinator visitation. Societal demand (need) is mapped by identifying allotments, orchards and areas of agricultural land which contain crops which may depend on insect pollinators.

<u>Descriptive text</u>:

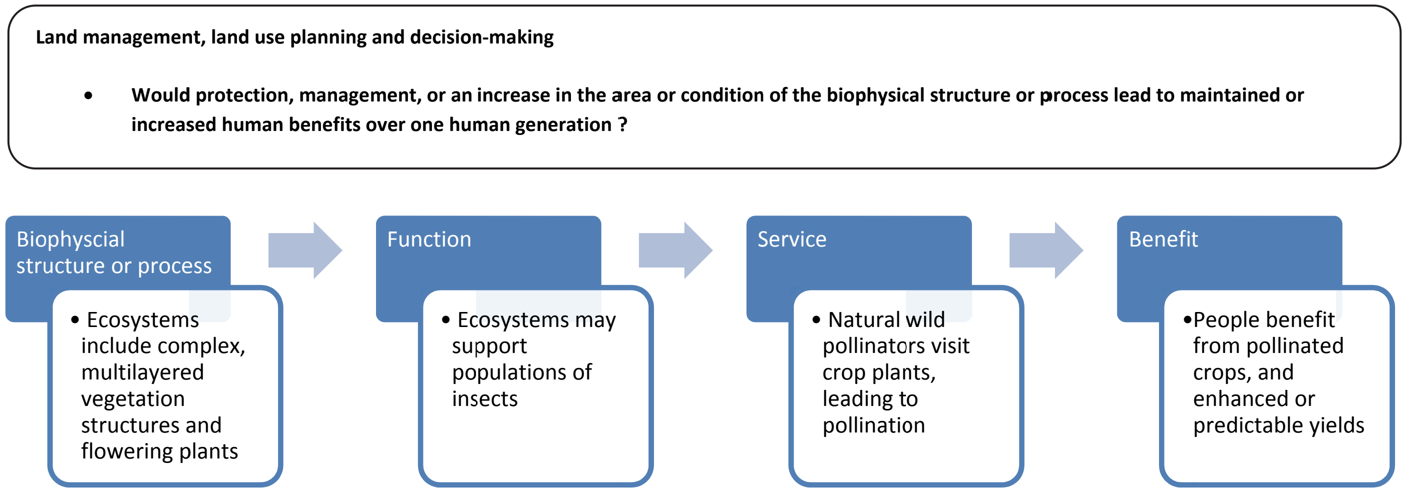
Semi-natural habitats, linear features and urban areas provide habitat for wild pollinators. Crops require pollination. Pollinators travel from nesting and breeding areas to visit nectar sources. Habitats close to crops may provide sources of natural pollinators.

<u>Service benefits description</u>

People may benefit from this service where crops are pollinated by wild pollinators in situations such as allotments, orchards or in agricultural land. Occurrence of wild pollinators may lead to higher yields. The links between habitats and pollinator yields are complex, and not all crops require pollination.

2. Service Cascade

As this toolkit is aimed at a county to regional scale the focus of land management and decision making is local. A timescale of one human generation (20 to 30 yrs) is set within which to consider, assess or measure the impacts of land use planning decisions and management. This is logical in relation to the long-term planning decisions of local authorities, health boards and infrastructure projects.



3. Literature review

Arable land, orchards and allotments all contain plants which require pollination in order to produce crops for sale or sustenance. Wild pollinators such as bees are vital to sustaining the production of these crops. UK pollination services have a high economic value (Breeze et al. 2015). Insect pollinated crops are important in UK agriculture (Breeze et al. 2011; Vanbergen et al. 2014). In the UK insect pollinators have been shown to be important to the apple crop industry by affecting both crop yield and quality (Garratt et al. 2014). A recent review in England highlighted the importance of the pollination ecosystem service (Defra 2013). The review highlighted that land use can be an important determinant of pollinator occurrence (Defra 2013). There is now a strategy focussed on sustaining pollinators in England (DEFRA 2014). The natural and semi-natural environment helps to sustain populations of bees and other pollinators, providing a free source of pollination. By protecting natural and semi-natural environments close to areas of arable agriculture the continued pollination of plants can be ensured. Although reviews have indicated that bee abundance or diversity is higher in areas where semi-natural habitats are more frequent or closer (Ricketts et al. 2008), detailed reviews of evidence on the conservation of bee species have shown that often detailed data or evidence is lacking on species-environment or management relationships (Dicks et al. 2010). However certain factors can promote bee conservation such as the beneficial impact of flower-rich field margins on pollinator abundance (Dicks et al. 2010).

