Quantification of ecological services for sustainable agriculture

7th Framework Programme Theme KBBE.2012.1.2-02
Managing semi-natural habitats and on-farm biodiversity to optimise ecological services
Collaborative Project

Deliverable D4.4
Report on spatially explicit “heat maps” for ES across Europe

This project has received funding from the European Union’s Seventh Framework Programme for research, technological development and demonstration under grant agreement N° 311879
This deliverable relates to Task 4.3 Upscaling ecosystem services provision beyond the scale of the case studies (methodological and pan-European dimension)

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Contents

List of abbreviations ...................................................................................................................................................... 3
Executive summary .................................................................................................................................................................. 4
1 Introduction and Background ........................................................................................................................................... 5
2 Identification of datasets and layers to map Semi-natural habitats ........................................................................... 6
   2.1 Needs and constraints in the QUESSA framework.................................................................................................. 6
   2.2 Woody SNH ............................................................................................................................................................... 7
      2.2.1 Classification of Woody cover for the purposes of QUESSA .............................................................................. 8
   2.3 Herbaceous SNH ......................................................................................................................................................... 8
3 Description of the upscaling models at continental level ............................................................................................. 10
   3.1 Conceptual frame and main assumptions .................................................................................................................... 10
   3.2 The Pollination model ............................................................................................................................................... 12
      3.2.1 The JRC Pollination model by Zulian et al., 2013 ............................................................................................ 12
      3.2.2 The refined QUESSA pan-European Pollination model ................................................................................... 15
   3.4 The pest control model .......................................................................................................................................... 22
4 Results .............................................................................................................................................................................. 24
   4.1 Pollination ............................................................................................................................................................... 24
   4.2 Pest Control .......................................................................................................................................................... 28
5 Conclusions ................................................................................................................................................................. 31
References .......................................................................................................................................................................... 31
List of abbreviations

CLC = Corine Land Cover
ES = Ecosystem Services
FHI = Farmland Heterogeneity Index
JRC = Joint Research Centre
HA = Herbaceous Areal
HL = Herbaceous Linear
MSPA = Morphological Spatial Pattern Analysis
SNH = Semi Natural Habitats
WA = Woody Areal
WL = Woody Linear
WP = Work Package
Executive summary

In the present deliverable two models are described, to map pollination and pest control ecosystem services at European scale.

The two models are based on existing data layers that describe crops distribution, landscape structure in terms of presence of semi-natural habitats (SNH - i.e. tree lines, hedges, forest edges) and interspersion with other land uses, and on results provided by in-field surveys carried out in QUESSA WP2 and WP3, in which the level of the actual service (in particular pollinators and predators counts) was measured in 10 case studies comprising 180 “landscape sectors” across Europe, representative of different cropping systems and landscape contexts, and with varying abundance and spatial arrangements of SNH within and outside crop fields.

Both models are based on the main assumptions that landscape configuration in terms of spatial distribution of SNH exerts an influence on the measured levels of ecosystem services in agricultural land, depending on their types and location. In particular, the pollination model assesses the potential suitability of the entire landscape to support wild bees, whilst the pest control model maps the contribution of SNH to support flying pest predators.

Results show the spatial distribution of the ecosystem services across Europe with a 100 m resolution, and in particular highlight areas where the provision of the ecosystem service should be enhanced through the establishment of an appropriate SNH network, especially where the demand of crops depending on pollination and/or needing pest control is high. This is a situation in which an appropriate implementation (either by one farm but even more in case of collective implementation) of Ecological Focus Areas (EFA) as regulated by the Common Agricultural Policy in its Greening package could play a major role.
1 Introduction and Background

The aim of the QUESSA project is to assess and map Ecosystem Services (ES) provided by semi-natural habitats (SNH) in agricultural land. The focus is on two main ES delivered by mobile agents: pollination and pest control. The present deliverable describes how results collected at field level can feed geospatial models aimed at quantifying the potential of landscape to provide both ecosystem services. In the case of pollination an existing model (Zulian et al., 2013) was improved, in the case of pest control the first EU-wide mapping of the service was achieved.

Through fieldwork carried out in Work Packages (WP) 2 and 3, the level of actual service was measured in 10 case studies comprising 180 “landscape sectors” across Europe, representative of different cropping systems and landscape contexts, and with varying abundance and spatial arrangements of SNH within and outside crop fields. Each landscape sector is identified by a focal field (on which the services are measured) and the area around it within a radius of 1 km.

Four main types of semi-natural habitats (SNH) are defined in the project: Woody Areal (WA), Woody Linear (WL), Herbaceous Areal (HA), Herbaceous Linear (HL). SNH habitats and other land cover types were mapped in detail in each landscape sector according to a common standard procedure (mapping protocol). This data was provided in digital format to WP4 partners as the basis for the development of spatial models.

Such models aim at identifying statistical relations between the type and amount of SNH around the focal field and the level of service measured to map it in a spatially explicit way. First, spatial models are elaborated at the landscape scale (deliverables 4.1 and 4.2), defined in this context as the scale of single landscape sectors. The main assumptions are that SNHs exert an influence on ES provision at the focal field and that such influence depends on the SNH type and the Euclidean distance between the source patch and the target patch. The influence decreases monotonically with distance according to a function (termed kernel hereafter), which is considered invariant for all SNH types.

These main assumptions are maintained in the pan-European models for pollination and pest control, which aim to summarise the information collected and generated in the project, and to use it in combination with existing data bases for land use, agricultural practices and natural habitat.

This deliverable is structured as follows:

- Chapter 2 describes the layers that have been used and produced to feed the above mentioned models, the spatial and statistical analyses performed to assess their reliability and the main limitations and constraints.
- In chapter 3, the pan European models of pest control and pollination are described and how the information produced in the QUESSA project has been used to inform such models is explained.
- Chapter 4 presents the results of the modelling exercise at European level.
- In chapter 5, potential developments to improve the models are put forward and discussed.
- Annex A provides more details on the statistical analyses carried out on the input layers.
2 Identification of datasets and layers to map Semi-natural habitats

2.1 Needs and constraints in the QUESSA framework

As mentioned in the introduction, one major constraint in the elaboration of continental-scale, spatially explicit models on pollination and pest control is the availability of datasets and layers describing the presence and abundance natural and semi-natural elements that are at the core of the QUESSA project.

SNH as identified in QUESSA are by definition small elements like tree lines or grass strips, not easily detectable at the typical resolution of pan-European land use/land cover layers. Furthermore, whilst woody areal/linear element in agricultural land may be considered relatively stable in time, herbaceous elements, particularly linear ones, may be more ephemeral and change from one cropping season to the next.

As part of the work in task 4.3, existing and available datasets were identified, combined and processed to produce new or improved layers fulfilling the requirements and needs of the project as inputs for the models presented in section 3. The main requirement is full European coverage, or at least of the EU Member States. Adequate resolution is the main criterion: the objective of the present work is to develop pollination and pest control models at a resolution of 100 m, so all input layers should have a compatible resolution.