Managed honeybees are not necessarily critical to crop pollination in the UK as during the period of honey bee decline the insect crop pollinated crop yields have increased (Breeze et al. 2011). Studies have indicated that wild pollinators are required, in addition to honey bees to help pollinate crops (Button & Elle 2014). Although widely valued as an economically important resource the actual valuation of the pollination service has been contested due to the large assumptions often made (Melathopoulos et al. 2015).

Detailed methods to map pollination supply would ideally use information on the occurrence, diversity, abundance and foraging ability of local pollinators. Some mapping work aims to model to this level of detail, such as the InVEST analysis (Natural Capital Project). However typically data on the location and population size of all local pollinating species is unavailable.

Although some research examined small scale detailed pollinator behaviour and found that bees were sensitive to wildflower patch area and richness even at small scales (Blaauw & Isaacs 2014), most research has been at broader field or landscape scales. This has often examined landscape composition in relation to pollinator occurrence. It has recently been noted that the use of positive conservation features in the landscape e.g. sown wildflowers may complicate the picture of landscape use by pollinators (Korpela et al. 2013). Nevertheless models have been produced relating abundance of pollinators in nesting habitats and on farms to landscape variables (Lonsdorf et al. 2009). It has been shown that mapping of the pollination service is very dependent on land cover map data sources (Schulp & Alkemade 2011).

Recent mapping work in Europe instead uses generalised relationships to estimate pollinator occurrence / visitation likelihood (Schulp et al. 2014). This method assumes that the location and number of wild bees are representative of pollinators as a whole. Following this method, with the exception of agricultural land, all open natural and semi-natural sites, and areas of woodland 100 m from open areas act as habitat for bees. It is assumed that all areas of habitat identified this way act as equally good habitat for bees. 688 m was taken as the distance bees will travel from habitat to each cell. This figure was taken from Ricketts et al. 2009, who present a meta-study evidence which suggests that there is only a 50% chance that pollinators will travel 668 m from habitat areas. The likelihood of a pollinator travelling to a focal cell from its habitat is used as a proxy for the amount of pollination within each cell. Further information on this method can be found in Schlup et al. 2013. This method does not take into account the additive effect of multiple patches of bee habitat within travelling distance from a cell. For example, two sites will receive the same capacity if they are the same distance from bee habitat regardless of any difference in the amount of bee habitat within 668 m.

Several insights from the following research were used to help construct the current GIS model:

- A study in France showed that bee abundance and taxa richness declined with distance from forest edge in oilseed rape fields (Bailey et al. 2014). A maximum distance of 230 m from forest edge were measured, as forest edges were likely to be important nesting or mating sites.
- Research in USA illustrated landscape composition had a significant impact on bee abundance and diversity (Bennett & Isaacs 2014), being correlated with perennial grassland cover. The strongest response to landscape variables occurred at the 1500 m scale. Relationships were positive for bee abundance (grassland cover) and bee diversity (forest cover).
- Research on honeybees and wild pollinators in Canada measured distance from field edges to assess pollination at 0, 50 and 100 m scales (Button & Elle 2014).
- European scale analysis showed complex relationships between landcover in a 3 km radius around focal areas on bee abundance and diversity (Carré et al. 2009). Forest and shrub cover were found to be positively associated with wild bee diversity (Carré et al. 2009).
- Californian research has shown a method of assessing pollination services by assessing the nearby area of habitat suitable for pollinators (Chaplin-Kramer et al. 2011). The authors examined vegetation types within 2.4 km of focal patches and extrapolated from studies of pollinator use measurements.
- Research on a single plant species found that seed viability was related to landscape variables, being higher in farms close to semi-natural habitat, but actually lower in landscapes with a high cover of semi-natural habitats (Chateil & Porcher 2015). Distances in the study were up to 698 m to nearby habitat with area proportions measured in 250, 500, 750 and 1000 m buffers. The interesting effect of area may be due to pollinators staying in high quality natural habitat rather than venturing into fields in high nature cover areas. The study noted and used short distance measured for some foraging distances, e.g. bumblebees, 300 m.
- Work in Germany indicated that thresholds occurred, in landscapes with more scarce grassland cover then species richness of wild bees declined with distance from main nearby habitat type, but did not have the same relationship in landscape with higher cover (Jauker et al. 2009) (although this could potentially be due to unrecorded or measured site features). Abundance however declined with distance in all landscape matrix types. Hoverflies relationships were more complex and contradictory. This work shows that ideally all taxa need to be considered for pollination. The study measured transects up to 2000 m from main habitats.
- Canadian research in orchards found pollination (fruit set) increased with functional pollinator diversity, and decreased with distance from nearby meadows. Bee functional diversity was positively correlated with area of nearby meadow and forest (Martins et al. 2015). The authors used an average foraging range of local pollinator species of 680 m. This was used to set the areal extent of analyses extents.
- In Sweden bee abundance and richness was found to be positively associated with distance to gardens in intensive agricultural landscapes (Samnegård et al. 2011). In the study distant sites were considered to be 140 m from garden habitats.
- Research examining pollinator-landscape relationships over multiple scales found pollinator numbers could be explained only at small scales (up to 1000 m) (Steffan-Dewenter et al. 2001).
- In urban areas in Belgium research illustrated that pollination of certain species is not negatively associated with urban cover (Verboven et al. 2014).
- Research in California indicated that pollination was better predicted by habitat characteristics rather than landscape composition (Williams & Winfree 2013).
- Work in Europe has mapped both the supply and demand of pollination service (Schulp et al. 2014). The method located crops needing pollination per 1 km cell and then modelled potential wild bee habitat and visitation probability, based on distance from nesting habitats. Bee habit comprised land cover map elements of habitat and green linear elements . Edges were <=100 m from open habitat, but the area was calculated as each cell provided 150 m length but 10 m width of “edge”. Visitation probability was calculated twice and the maximum

used per cell, e.g. for edges and for bee habitat area. Calculated from visitation probability = e(-0.00104 x distance to habitat).

- Another study in Europe modelled potential for pollination by using habitat and landscape characteristics (Zulian et al. 2013). The method used expert assessment of links to habitat type for pollinators, floral availability, foraging ranges and sites and effective pollinator activity, all applied to Corine landcover maps. Habitat types included: forest cover, roadsides, riparian, forest edge zones (25 m buffers were used around riparian areas, and roadsides). Pollinator foraging distance was based on 200 m. This research used a method to use locally accurate mapping data, where available, but in its absence used Corine data (Zulian et al. 2013).

Relationships between pollinators and landscape are complex and variable between taxa groups and landscape types (Winfree et al. 2011). Any broad relationship will be a crude simplification due to the complexity of relationships among taxonomic types and landscape composition and structure. However in summary, a variety of studies have related habitat cover, isolation or other landscape variables to wild pollinator diversity or abundance at scales from 100 to 3,000 m, around focal sites (Bennett & Isaacs 2014; Carré et al. 2009; Chaplin-Kramer et al. 2011; Chateil & Porcher 2015; Jauker et al. 2009; Martins et al. 2015; Steffan-Dewenter et al. 2001). Many studies use short distances to indicate the likely foraging distance of wild pollinators (e.g. 300 to 700 m). Most previous work suggests that "edge habitat" is an important resource for pollinator in the landscape in addition to key areas of habitat (Bailey et al. 2014; Button & Elle 2014; Schulp et al. 2014). Several studies indicate that pollinators are not negatively impacted by urban cover (Williams & Winfree 2013; Verboven et al. 2014). A range of research suggests that species - environment relationships would most likely to be modelled differently in landscapes with differing proportions of natural habitat or linear features, however there are no generalised information currently available to allow this. It seems probable that area of available pollinator habitat would influence pollinator occurrence although no generalised method was available to illustrate this.

4. Summary of constructing the GIS mapping service model

Relatively limited information was available in the literature with which to build the mapping rules. However sufficient insight, together with broad GIS data was available to build a basic logic / process based model of the service. A large number of approximations and assumptions had to be made. The main literature identified rules used to build the models were:

Capacity

- Visitation likelihood / probability by wild pollinator was selected as an indicator to represent the capacity of the natural environment of pollination.
- This was modelled based on the formula published in Schlup et al 2014 to convert distance from habitat to visitation probability.
- Pollinator habitat was identified as:
    - "Ph1code" = 'J21' OR "Ph1code" = 'J22' OR "Ph1code" = 'J23' OR "Ph1code" = 'Linear' OR "Ph1code" = 'H84' OR "Ph1code" = 'H85' OR "HabBroad" = 'Gardens / Parks / Brownfield' OR "HabBroad" = 'Garden' OR "HabBroad" = 'Grassland, semi-natural' OR "HabBroad" = 'Heathland' OR "HabBroad" = 'Scrub'.
    - Edge habitats were mapped as woodland habitat types.
    - A buffer distance of 20 m was used to indicate the edge zone in woodland habitat .