Corine Land Cover (CLC) is the most used land use/cover dataset as it is the only coherent and consistent European-wide dataset. Recently, the most updated version (as of 2012) has been released by the European Environmental Agency\(^1\). The resolution (cell size) is 100 m, but its minimum mapping unit is 25 ha, therefore smaller elements such as SNH defined in QUESSA are not detectable. The need to resort to complementary and more detailed information thus emerges. CLC can and shall nevertheless be used as the base land cover layer, as it provides information on the matrix within which finer elements are embedded, such as tree lines within agricultural land.

In the following sections of this chapter, the different datasets that have been identified for the purpose of estimate SNH presence and abundance across the whole Europe are described, as well as the additional processing and analyses carried out and the outputs obtained. Statistical analyses to assess the reliability of the identified dataset as proxies of the actual presence of SNH in the landscape were carried out. Results of this validation process show that the correlation is very good for woody areal SNH and – as expected – less good for herbaceous areal and woody linear element. However, the presence of a functional relation between mapped and estimated SNH (verified by testing the significance of the value of the correlation coefficients being not = 0) always yielded significant results with p-value <0.05. A more detailed presentation of the statistical analyses carried out is provided in Annex A.

No reliable layer could instead be identified as a descriptor of the abundance of herbaceous linear (HL) vegetation at the European scale, as the dimension of this SNH type is generally too small to be detected by satellite images. An attempt to quantify the presence of linear elements in agricultural landscapes Europe-wide is presented in van der Zanden et al (2013). The authors elaborated a European map for green lines, ditches and grass margins for Europe, using spatial modelling of ground observations on linear features from the 2009 LUCAS (land use/cover area frame statistical survey) database. Grass margins (width < 3 m) are one of the element class included in the map, which could be associated to HL as defined in QUESSA. However, the map resolution is 1 km\(^2\), which is too coarse for the purposes of

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\(^1\) Available at: [http://land.copernicus.eu/pan-european/corine-land-cover/clc-2012](http://land.copernicus.eu/pan-european/corine-land-cover/clc-2012)
the present work; moreover, the LUCAS survey only reports the presence of linear elements (number of intersection along an eastbound 250 m transect), whilst no information is provided on their size, which is indeed a key input in the modelling framework described in the next chapter. For these reasons, the option to include this dataset in the modelling framework was eventually discarded.

2.2 Woody SNH

In the frame of the Copernicus Programme - The European Earth Observation Programme - several pan-European High Resolution Layers are being produced under the coordination of the European Environmental Agency\(^2\). These layers are obtained through processing satellite imagery. They provide information on specific land cover characteristics at the resolution of 20 or 25 m. Five datasets are under development for the following themes: imperviousness (artificial cover), forest, wetlands, grasslands and water bodies. The forest layers are the most advanced ones: four main products are being developed:

- A first set (Service Element 1) of two layers with a spatial resolution of 20 m: tree cover density and forest type.
- A second set (Service Element 2) of two additional products specifically produced for the JRC with a spatial resolution of 25 m. These products are
  - tree cover presence/absence;
  - dominant leaf type.

Currently, Service Element 2 is in a more advanced state of elaboration and validation across Europe (but not fully validated yet) and it is therefore used in the present exercise.

The layers have been developed according to the following technical specifications: the tree cover presence has been mapped such that as a minimum the occurrence of patches of trees on the ground, showing a leaf ground coverage of at least 30% on a contiguous area of at least 50 m in diameter, is detected with a probability matching at least the User’s Accuracy of the Tree Cover class. A contiguous area is defined as an area not containing subarea(s) with less than 10% leaf coverage and with a diameter of more than 10m. The dominant leaf type indicates whether the canopy is either broadleaved or coniferous vegetation.

No further processing of Tree Cover Presence/Absence to a Forest/Non Forest mask is performed. Five lots covering all European countries have been assigned to different contractors. Accuracy assessment was carried out following a standard sampling scheme elaborated by JRC based on a regular grid and a stratified random point sampling approach. Minimum acceptable accuracy was set at 85% (European Environment Agency, 2014b).

This dataset currently represents the most accurate layer on woody vegetation with a full European coverage and was used as a basis to identify woody natural and semi-natural vegetation within and outside agricultural areas. To this end, further processing was performed, as described in the next subsection.

\(^2\) Information available at: http://land.copernicus.eu/pan-european/high-resolution-layers
2.2.1 Classification of Woody cover for the purposes of QUESSA

According to the SNH taxonomy defined in QUESSA, the first need is to distinguish, within woody coverage, between woody linear and woody areal elements. To this end, a Morphological Spatial Pattern Analysis (MSPA) was carried out on the whole European High Resolution Forest layer using the software GUIDOS (http://forest.jrc.ec.europa.eu/download/software/guidos/).

MSPA is a sequence of mathematical morphological operators targeted at the description of the geometry and connectivity of the image components. Based on geometric concepts only, this methodology can be applied at any scale on a binary map (foreground/background), to categorise the foreground (in this case, forest) into seven mutually exclusive classes: Core, Islet, Perforation, Edge, Loop, Bridge, and Branch as illustrated by Figure 1. Each 25 m pixel classified as Core, Edge, or Perforation was considered “Woody areal”, the rest of the MSPA classes were considered woody linear, as shown by Table 1 below.

<table>
<thead>
<tr>
<th>MSPA class</th>
<th>QUESSA woody SNH type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core, Perforation, Edge</td>
<td>Woody Areal</td>
</tr>
<tr>
<td>Islet, Loop, Bridge, Branch</td>
<td>Woody Linear</td>
</tr>
</tbody>
</table>

Table 1 Correspondence between the classification of the woody cover according to the MSPA and the woody SNH defined in QUESSA

![Figure 1 Example of segmentation of the forest high resolution layer according to the Morphological spatial pattern analysis in a QUESSA landscape sector (black circle, 1 Km radius). Resolution 25 m](image)

2.3 Herbaceous SNH

To identify the presence and abundance of herbaceous SNH in the European landscape the Pan European map of semi-natural vegetation abundance in Europe elaborated by the JRC (García-Feced et al., 2014) was used. This map estimates the abundance of woody (trees, hedgerows) and herbaceous SNH, (semi-natural grasslands) in agricultural land. The method builds on the analysis of satellite imagery and geospatial data and resorted to the spectral rule-based preliminary classifier (SRC), called Satellite Image Automatic Mapper™ (SIAM™). This consists of a mosaic of spaceborne multi-spectral images with
a resolution of 25 m. The output map legend consists of a set of 59 spectral categories (spectral-based semi-concepts), e.g. “Weak Vegetation”, “Strong Shrub Rangeland” etc.

The final map is the sum of two sub-components, woody and herbaceous vegetation. For the purposes of the present work, we used the herbaceous component only, since the woody component is already covered by the more detailed forest high resolution layer described in the previous section. The full method and processing used to derive the herbaceous component is described in García-Feced et al., 2014 and is summarised hereafter. Spectral categories matching the target semi-natural land cover classes (grassland) were identified by cross-tabulation against the 100 m resolution CLC 2006 map, by selecting those with the highest occurrence in the CLC classes 2.3.1 “Pastures” and 3.2.1 “Natural grasslands”, and low occurrence in the class 2.1.1 “Non-irrigated arable land”.

At this stage, permanent grasslands had to be separated from temporary ones, with the assumption that temporary grasslands cannot reach the status of being “semi-natural”, therefore characterised by a higher rate of biodiversity. A phenology-based indicator was developed, by extracting vegetation dynamics from a 250 m-resolution Moderate Resolution Imaging Spectro-radiometer image derived time series (2004–2009) of 10-day maximum Normalized Difference Vegetation Index composites at European scale (Weissteiner et al., 2008). These parameters describe proportions of seasonally changing and permanent vegetation throughout a growing season, including timing of the vegetation peak, and allow identifying areas where vegetation is removed through tillage. Information on aridity provided by the Desertification Indicators System for Mediterranean Europe (Brandt et al., 2003), environmental zoning (Metzger et al., 2005) and olive farming intensity data (Weissteiner et al., 2011) were also used as complementary data to distinguish arable land from stable or permanent vegetation. The resulting phenology-based indicator was discretized into quintiles, such that the 1st and 2nd quintiles were likely to represent temporary grasslands or arable lands and were therefore removed. Permanent grasslands thus identified were those remaining in place for the five years documented in the remote sensing images time series.

To discern between intensive and extensive grasslands, two sources of information were used: the Common Agricultural Policy Regionalised Impact (CAPRI) model (Britz, 2008) and the High Nature Value farmland map (100-m resolution) elaborated by Paracchini et al. (2008). The CAPRI model provides energy input (MJ/ha) in grasslands at the spatial resolution of the so-called homogeneous spatial mapping units (resolution, 1 km) and this indicator was used as a descriptor of management intensity. Energy inputs included in the indicator comprise fertilizer application (organic and mineral manure), machinery and human labour. Again, this indicator was discretized into quintiles for each of the main 12 environmental zones of Europe, and only cells belonging to the first quintile were considered as extensively managed grasslands. As a second source of evidence of the presence of herbaceous semi-natural vegetation, the High Nature Value farmland map (100-m resolution), was identified. Finally, the CLC classes “Inland marshes” (class 4.1.1) and “Salt marshes” (class 4.2.1) in High Nature Value farmlands were also included.

The final layer has a 100 m resolution and the value of each pixel corresponds to the share of land identified as semi-natural grasslands (ranging from 0/16 to 16/16). Validation tests reported in García-Feced et al (2014) show that this layer provides a further step in semi-natural vegetation mapping complementing pre-dated alternative maps. However, a drawback of the grassland component is that overall, it overestimates the abundance of semi-natural grassland in some regions. In order to partly correct this, the layer was further processed by overlapping it with two Copernicus High Resolution layers, the forest one described above and the imperviousness layer, assuming those ones to be more
accurate than the former. Whenever an overlap occurred, the semi-natural grassland value was corrected accordingly by deleting the overlapping cells. The problem of overestimation however remains in certain agricultural areas, such as arable land in some regions known to be intensively managed. The layer was however used in the model as it is an indicator of the presence of herbaceous vegetation within cropland and because further analysis confirmed a positive statistically significant correlation with HA SNH mapped in landscape sectors (see Annex A).

3 Description of the upscaling models at continental level

3.1 Conceptual frame and main assumptions
The models at the European scale maintain the main assumptions and the core architecture of the landscape-scale ones described in Deliverable 4.1 and 4.2, hypothesizing that SNH are a source of ecosystem services, whose strength decreases with distance from the source, according to a kernel function. The total service measured at any point in the landscape is the summation of the contribution from all surrounding SNH modulated by the kernel (see Figures 1 and 2 in deliverable 4.2). In ecological terms, this means that SNH area is conceptualized as a source of beneficial insects (pollinators and predators respectively) that disperse in the surrounding landscape, and that the service delivered to a point in the landscape is proportional to the abundance of insects that reaches it.

The 2Dt-distribution described in Deliverable 4.1 was used for both the pollination and pest control models; it is defined by two parameters, a length scale \( u \) in m, and a shape parameter \( \nu \) (Clark et al., 1999; Robinet et al, 2012). Equation 1 below shows the general form of the function:

\[
K_{2Dt}(r) = \frac{1}{u^2 \pi \nu} \frac{\Gamma\left(\frac{\nu+1}{2}\right)}{\Gamma\left(\frac{\nu-1}{2}\right)} \left(1 + \frac{r^2}{u^2}\right)^{-\frac{\nu+1}{2}}
\]  

(1)

Where:

\( r \) = radial distance in meters from the source
\( u \) = length scale parameters (dispersal)
\( \nu \) = shape parameters
\( \Gamma \) = gamma function: \( \Gamma (n + 1) = n! \)

As explained in Deliverable 4.1, this is a probability distribution function in a 3-dimensional space. Depending on the parameter \( \nu \) the function can approach a thin tailed normal distribution (\( \nu = \infty \)) or approach a fat tailed Cauchy distribution (\( \nu = 1 \)) enabling long distance dispersal. \( u \) is a length scale parameter reflecting smaller or longer dispersal distances, \( \nu \) is linked to the frequency of long distance dispersal (Robinet et al, 2012). Based on preliminary estimations carried out in tasks 4.2, the shape parameter was set to \( \nu = 25 \) (the largest value that can be used with the software R) as during all test simulations this was found to be the optimal value. This indicates that the function approaches a normal distribution. For the purpose of the pan-European models, we rescaled it so that the value at distance zero equals 1. In fact, the pollination and pest control potential calculated by our models are scores on a predetermined scale and do not represent physical units, so we use the kernel function as a weighting factor and not strictly as a mass probability function. Figure 2 below show the utilised kernel function in 3 dimensions and in a two-dimensional space.
Figure 2 Three dimensional (upper) and two dimensional (lower) shape of the kernel function modelling the foraging behaviour of wild bees. The x axis represents the radial distance from the focal cell to the source cell. The vertical axis shows the weighting factor assigned to cells at distance D in equation (2)
From both a conceptual and operational point of view, the upscaling at the continental level poses two major challenges: the first one concerns the modelling framework, the second one the availability of adequate data. The latter inevitably limits the former, as data availability is severely constrained by two contrasting requirements: coverage of the whole EU territory, and acceptable resolution.

Two main modelling approaches have been considered and explored for the purposes of QUESSA: the first one can be described as a “bottom-up” one, whereby the model architecture is defined starting from a conceptualization of how the ecological processes of pollination and pest control work and trying to mimic it in a spatially explicit way.