Demand

- All habitats and land use types that may potentially require the pollination service are selected from the BaseMap.
- This includes all agricultural land, allotments, orchards.

- Users can optionally use an alternative dataset to locate land requiring pollination, e.g. if a map of crops types are available.
- A distance analysis is used to identify demand for pollination service. This is based on the occurrence of habitat that is likely to hold pollinators. High demand occurs in areas of habitat that require pollinators to be present, whilst demand reduces with distance from such habitats.
- A maximum distance can be set by the user (default 800 m).

There is much research into crop pollination by bees and peer-reviewed attempts to model the pollination ecosystem service at relevant scales. Although research into the pollination ecosystem service exists there are gaps in the literature. For example there is little research measuring the impact of pollinator diversity or habitat diversity on pollination capacity, although research suggests that both are important for the pollination ecosystem service. Another issue with developing the model was a lack of data. No single dataset exists detailing the location of all areas of arable land, orchards and allotments. Further, no data exists on whether these areas containing plants which require pollination to produce crops. A single dataset of all areas containing crops which require pollination is unavailable. It is assumed that sites which are classified as cultivated land, orchards or allotments contain plants which require pollination to produce crops. It is also assumed that such plants occur across the entire extent of these sites.

The minimum number of pollinators/pollination needed to pollinate each site will vary depending on the size of each site along with the type and density of plants within each site. Information at this level of detail is unavailable. It is assumed that all land use types require the same amount of pollination regardless of differences in crop type and density. It is therefore assumed that each cell of agricultural land requires the same amount of pollination.

Data on the population location and size of all pollinating species is unavailable. The number and location of pollinators therefore is estimated using the method outlined in Schlup et al 2014. This method assumes that the location and number of bees are representative of pollinators on a whole. It is assumed that all areas of habitat identified this way act as equally good habitat for bees. 688 m is taken as the distance bees will travel from habitat to each cell. This figure is taken from Ricketts et al. 2009, who present meta-study evidence which suggests that there is only a 50% chance that pollinators will travel 668 m from habitat.

5. Spatial occurrence and service flows

The service is provided by areas of the natural and semi-natural environment which are able to act as habitat for pollinators. Pollinators are likely to nest in the edges of woodlands or anywhere within less dense vegetation. The flow of service is local. Pollination capacity depends on distance from pollinator habitats. The closer to pollinator habitat a site is, the more likely it is a pollinator will visit. The service occurs where pollinators and areas which require pollination coincide in space.

6. Ideal Data

The ideal data with which to map the service would be locally collected site measurements, at a relevant local spatial scale, compared to reference measures at a national scale. Data would be recently collected and updated regularly. Scientific research would be available which measures the impact of marginal changes in the extent, composition or condition of the natural capital asset on the level of the service delivered to people, and the benefits experienced. There would be detailed data on the number per socio-economic category, age or other suitable classification category of people who could benefit from the service, along with research on how changes in these social characteristics alter their relative levels of service demand over time. Finally there would be data on how levels of human use impact ecosystem condition.

In order to reliably map the service the following information would be required:

Capacity

- The type, location, extent, condition, quality and management status of semi-natural habitats, ecosystems or Greenspace
- The extent to which different habitats and ecosystems support populations of insect pollinators.

Demand

- The location, extent and management of areas of crops requiring pollination.

Service Flows and benefits

- The levels of pollination necessary to effectively result in pollination.
- The level of crops resulting from natural pollinators.

7. Proxies for ideal data

In the absence of the full range of ideal data to map the service, assumptions have been made, and additionally proxies have been used to represent selected elements of the ideal set of data.

Capacity

- The type, location, extent, condition, quality and management status of semi-natural habitats, ecosystems or Greenspace.
  - *Type, location, extent*: BaseMap - A combination of local data and several (optional) national datasets including: OS MasterMap, priority BAP habitats, local and national nature reserves, combined with Local Authority Open Space Survey / Green Infrastructure Survey (or equivalent).
  - *Condition, quality and management*: No consistent, reliable information.
- The extent to which different habitats and ecosystems support populations of insect pollinators.
  - All core habitats and mapped "edge" habitats are considered to support wild pollinators equally.

Demand

- The location, extent and management of areas of crops requiring pollination.
  - *Type, location, extent*: BaseMap - A combination of local data and several (optional) national datasets including: priority BAP habitats, local and national nature reserves, combined with Local Authority Open Space Survey / Green Infrastructure Survey (or equivalent).
  - *Condition, quality and management*: No consistent, reliable information.
- The location and extent of crops which require pollination to produce crops.
  - A combination of OS MasterMap and Landscape Character Area assessment or Land Cover Map 2007, or user supplied data is used to select land parcels which are likely to contain crops.
- The level of pollination necessary to effectively pollinate crops at each site.
  - It is assumed that each raster cell containing crops requires the same amount of pollination.
  - It is assumed that all crop types require the same number of pollinators to be adequately pollinated.
- The location and magnitude of pollination provided by natural pollinators.
  - Calculation of the probability that a pollinator will travel from its habitat to a site.
  - Location of potential pollinator habitat (a combination of local and national datasets including: priority and locally available BAP habitats and MasterMap).

Service / Flow

- The levels of pollination necessary to effectively result in pollination.
  - No data / information.
- The level of crops resulting from natural pollinators.
  - No data / information.
- The long term human benefits of the pollination service compared to the absence of the service.

- Spatial overlay of capacity and demand is used to indicate potential flow and benefits of the service.
- Ranking by quintiles is used to identify areas of relative high priority, improvement areas and gaps.

8. Limitations to the model and potential future improvement (where relevant)

The model assumes that all cells require the same amount of pollination regardless of crop density. Take care when interpreting the outputs from the map, particularly in areas where agriculture is known to be particularly intensive or extensive. Within intensive areas, the model may underestimate the demand for pollination. In extensive areas the model may overestimate the demand for pollination.

The model assumes that all areas of agriculture contain plants which require pollination in order to produce crops. This will not be the case, only a subset of plants are highly reliant on pollinators to produce crops. As such the model will overestimate the extent of pollination demand. This limitation can be avoided by ensuring that agricultural data used to produce the BaseMap accurately represents areas of agriculture which require pollination. Otherwise, take care when interpreting demand and flow maps and use local knowledge, or a user defined dataset of agricultural areas.

The model predicts pollination capacity by estimating the likelihood that a pollinator will visit a site. The meta-study which produced the logistic regression used to estimate likelihood of visitation was calculated based on a set of global studies, rather than just studies conducted in Britain. It is likely that the findings of this research would differ if only studies from Britain were used. Care should be taken when interpreting capacity and flow maps. Pollinator visitation rates may decrease with distance from habitat at a different rate to that used in the model.

The model does not take the amount of pollinator habitat into account when estimating pollination. Care should be taken when interpreting capacity and demand maps in areas with large amounts of nearby pollinator habitat. It is likely that capacity will be underestimated within these areas.

Limitation	Impact
Source data	Habitat mapping is often only available at the broadest level. There may be gaps and omissions in the location of areas of agriculture. Further, it is impossible to determine from the data which site contain plants which require pollination in order to produce crops.
Literature	There were relatively few published sources on which to base the mapping rules
Mapping rules transferability	The logistic regression used to calculate likelihood of visitation was developed based on a meta-analysis of a set of global studies. This may differ from British pollinators.
Study area extent	Very small study areas may not contain areas of demand
Landscape composition	In rare cases of upland or entirely arable landscapes there may be no areas of mapped capacity
Buffer zone impacts	N/A
Landscape pattern	N/A
Topography	N/A

9. Final List of Indicators

Indicators with a suffix of _IndC or _IndD are saved in the Indicators Geodatabase.