Conversely, the second approach – that can be defined “top-down”– consists in developing the models building on the results of the statistical analyses carried out in tasks 4.1 and 4.2 (landscape-scale models of pest control and pollination respectively) on the relationships between presence of different SNH types and ES provision within the focal fields, and by extrapolating them at the continental scale.

Both approaches have pros and cons, but the second one would require that clear and consistent trends linking SNH type and measured ES are found at the landscape scale, robust enough to be extended far beyond the geographic locations of the analysed case studies. However, results so far indicate that the nature of these relationships is highly context and scale-dependent, and at the time of writing of this report, “landscape-scale” models have not converged to the identification of generalised trends that can be consistently upscaled.

The first approach has therefore been pursued for the present exercise. Concerning pollination, a pan European model based on land cover data to map and assess the potential pollination service provided by wild bees was elaborated by the JRC (Zulian et al, 2013) and it is used as a basis for the development of the model presented here. To the authors’ knowledge, there is no Europe-wide model on pest control on which to build on, therefore the one described in section 3.3 can be considered the first attempt.

The two models share some main features but present also some differences that are explained in detail in the next sections. The main one is that the pollination model is more comprehensive and aims to map and assess the potential of the entire landscape to support bees presence and hence pollination. The pest control model instead is focused on mapping and quantifying the specific role of semi-natural habitats in the agricultural matrix to support beneficial predators.

3.2 The Pollination model

3.2.1 The JRC Pollination model by Zulian et al., 2013

The European-wide pollination model implemented for the QUESSA project builds on the model developed at JRC by Zulian et al (2013), in turn based on the modelling framework proposed by Lonsdorf et al (2009), included in the InVEST suite (Sharp et al, 2016). The whole landscape is conceptualised as a grid of square cells, each of which is scored according to its potential to host and provide forage to pollinators, depending on its land cover and use. By using a kernel function to determine the influence of each cell on the surrounding ones, an index of the potential suitability of landscape to support pollinator insects is computed and then linked to the potential service provided to agricultural land.

Each landscape cell is assigned two different scores for nesting suitability and floral availability. The first score reflects the capacity of the cell to host pollinators, whilst the second one measures the potential
availability of nectar and thus its attractiveness for pollinators as a source of food. In the original model, these scores are assigned based on literature review and expert judgements.

Given a set of scores for different land covers and a kernel function, the suitability of landscape to host pollinators is determined by using a land cover map as input and by considering the landscape composition within the range defined by the kernel. For any single cell \( x \) in a landscape, a first index \( P_x \) is computed by summing up the contributions of surrounding cells (moving window approach) according to the following equation:

\[
P_x = N_x \frac{\sum_{m=1}^{M} F_m \cdot f(D_{m,u})}{\sum_{m=1}^{M} f(D_{m,\alpha})}
\]  

(2)

Where:

- \( P_x \) is the potential suitability of cell \( x \) to support insect pollination.
- \( N_x \) is the nest suitability score of cell \( x \);
- \( f(D_{m,\alpha}) \) is the kernel function. In the original model it is a negative exponential; \( M \) is the number of cells within the maximum distance from cell \( x \), determined by the kernel function, including cell \( x \)
- \( F_m \) is the floral availability score of cell \( m \);
- \( D_m \) is the Euclidean distance between cell \( m \) and cell \( x \) (meters);
- \( \alpha \) length scale parameter governing the distance-weighted decline in influence

The denominator of the equation is a scalar used to normalize the output value to 0-1.

Once the potential capacity to supply the service is determined with equation (2), a further processing step is needed to match this with the demand side. By using again the same kernel function, an index of the abundance of the service delivered to each cell is calculated as described by equation (3).

\[
P_o = \frac{\sum_{m=1}^{M} P_{xm} \cdot f(D_{m,\alpha})}{\sum_{m=1}^{M} f(D_{m,\alpha})}
\]  

(3)

Where:

- \( P_o \) = total (potential) pollination service delivered to cell \( o \)
- \( P_m \) = potential suitability of cell \( m \) to support insect pollination.
- \( M \) = number of cells within the maximum distance from cell \( o \), including cell \( o \)

The model developed by Zulian et al (2013) focuses on wild bees, maintains the core structure defined by equations (2) and (3) but introduces three major improvements:
• different input data sources were used to derive detailed values for floral availability and nesting suitability;
• a specific land parcel system based on the CAPRI (Common Agricultural Policy Regionalized Impact) model was used to estimate the contribution of crops to floral availability and nesting suitability and to estimate the relative benefits derived from pollination;
• an extra module was computed to estimate the activity of wild bee pollinators, which depends on climatic conditions and the specific functional traits of the pollinator species considered.

The following diagram in Figure 3 shows the full model’s processing flow.

![Figure 3 Flow chart of the pollination model. Modified from Zulian et al, 2013](image)

Specifically, Corine Land Cover (resolution 100 m) was used as the base land cover map to determine cells’ baseline floral availability and nest suitability scores. Then, the following layers were used to derive more detailed values:

• in **arable land**, spatial data obtained by the CAPRI model (Britz and Witzke, 2008) were used to assign different scores of nesting suitability and floral availability to different cells, based on the share of different crops within it.
• Scores were increased in areas identified as High Natura Value (HNV) farmland (Paracchini et al, 2008) or identified as extensive olive groves, since areas under extensive management are more supportive for pollinators.
• A further adjustment in cropland was made by considering the abundance of semi-natural vegetation in agricultural areas based on a preliminary version of the map elaborated by García-Fecéd et al (2014), as the presence of semi-natural features increases the abundance of flowering resources and nesting sites.
• In **forest** areas, a distinction was made between forest edges and forest cores. The former are particularly suitable to host and feed pollinators and were assigned a high scores, while for the latter, the score for floral availability was decreased exponentially with distance from the edge. A Pan-European Forest/Non-Forest high resolution map (Kempeneers et al, 2011) was used to complement CLC data.
• A **road network** map was introduced, as roadsides often have increased floral availability. The TeleAtlas dataset was used and scores of cells adjacent to roads were adjusted depending on road types and size.
• The scores were also increased in High Nature Value farmland areas (Paracchini et al, 2008) and in riparian zones, lake boundaries, levees and ditches in semi-natural areas, since these areas constitute suitable habitats for pollinators. Concerning riparian areas, the European riparian
zone model (Clerici et al, 2013) at 25 m resolution was used, complemented with a buffer of 25 m along rivers and lakes.

Another feature of the original JRC model is that bee’s activity is not considered constant in space, but depends on local temperature. Solitary wild bees in fact increase their activity linearly with temperature after a certain threshold is reached. An additional layer of the Pollinator Activity Index was thus used at this step, derived by data provided by the JRC climate database on temperature and solar radiation on a 10 km square grid covering all Europe. The intermediate layer of landscape suitability for pollinators was multiplied by the activity to compute the overall index.