Indicator Name	Type	Description
Corehabitat_IndC	Capacity	Areas of core pollinator habitat
DisFromHabitat_IndC	Capacity	Euclidean distance from the closest habitat (up to 668 m).
AgriculturalFeat_IndD	Demand	All areas of cultivated land, orchards and allotments.
EdgeZone_IndC	Capacity	All edge habitat for pollinators
PollinatorHabitat_IndC	Capacity	All pollinator habitat (core + edges)
VisitationProbability_IndC	Capacity	Likelihood of pollinator visitation, based on distance to habitat

Detailed GIS Analysis steps

Model: ES1PollinationCapacity

This model makes predictions on an area's capacity to provide pollination services by calculating the likelihood that pollinators will travel from habitat to land with crops that require pollination.

- Defaults are set for cell size and extent, but can be altered by the user.
- Sub models delete all previously run data from Scratch, Outputs, Indicators, Shapefiles geo database and folders (mainly required during model testing rather than the final models).
- Sub models extract polygons from the BaseMap and map core pollinator habitat and edge habitat.
- Distance of 20 m is used to identify edge zones in woodland and trees habitats, but can be altered by the user
- The model firstly identifies pollinator full habitats from the BaseMap using make feature layer. This selection is copied out to create the FullHabitat vector indicator.
- To identify edge habitats, the model makes a new feature layer of all edge habitats (woodlands) and copies this out to form a new vector dataset. The model then selects all non-edge habitats using a make feature layer and copies this out to a new vector dataset. This dataset is then buffered by 20 m and used to clip all edge habitats. This forms a new indicator called EdgeHabitat containing of all edge habitats within 20 m of open space.
- FullHabitat and EdgeHabitat are merged to create the PollinatorHab indicator with all pollinator habitats.
- PollinatorHab is converted to a raster. Euclidean distance from PollinatorHab is calculated with a maximum distance of 668 m to create the DisFromHabitat indicator raster. Cell statistics sums DisFromHabitat with the raster version of PollinatorHab to create a new raster dataset which contains a 0 value for all pollinator habitat and all other cells given a value according to their distance from habitat. This dataset is passed to the times tool where it is multiplied by -0.00104. This new dataset is passed to a power tool which multiplies 2.718281828 to the power of the previously created raster dataset (distance * -0.00104). This produces the VisitationProbability indicator, the likelihood that a pollinator will travel from its habitat to any cell.
- Extract by mask is applied (default Study Area buffer). Values are re-scaled onto a 1 to 100 scale.
- A version of the dataset with NoData replaced by 0 is created.
- Datasets (raster) saved as Pollination_Capacity and Pollinatin_Caapcity_0_100.
- A submodel converts the raster data to vector shapefiles. The values are grouped into simplified categories, e.g. 1-10 (10), 10-20 (20), 20-30 (30) etc.

Model: ES2PollinationDemand

This model illustrates the distribution of parcels of land where food may be grown which relies on animal pollination to some degree.

- Defaults are set for cell size and extent, but can be altered by the user.
- Sub models delete all previously run data from Scratch, Outputs, Indicators, Shapefiles geo database and folders (mainly required during model testing rather than the final models).
- Model creates a raster layer of all arable land use types (cultivated land, orchards and allotments) which may contain plants which require pollination to produce crops (or uses an optional user defined layer).
- This feature layer is copied out to create the AgriculturalFeat indicator.
- Distance analysis is conducted up to a maximum distance (default 800 m).
- Extract by mask is applied (default Study Area buffer). Values are re-scaled onto a 1 to 100 scale.
- A version of the dataset with NoData replaced by 0 is created.
- Datasets (raster) saved as Pollination_Demand.
- A submodel converts the raster data to vector shapefiles. The values are grouped into simplified categories, e.g. 1-10 (10), 10-20 (20), 20-30 (30) etc.

Model: ES3Pollination Flows

The capacity and demand data are converted to quintiles and overlaid to identify benefitting areas and gaps

<u>The service flow model is the same for each service</u>

- Defaults are set for cell size and extent, but can be altered by the user.
- Sub models delete all previously run data from Scratch, Outputs, Indicators, Shapefiles Geodatabase and folders (mainly required during model testing rather than the final models).
- Sub model takes the separate capacity and demand datasets and produces the following datasets for either the Study Area of the Study Area plus buffer.
    - Capacity quintiles based on area and value.
    - Demand quintiles based on area and value.
    - All areas where there is some level of demand.
    - When the quintiles are calculated for capacity these are only created for areas with Demand > 0
- The service occurrence, demand and quintiles data are combined to create two sets of benefitting area data:
    - Ecosystem Service Benefiting Areas (ESBA) and gaps.
    - Ecosystem Service Benefiting Areas (ESBA) and gaps - prioritised.
- Ecosystem Service Benefiting Areas occur where Demand > 0 and Capacity > 0.
- Service Gaps occur where Demand > 0 and Capacity = 0.
- The prioritised data are defined by selecting the highest quintile (5) as high demand or high capacity, this allows the following categories to be produced:
    - A1 - Service Benefiting Area - High Demand (Q=5) and High Capacity (Q=5).
    - A2 - Service Benefiting Area - High Demand (Q=5) and Low Capacity (Q=1).
    - A - Service Benefiting Area - other (Demand Q>0<5 and Capacity Q>0).
    - B1 - Service Gap - High Demand (Demand Q=5 and Capacity Q=0).
    - B - Service Gap (Demand Q>0<5 and Capacity Q=0).
    - C1 - Restricted Service - High Demand (Demand (Q=5) and Capacity (Q>0 but restricted).
    - C - Restricted Service - other (Demand (Q>0<5) and Capacity (Q>0 but restricted).
- The ESBA and ESBA - prioritised datasets are each comprised of a single dataset to facilitate their use in later zonal statistics analysis.
- A sub model identifies "GI assets" by masking the service capacity maps to illustrate only those areas where there is a level of demand.
- A sub model exports the raster files to shapefiles. An optional patch area threshold allows small areas to be removed during the conversion process (default shape area > 200 m^2).

References

Bailey, S. et al., 2014. Distance from forest edge affects bee pollinators in oilseed rape fields. *Ecology and evolution*, 4(4), pp.370–80. Available at: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3936384&tool=pmcentrez&rendertype=abstract [Accessed September 28, 2014].

Bennett, A.B. & Isaacs, R., 2014. Landscape composition influences pollinators and pollination services in perennial biofuel plantings. *Agriculture, Ecosystems and Environment*, 193, pp.1–8. Available at: http://dx.doi.org/10.1016/j.agee.2014.04.016.

Blaauw, B.R. & Isaacs, R., 2014. Larger patches of diverse floral resources increase insect pollinator density, diversity, and their pollination of native wildflower. *Basic and Applied Ecology*, 15(8), pp.701–711. Available at: http://dx.doi.org/10.1016/j.baae.2014.10.001.

Breeze, T.D. et al., 2015. A stated preference valuation of the non-market benefits of pollination services in the UK. *Ecological Economics*, 111, pp.76–85. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0921800915000087.

Breeze, T.D. et al., 2011. Pollination services in the UK: How important are honeybees? *Agriculture, Ecosystems and Environment*, 142(3-4), pp.137–143. Available at: http://dx.doi.org/10.1016/j.agee.2011.03.020.

Button, L. & Elle, E., 2014. Wild bumble bees reduce pollination deficits in a crop mostly visited by managed honey bees. *Agriculture, Ecosystems & Environment*, 197, pp.255–263. Available at: http://www.sciencedirect.com/science/article/pii/S0167880914003946.

Carré, G. et al., 2009. Landscape context and habitat type as drivers of bee diversity in European annual crops. *Agriculture, Ecosystems & Environment*, 133(1-2), pp.40–47. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0167880909001406 [Accessed August 29, 2014].

Chaplin-Kramer, R., Tuxen-Bettman, K. & Kremen, C., 2011. Value of wildland habitat for supplying pollination services to Californian agriculture. *Rangelands*, 33(3), pp.33–41. Available at: http://www.bioone.org/doi/abs/10.2111/1551-501X-33.3.33 [Accessed July 26, 2011].

Chateil, C. & Porcher, E., 2015. Landscape features are a better correlate of wild plant pollination than agricultural practices in an intensive cropping system. *Agriculture, Ecosystems & Environment*, 201, pp.51–57. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0167880914005520.

Defra, 2013. Bees and other pollinators: their value and health in England Review of policy & evidence. , (July).

DEFRA, 2014. *The National Pollinator Strategy : for bees and other pollinators in England*,

Dicks, L. V, Showler, D. a & Sutherland, W.J., 2010. Bee conservation: evidence for the effects of interventions. *Conservation Evidence*, p.146.

Garratt, M.P.D. et al., 2014. Avoiding a bad apple: Insect pollination enhances fruit quality and economic value. *Agriculture, Ecosystems and Environment*, 184, pp.34–40. Available at: http://dx.doi.org/10.1016/j.agee.2013.10.032.