The final index does not represent the actual pollination service delivered to crops, but should rather be intended as the potential of the landscape - in its current spatial configuration – to support the presence of wild bees and the potential service supply associated to them.

3.2.2 The refined QUESSA pan-European Pollination model

Whilst keeping the general structure of the model described in the previous section, a number of refinements/modifications were implemented for the QUESSA pan-European model.

Firstly, the more recent versions of the main input layers were used whenever available. The updated version (as of 2012) of Corine Land Cover was used as the base map to assign floral availability and nesting suitability scores to single cells (100 m resolution). Tables 2 below shows the baseline scores assigned to different CLC classes.

*Table 2 Baseline scores of floral availability and nesting suitability for wild bees assigned to different CLC classes. Source: Modified from Zulian et al (2013)*

<table>
<thead>
<tr>
<th>CLC Code</th>
<th>Description</th>
<th>FA</th>
<th>NS</th>
</tr>
</thead>
<tbody>
<tr>
<td>111</td>
<td>Continuous urban fabric</td>
<td>0.05</td>
<td>0.1</td>
</tr>
<tr>
<td>112</td>
<td>Discontinuous urban fabric</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>121</td>
<td>Industrial or commercial units</td>
<td>0.05</td>
<td>0.1</td>
</tr>
<tr>
<td>122</td>
<td>Road and rail networks and associated land</td>
<td>0.25</td>
<td>0.3</td>
</tr>
<tr>
<td>123</td>
<td>Port areas</td>
<td>0</td>
<td>0.3</td>
</tr>
<tr>
<td>124</td>
<td>Airports</td>
<td>0.1</td>
<td>0.3</td>
</tr>
<tr>
<td>131</td>
<td>Mineral extraction sites</td>
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<tr>
<td>132</td>
<td>Dump sites</td>
<td>0</td>
<td>0.05</td>
</tr>
<tr>
<td>133</td>
<td>Construction sites</td>
<td>0</td>
<td>0.1</td>
</tr>
<tr>
<td>141</td>
<td>Green urban areas</td>
<td>0.25</td>
<td>0.3</td>
</tr>
<tr>
<td>142</td>
<td>Sport and leisure facilities</td>
<td>0.05</td>
<td>0.3</td>
</tr>
<tr>
<td>211</td>
<td>Non-irrigated arable land*</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>212</td>
<td>Permanently irrigated land*</td>
<td>0.05</td>
<td>0.2</td>
</tr>
<tr>
<td>213</td>
<td>Rice fields</td>
<td>0.05</td>
<td>0.2</td>
</tr>
<tr>
<td>221</td>
<td>Vineyards</td>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>222</td>
<td>Fruit trees and berry plantations</td>
<td>0.9</td>
<td>0.4</td>
</tr>
<tr>
<td>223</td>
<td>Olive groves</td>
<td>0.4</td>
<td>0.5</td>
</tr>
<tr>
<td>231</td>
<td>Pastures</td>
<td>0.2</td>
<td>0.3</td>
</tr>
<tr>
<td>241</td>
<td>Annual crops associated with permanent crops</td>
<td>0.5</td>
<td>0.4</td>
</tr>
<tr>
<td>242</td>
<td>Complex cultivation patterns</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>243</td>
<td>Land principally occupied by agriculture, with significant</td>
<td>0.75</td>
<td>0.7</td>
</tr>
</tbody>
</table>
As regards the agricultural component, data on crop shares at the spatial resolution of Homogeneous Spatial Mapping Units (1 km²) were updated using the most recent available baseline of the CAPRI model, as of 2008 (representing the average of the statistics data for the years 2007, 2008, 2009 and, for some countries, 2010). More detailed scores of floral and nesting potential where thus calculated by computing a weighted average of different crops’ scores (shown in Table 3) using their share on total utilised agricultural area as weighting factors. These scores replaced the baseline ones in all agricultural cells classified by CLC as Non-irrigated arable land and Permanently irrigated arable land.³

Table 3 specific scores of floral availability and nesting suitability of crops included in the CAPRI model. Source: Modified from Zulian et al (2013)

<table>
<thead>
<tr>
<th>Group</th>
<th>Crop Type</th>
<th>Floral Availability</th>
<th>Nesting Suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oilseeds</td>
<td>Rapeseed</td>
<td>0.9</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Sunflower</td>
<td>0.9</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Soya</td>
<td>0.5</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Olives for oil</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>Other oilseeds</td>
<td>0.5</td>
<td>0.1</td>
</tr>
<tr>
<td>Other annual crops</td>
<td>Pulses</td>
<td>0.7</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Potatoes</td>
<td>0.7</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Sugar beet</td>
<td>0.25</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Flax and hemp</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Tobacco</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Other industrial crops</td>
<td>0.5</td>
<td>0.1</td>
</tr>
<tr>
<td>Vegetables</td>
<td>Tomatoes</td>
<td>0.7</td>
<td>0.4</td>
</tr>
<tr>
<td>Fruits</td>
<td>Other vegetables</td>
<td>0.75</td>
<td>0.4</td>
</tr>
<tr>
<td>Other perennials</td>
<td>Apples, pear &amp; peaches</td>
<td>0.9</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>Citrus fruits</td>
<td>0.9</td>
<td>0.4</td>
</tr>
</tbody>
</table>

³ CAPRI data are not available for non-EU countries and Croatia, Malta and Cyprus. For agricultural cells in these countries, the baseline values in Table 2 were used.
Scores were also incremented in riparian areas, identified by the same European riparian zone model described in the previous sub-section (Clerici et al, 2013). Specifically, for both floral and nesting potential, an additional score of 0.8 multiplied by the share of semi-natural vegetation in a 100 m pixel was assigned,

The main novelty introduced in the present model is a more detailed consideration of semi-natural vegetation through the use of the forest High resolution layer, the Morphological Spatial Pattern Analysis and the semi-natural grassland layer (see sections 2.2 and 2.3) in combination with real data produced in QUESSA on the potential of SNH to support pollination. As part of the work carried out in WP2 and WP3, pollinators and predators abundance in the four different types of SNH was measured though field surveys according to the common methodology (sampling protocol) defined by the project in the different landscape sectors. This raw data was then analysed with statistical methods to produce a dataset on the potential contribution of SNH to pollination and pest control - the so-called “scoring systems”. Generalized linear mixed models were used, with pollinators/predators abundance as response variables and two coarse-level SNH descriptors imposed by the project design as predictors: i) type of SNH (either woody areal, woody linear, herbaceous areal and herbaceous linear) and ii) “distance” – i.e. whether the measure was taken at the edge or in the interior of the SNH. Separate estimations were made both for Europe as a whole and for some countries separately.