Jauker, F. et al., 2009. Pollinator dispersal in an agricultural matrix: opposing responses of wild bees and hoverflies to landscape structure and distance from main habitat. *Landscape Ecology*, 24(4), pp.547–555. Available at: http://www.springerlink.com/index/10.1007/s10980-009-9331-2 [Accessed March 15, 2012].

Korpela, E.L. et al., 2013. Can pollination services, species diversity and conservation be simultaneously promoted by sown wildflower strips on farmland? *Agriculture, Ecosystems and Environment*, 179, pp.18–24. Available at: http://dx.doi.org/10.1016/j.agee.2013.07.001.

Lonsdorf, E. et al., 2009. Modelling pollination services across agricultural landscapes. *Annals of botany*, 103(9), pp.1589–600. Available at: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2701767&tool=pmcentrez&rendertype=abstract [Accessed June 11, 2011].

Martins, K.T., Gonzalez, A. & Lechowicz, M.J., 2015. Pollination services are mediated by bee functional diversity and landscape context. *Agriculture, Ecosystems & Environment*, 200, pp.12–20. Available at: http://dx.doi.org/10.1016/j.agee.2014.10.018.

Melathopoulos, A.P., Cutler, G.C. & Tyedmers, P., 2015. Where is the value in valuing pollination ecosystem services to agriculture ? *Ecological Economics*, 109, pp.59–70. Available at: http://dx.doi.org/10.1016/j.ecolecon.2014.11.007.

Ricketts, T.H. et al., 2008. Landscape effects on crop pollination services: are there general patterns? *Ecology letters*, 11(5), pp.499–515. Available at: http://www.ncbi.nlm.nih.gov/pubmed/18294214 [Accessed March 2, 2012].

Samnegård, U., Persson, A.S. & Smith, H.G., 2011. Gardens benefit bees and enhance pollination in intensively managed farmland. *Biological Conservation*, 144, pp.2602–2606.

Schulp, C.J.E. & Alkemade, R., 2011. Consequences of uncertainty in global-scale land cover maps for mapping ecosystem functions: an analysis of pollination efficiency. *Remote Sensing*, 3(9), pp.2057–2075. Available at: http://www.mdpi.com/2072-4292/3/9/2057/ [Accessed September 16, 2011].

Schulp, C.J.E., Lautenbach, S. & Verburg, P.H., 2014. Quantifying and mapping ecosystem services: Demand and supply of pollination in the European Union. *Ecological Indicators*, 36, pp.131–141. Available at: http://dx.doi.org/10.1016/j.ecolind.2013.07.014.

Steffan-Dewenter, I., Münzenberg, U. & Tscharntke, T., 2001. Pollination, seed set and seed predation on a landscape scale. *Proceedings. Biological sciences / The Royal Society*, 268(1477), pp.1685–90. Available at: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1088795&tool=pmcentrez&rendertype=abstract [Accessed March 12, 2012].

Vanbergen, A.J. et al., 2014. *Status and Value of Pollinators and Pollination Services*,

Verboven, H. a F. et al., 2014. Pollination and seed set of an obligatory outcrossing plant in an urban-peri-urban gradient. *Perspectives in Plant Ecology, Evolution and Systematics*, 16(3), pp.121–131. Available at: http://dx.doi.org/10.1016/j.ppees.2014.03.002.

Williams, N.M. & Winfree, R., 2013. Local habitat characteristics but not landscape urbanization drive pollinator visitation and native plant pollination in forest remnants. *Biological Conservation*, 160, pp.10–18. Available at: http://dx.doi.org/10.1016/j.biocon.2012.12.035.

Winfree, R., Bartomeus, I. & Cariveau, D.P., 2011. Native Pollinators in Anthropogenic Habitats. *Annual Review of Ecology, Evolution, and Systematics*, 42(1), pp.1–22. Available at: http://www.annualreviews.org/doi/pdf/10.1146/annurev-ecolsys-102710-145042 [Accessed July 10, 2014].

Zulian, G., Maes, J. & Paracchini, M., 2013. Linking Land Cover Data and Crop Yields for Mapping and Assessment of Pollination Services in Europe. *Land*, 2(3), pp.472–492. Available at: http://www.mdpi.com/2073-445X/2/3/472/ [Accessed September 22, 2014].