The process generated a set of values – the “scores” – representing the mean number of beneficials that can be expected in a specific type of SNH and position (edge-interior). Concerning pollination, two distinct sets of scores were calculated for:

- all bee species, including honeybees (*Apis mellifera*) and all wild bees species (*Bombus, Eucera*, etc),
- wild bees alone, thus excluding honeybees.

Tables 4 and 5 below show the values of the scores for all bees and wild bees respectively, for all Europe. They resulted from pooling all the available observations obtained with the two sampling methods used in QUESSA– pantraps and transects. This was decided because each of the two methods proved selective for some pollinators species, so using only one would have left a whole set of insects out of the analysis; analysing the two datasets separately was also considered, but this option was discarded due to the extremely low numbers of counts in some Countries. Therefore, country-specific scores were calculated only for those countries in which both sampling methods were used. Furthermore, raw data from Hungary and Estonia could not be used, again because of the low number of bees found in their transects-only datasets.
Table 4 Pollination scores of different SNH types for all Europe (derived from QUESSA sampling). Scores are the expected abundances of bees predicted by the generalised linear mixed model; upper and lower: confidence intervals at the 95% level. Distance: E=exterior I=interior.

<table>
<thead>
<tr>
<th>Country</th>
<th>beneficial</th>
<th>SNH</th>
<th>distance</th>
<th>score</th>
<th>lower</th>
<th>upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Europe</td>
<td>All bees</td>
<td>Herbaceous areal</td>
<td>E</td>
<td>11.88</td>
<td>8.29</td>
<td>17.02</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>I</td>
<td>12.47</td>
<td>8.70</td>
<td>17.86</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Herbaceous linear</td>
<td>E</td>
<td>10.94</td>
<td>7.90</td>
<td>15.14</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>I</td>
<td>11.29</td>
<td>8.07</td>
<td>15.79</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Woody areal</td>
<td>E</td>
<td>9.15</td>
<td>6.55</td>
<td>12.79</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>I</td>
<td>3.15</td>
<td>2.24</td>
<td>4.43</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Woody linear</td>
<td>E</td>
<td>9.60</td>
<td>6.95</td>
<td>13.28</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>I</td>
<td>8.56</td>
<td>6.13</td>
<td>11.94</td>
</tr>
</tbody>
</table>

Table 5 Pollination scores of different SNH types at the European level (derived from QUESSA sampling). Score: expected abundances of Wild bees predicted by the generalised linear mixed model; upper and lower: confidence intervals at the 95% level. Distance E=exterior I=interior.

<table>
<thead>
<tr>
<th>Country</th>
<th>beneficial</th>
<th>SNH</th>
<th>distance</th>
<th>score</th>
<th>lower</th>
<th>upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Europe</td>
<td>Wild bees</td>
<td>Herbaceous areal</td>
<td>E</td>
<td>7.35</td>
<td>5.25</td>
<td>10.30</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>I</td>
<td>7.32</td>
<td>5.23</td>
<td>10.26</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Herbaceous linear</td>
<td>E</td>
<td>6.96</td>
<td>5.13</td>
<td>9.43</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>I</td>
<td>7.26</td>
<td>5.30</td>
<td>9.94</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Woody areal</td>
<td>E</td>
<td>7.25</td>
<td>5.30</td>
<td>9.91</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>I</td>
<td>2.67</td>
<td>1.94</td>
<td>3.68</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Woody linear</td>
<td>E</td>
<td>6.43</td>
<td>4.75</td>
<td>8.71</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>I</td>
<td>5.40</td>
<td>3.95</td>
<td>7.39</td>
</tr>
</tbody>
</table>

This means that country-specific scores were obtained for four States: Italy (Sunflower case studies), Switzerland (oilseed rape), Germany (pumpkin) and United Kingdom (oilseed rape). This poses serious limitations to the possibility – initially envisaged for the upscaling – to build a Europe-wide model by extrapolating in a stepwise manner the country specific scores to the whole continent, which would require a larger number of case-studies specific scores. The decision has thus been, for the current exercise, to use the average pan-European values; the option of using the country specific scores remains open as a potential future development if further statistical analysis yields robust results for other case studies (as discussed in section 5). Country-specific scores can instead be used as ground observation of bees abundance in different locations to verify whether they are correlated with model predictions (see section 4.1, Figure 8).

The values in Tables 3 and 4 are the average abundance of bees across time found in a given area of SNH (approximately 75 m²) and represent a proxy of the potential of different SNH types to support pollinators. In the modelling framework described above, they can be interpreted as scores of floral availability, since bees found in pantraps and transects were foraging in the SNH and were not in nests. Since the model is designed to assess the service provided by wild bees - honey bees being mainly
managed so that their presence in the landscape cannot be modelled following the same assumptions - only scores of wild bees were used in the present work.

In WP 2 and 3, further statistical tests were carried out on the pollination scores to assess whether the difference between “external” and “internal” SNH (the “distance” variable) were statistically significant. Results (not shown here, reported in the corresponding deliverable) indicate that this distinction is not significant for all SNH types except woody areal elements, for which the value is significantly lower (p-value <0.001). This finding strongly supports the original JRC model’s assumption that the capacity of woody vegetation to support pollinators decreases with distance from the forest edge. In ecological terms, forest edges adjacent to open land constitute an ecotone habitat more suitable for pollinators than forest cores. Scores from empirical surveys in WP2 also confirm another assumption of the model, that (semi) natural grasslands have the highest value of floral availability among all SNH types.

Specific values of Floral Availability were thus given to WL, WA-edge, WA-core pixels - identified from the forest high resolution layer through the MSPA – and HA by normalizing to 1 the scores generated in WP2 (Table 6). These scores, based on real data from field surveys, replace the original ones based on expert judgements in forest and grassland, and increase the baseline values of agricultural cells (Table 2) whenever SNH are present, proportionally to their share. Since the resolution of the utilised input layers does not allow to discriminate between internal and external WL and HA, the average value (of “external” and “internal”) was assigned to the SNH type. The difference between the two values being not significant guarantees that this simplification does not affect results at the landscape scale.

As for nesting suitability, edges and cores were assigned the same values of the model by Zulian et al (2013); herbaceous elements were given the same score therein assigned to semi-natural grasslands (0.8). Woody linear elements were assigned the same nesting suitability of Woody areal - edges.

<table>
<thead>
<tr>
<th>Original SNH type</th>
<th>Original score</th>
<th>SNH type</th>
<th>Floral availability (0-1)</th>
<th>Nesting suitability (0-1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herbaceous areal</td>
<td>7.35</td>
<td>Herbaceous areal</td>
<td>1 *</td>
<td>0.8</td>
</tr>
<tr>
<td>external</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Herbaceous areal</td>
<td>7.32</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>internal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Woody areal</td>
<td>7.25</td>
<td>Woody Areal - Edge</td>
<td>0.987</td>
<td>0.9</td>
</tr>
<tr>
<td>external</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Woody areal</td>
<td>2.67</td>
<td>Woody Areal - Core</td>
<td>0.364 (max)</td>
<td>0.7</td>
</tr>
<tr>
<td>internal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Woody linear</td>
<td>6.43</td>
<td>Woody Linear</td>
<td>0.806*</td>
<td>0.9</td>
</tr>
<tr>
<td>external</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Woody linear</td>
<td>5.40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>internal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6 Scores assigned to Floral Availability for different classes of SNH in the pollination model and correspondence with the original scores provided by WP2-3. *=average value between “external” and “internal” SNH.

The floral availability value of forest cores refers to the cells adjacent to edges, whilst the values given to farther cells decreases with distance as a negative exponential such that the value at distance =0 equals the edge value in table 4, and the value at distance 25 equals that of cores. The value of cells at distance >100 is negligible and considered null. (Figure 4).
As the scores for woody habitats provided by WP2 refer specifically to semi-natural habitats, and not to woody crops such as orchards or olive groves, we didn’t consider in the final woody cover layer all trees under agricultural use. By applying the same procedure adopted by the EEA to produce the “Forest Type” high resolution layer, this was done by removing cells classified by CLC as fruit trees and olive groves. These cells were however assigned the baseline scores reported in Table 2. For the final processing the woody cover and the riparian areas component were aggregated at 100 m resolution. The following processing steps were implemented to obtain the final floral and nesting scores in each 100 m land cell in Europe.

1. Initial baseline scores are assigned to cells according to their CLC class (Table 2). Forest CLC classes and Agro-forestry areas are assigned a zero value.
2. The baseline scores of cells classified as arable land by CLC are replaced by the more detailed values derived by the CAPRI model, whenever available (that is, in all countries except Norway, Croatia, Malta and Cyprus).
3. Scores assigned to woody cover from the MSPA on the High resolution (aggregated at 100 m) are added to the baseline layer. The final score is proportional to the abundance of 25 m woody cell in each 100 m cell, multiplied by the specific score reported in table 4.
4. Cells in riparian areas get an additional score, obtained by multiplying the correspondent score by the share of semi-natural vegetation in 1 ha cells.
5. Cells identified as SNH grassland get an additional score, again equal to the HA score in Table 6 multiplied by their share in 1 ha cell.

*Figure 4* Floral availability scores assigned to core woody areal cells depending on their distance from the closest edge
Given the more detailed layers used in this exercise to assess the abundance of SNH at European scale, some of the ancillary layers used in the original JRC model as proxies of the presence of semi-natural vegetation were not included in the present model, such as river networks, lake boundaries and road sides. The final values for Floral availability and Nesting suitability are used as inputs in equations (1) and (2). At this stage, another change from the original model was introduced, as the function described by equation 1 was used as the kernel function. Finally, the relative pollination potential index was adjusted by taking into account the bees Activity Index.
3.4 The pest control model

The pest control model shares the same core architecture of the pollination model but with some simplifications due to more limited knowledge about the corresponding ecological process. In this case the model estimates the overall contribution to pest control provided by the different types of SNH and by some functional groups of beneficial predators, not the contribution of the landscape as a whole.

The main input data layer used to estimate the presence and abundance of semi-natural vegetation in the landscape are the same used for the pollination model. Again, we ground our model on the scores provided by WP2 as indicators of the source strength of SNH and assume that this propagates in the landscape according to the same mathematical function expressed by equation (1).

Scores were calculated for different functional groups of beneficials:

- Predatory flies (Empididae, Dolichopodidae, Asilidae)
- Parasitica (Chalcidoidea, Ichneumonoidea)
- Syrphidae
- the sum of all above listed groups (“All flying predators”)

Due to limitations in available observations, scores for ground dwellers could not be derived. In this case, no transect data were available, therefore only pantrap data were used (again from Italy, Germany, UK and Switzerland). Like in the pollination case, analyses were carried out at Pan-European and Country level. Table 7 below shows the scores for different SNH types and predator groups identified for the pan European level analysis.

<table>
<thead>
<tr>
<th>SNH type</th>
<th>Distance</th>
<th>All flying predators</th>
<th>Predatory flies</th>
<th>Parasitica</th>
<th>Syrphidae</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herbaceous areal</td>
<td>E</td>
<td>26.8</td>
<td>10.7</td>
<td>7.2</td>
<td>2.3</td>
</tr>
<tr>
<td>Herbaceous areal</td>
<td>I</td>
<td>28.2</td>
<td>12.4</td>
<td>6.1</td>
<td>2.1</td>
</tr>
<tr>
<td>Herbaceous linear</td>
<td>E</td>
<td>24.7</td>
<td>8.6</td>
<td>7.6</td>
<td>2.3</td>
</tr>
<tr>
<td>Herbaceous linear</td>
<td>I</td>
<td>24.2</td>
<td>7.9</td>
<td>7.0</td>
<td>2.5</td>
</tr>
<tr>
<td>Woody areal</td>
<td>E</td>
<td>45.6</td>
<td>16.7</td>
<td>12.7</td>
<td>4.8</td>
</tr>
<tr>
<td>Woody areal</td>
<td>I</td>
<td>20.7</td>
<td>5.9</td>
<td>7.7</td>
<td>2.5</td>
</tr>
<tr>
<td>Woody linear</td>
<td>E</td>
<td>34.4</td>
<td>13.5</td>
<td>10.4</td>
<td>3.3</td>
</tr>
<tr>
<td>Woody linear</td>
<td>I</td>
<td>29.6</td>
<td>10.0</td>
<td>10.8</td>
<td>3.3</td>
</tr>
</tbody>
</table>

Table 7 - Pest control scores for different functional groups of flying predators for different types of SNH (Pan-European level). Scores represent the expected abundance of insects in a given surface of SNH.

In WP2, also in this case statistical tests were performed to verify whether the difference in the estimated values between the interior and exterior of SNH are statistically significant. Again, results confirm that the only statistical difference concerns woody areal SNHs, so in all other cases we used the average value. We therefore applied the same procedure described in the pollination model to obtain a layer of the abundance of WL, WA-edge and WA-core cells. WA-cores were assigned a decreasing score in the same fashion as described by Figure 5 above, rescaled to fit the values reported in Table 7 (no normalization of the scores was necessary in this case).

The impact on a cell (termed here Pest Control Potential Index) is the weighted summation of all the impacts from different SNH types, as expressed by Equation (4)

\[ PC_{xb} = f(r_i) \sum_{i=1}^{n} \sum_{j=1}^{4} SNH_{ji} * S_{jb} \quad (4) \]
Where:

\[ PC_{xb} = \text{Pest Control Potential Index of cell } x \text{ for the functional group } b \text{ of beneficial}; \]

\[ r_i = \text{Euclidean distance between cell } i \text{ and cell } x \]

\[ f(r_i) = \text{value of the kernel function at cell } i \]

\[ n = \text{number of cells surrounding cell } x \text{ for which } f(r_i) > 0 \]

\[ SNH_{ji} = \text{abundance (0-1) of the } j^{\text{th}} \text{ SNH type (WL, WA-edge, WA-core, HA) in cell } i \]

\[ s_{jb} = \text{pest control score of the } j^{\text{th}} \text{ SNH type for predators functional group } b \text{ (Table 5)} \]

The model was implemented using the pan-European scores as the same considerations expressed for pollination on the extrapolation of the country-wise results based on only four countries apply. Some other simplifications were introduced to run the model with currently available information within the QUESSA project. No specific information is available on the functional groups of flying predators considered, in turn made up of different taxa and species with arguably quite different traits. The values of the parameters in the kernel function were based on preliminary results from task 4.1 and should represent an indicative average value for the totality of flying predators. In mathematical terms this means that currently the value of the kernel function \( f \) in equation (4) above is considered invariant with respect to different groups and SNH types. However, the model structure easily allows to add more detailed information if available, such as different flying ranges for different predators species and/or additional scores for functional groups currently not included, like ground dwellers insects.
4 Results

4.1 Pollination

Figure 5 below shows the map of the Relative Pollination potential for the whole Europe, rescaled from 0 (no pollination potential) to 100 (maximum potential). Classes represent quantiles; classes break values show that index values are concentrated in the 0-10 interval, indicating a dispersed distribution. At the European scale, the main visible trends are related to the macro-structure of the landscape morphology and to the Activity index that clearly increase pollination potential along a north-south gradient, with visible effect for example in the Fennoscandian region.

Figure 5a Index of Overall Landscape Suitability to support pollinators (0-100) in Europe. Map resolution = 100 m
Some intensively cropped land characterized by very low indicator value are identifiable already at the Pan European level, such as the Wallachian plane in Romania, the agricultural region in Castilla y Leon (central-northern Spain), central-Eastern England and the Pannonian plane.

More detailed maps are provided in figures 6-7 below, showing details of the areas where landscape sectors (black or red circles) were located, which allows to appreciate how the values vary among some of the different case studies locations included in the project.
Figure 7 Relative Pollination Potential in landscape sectors in France (Upper-left), Germany (upper-right) and Italy (lower left)
To test whether the modelled index is correlated with real on-field observations, we matched the resulting values of the index in landscape sectors from Italy, Switzerland, Germany and UK with the country-specific scores of SNH obtained in WP2. As said, such scores originally represent the average number of bees found in pantraps and transect in the different SNH types. The average value of the (intermediate) landscape suitability for pollinators index (block E in Figure 3) over the landscape sectors was computed for each of the above-mentioned case studies and plotted against the weighted average of the country specific scores. The latter was calculated using the relative share of SNH types as weighting factor. To speed up the computation at this stage, it was assumed that woody areal-edge accounts for a fixed percentage of the woody areal coverage (10% based on rough estimations) and woody-areal cores were excluded from the computation. This however has limited effects on the final numerical values as the contribution of woody core areas to the index is limited given the low and rapidly declining value of the floral availability score (all core cells at distance>100 from the edge have 0 value in fact, see Figure 4). We used the intermediate score and not the final one because field surveys were conducted in a relatively short period of time in springtime or summertime, so the effect of the bees Activity Index is much less relevant here.

Figure 8 below shows the results of this exercise. The value on the x axis is the weighted average of the scores calculated in WP2, i.e. a proxy of the observed abundance of bees on the ground in landscape sectors per each country. The y axis is the value of the landscape potential for pollinators.

![Figure 8](image-url)

Figure 8 Scatterplot showing the weighted average of scores of bees abundance as measured in WP2 and the average value of the intermediate landscape suitability for pollinators index. DE= Germany, UK= United Kingdom, CH= Switzerland, IT= Italy.

The diagram shows a very good correlation. Of course, this result should be taken with caution and cannot be considered a full model validation, given the relatively limited sample and the simplification described above. However, they can be considering a first promising empirical check of the model.
4.2 Pest Control

The main result of the pest control model is presented in Figure 9 below, showing the Pest Control Potential Index of flying predators in Europe on a 0-100 scale range.

It shall be pointed out again that, contrarily to the Landscape Suitability for Pollinators, the index shown here represents the contribution of SNH to biological pest control supplied by flying predators, not the potential of the entire landscape (for this reason non-agricultural land is masked out). The distribution of the re-scaled index value also reflects this by showing a lower dispersion as indicated by the class breaks values (classes represent quantiles). Whilst some similar patterns are identifiable for both

Figure 9 Pest Control Potential provided by SNH
services, some clear differences also emerge. In the case of pest control no correction factor related to climate or temperature was applied, so no macro trends related to latitude are visible. As expected, cropped areas, particularly arable land, show the lowest values. Figures 10 and 11 show more detailed maps centred on the landscape sectors for some case studies from UK, Estonia, the Netherlands, Germany, Switzerland, France and Italy.

Figure 10 Pest control potential in UK (upper-left), Estonia (upper-right), The Netherlands (lower-left) and Switzerland (lower-right).
Figure 11 Pest control potential in Germany (upper left), France (upper-right) and Italy (lower left)
5 Conclusions

We elaborated two Europe-wide, spatially explicit models for pollination and pest control ecosystem services at fine-grained resolution (100 m). The pollination model assesses the potential suitability of the entire landscape to support wild bees, whilst the pest control model maps the contribution of SNH to support flying pest predators. Both models are based on the main assumptions of the corresponding landscape sectors models described in QUESSA deliverable 4.1 and 4.2. SNH are considered to exert an influence on the measured levels of ecosystem services in agricultural land, depending on their types and distance in space.

We identified pan-European layers that are suitable to represent the abundance of SNH in agricultural land and validate their reliability to be used as inputs in the process. Models were also parameterised with inputs from ground-based surveys carried out in WP2 and WP3 to quantify the potential of different SNH types to support bees and flying predators.

The models can be easily adapted to input more detailed information once available or modify some of the input layers. Possible future developments include:

- Amend the models to upscale at the continental level emerging relationships between ES and different types of SNH as identified by landscape sector models
- Improve the geospatial data used as descriptors of SNH to take into account, for example, herbaceous linear elements, currently not included in the model
- Use different kernel functions to model the influence of different SNH or land cover types
- Further elaborate on the role of landscape configuration and composition in supporting pollination and pest control
- Explore the possibility of including the Farmland Heterogeneity Index in the modellng process
- Explore the possibility of linking to other projects collecting data on pollinators diversity and abundance
- Extending the model to pollinators other than wild bees
- Improving the validation part. Further analysis of field data may allow to do so (i.e. increasing the number of countries and analysed landscapes, including the values per each of the landscape sectors), but also setting up a validation exercise by contacting the main national and EU projects working on pollination.

References


