



J R C T E C H N I C A L R E P O R T S

# ESTIMAP: Ecosystem services mapping at European scale

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## GENERAL CONCEPTS ABOUT MAPPING ECOSYSTEM SERVICES

Mapping, visualisation and the access to suitable data as a means to facilitate the dialogue among scientists, policy makers and the general public are among the most challenging issues within current ecosystem service (ES) science and application (ESP working group on mapping ecosystem services, 2013). Recent reviews on spatial assessments of ecosystem services [1,2] reveal increasing attention of researchers to assess ecosystem services in a spatially explicit way and many authors provide maps of single or multiple ecosystem services delivered by particular ecosystems, such as wetlands or forests, or by landscapes which consists of several ecosystems. An essential question is how to operationalize this generated knowledge for policy making and implementation. The apparent need for spatial data of ecosystem services has thus triggered the development of practical tools such as InVEST, ARIES or Costing Nature which offer GIS based solutions to include ecosystem services in planning for land use, nature conservation or development. These models have proved their added value at local and regional scales.

Also at national, supra-national and global scale, there are explicit requests for a better coverage and increased model capacity to assess ecosystem services. At global level, the Aichi Biodiversity Targets 14 and 15, which are part of the global strategic plan under the Convention of Biological Diversity to stop biodiversity losses by 2020, particularly address ecosystem services. The 15% target, which aims to restore world-wide 15% of the degraded ecosystems, refers implicitly to space since it requires defining where degraded ecosystems are. At European scale, this policy request is made more explicitly. The EU Biodiversity Strategy to 2020 addresses the need to account for ecosystem services through biophysical mapping and valuation. Mapping of ecosystem services is one of the keystones of the strategy since Action 5 call the member states to map and assess ecosystems and their services on their national territory.

There are several ways to map ecosystem services at national scales [3]. Probably one of the most commonly used methods is value transfer which upscales local values for ecosystem services to larger areas making use of land cover and land use data which are readily available. Also popular is the use of national and supra-national statistics which help quantify essentially provisioning services such as products coming from agriculture, forestry or fishery. Sometimes, also statistics on recreation and tourism are available and can be used. More integrated but data-intensive approaches are based on the application of dynamic process-based models or on data models which estimate ecological production functions which are subsequently used to map potential or actual ecosystem services.

This report presents a suite of models that can be classified under the latter approach. ESTIMAP, which stands for Ecosystem Service Mapping Tool, is a GIS model based approach to quantify and model ecosystem services. It shows many similarities with the InVEST approach, be it that ESTIMAP is meant to run at continental scale. The main objective of the model is to support EU policies with information on ecosystem services. The mainstreaming of biodiversity and ecosystem services into EU policy and decision making is indeed dependent on the capacity to assess how changes in policy will impact biodiversity and the supply of ecosystem services. Scenario assessments are realized by coupling ESTIMAP to a dynamic land use model (LUMP, Land Use Modeling Platform).

ESTIMAP consists of a set of separate components, each of which can be run separately.

The models have been all framed in the ecosystem services cascade model [4] which connects ecosystem structure and functioning to human well-being through the flow of ecosystem services. At present, three modules are operational and described in further detail in this report: pollination, recreation and coastal protection. More modules are in development and will be added in the near future.

The objective of this report is to provide detailed technical background documentation of each of the ecosystem service modules of ESTIMAP.

## POLLINATION

Pollination by wild insect is an important ecosystem service with high natural and economic value. The productivity of many agricultural crops, approximately the 75% of the global crops that are used as human food, benefits from the presence of pollinating insects and the ecosystems that support them [5].

Several attempts have estimated the global economic value of pollination [6-8] and, although these estimates are still uncertain since the dependency of crops on insect pollination is not completely understood, these studies make clear that ecosystem services such as crop pollination are fundamental for human well-being.

In Europe, crop production is argued to be highly dependent on insect pollination with about 84% of all crops that have been studied depending on or benefiting from it [9]. The assumed dependence of European crops on pollination and the high monetary value associated with it triggered a demand to delineate places where semi-natural and natural ecosystems have the potential to provide pollination services in Europe so that the habitats characterizing them can be conserved or restored [10,11].

There is indeed an explicit policy request for better spatial data of ecosystem services in general and pollination services in particular. Action 5 of the EU Biodiversity strategy [12,13] calls the EU Member States to map and assess the state of ecosystems and their services in their national territory by 2014, assess the economic value of such services, and promote the integration of these values into accounting and reporting systems at EU and national level by 2020. The purpose of this effort is to provide the knowledge base on which decisions that affect land based resources can be made, especially by the EU's agriculture and regional policies.

## THE MODEL

Different habitats, but in particular forest edges, grasslands rich in flowers and riparian areas, offer suitable sites for wild pollinator insects such as solitary or honey bees, bumblebees or butterflies [14-16]. As soon as these insects start foraging, ecosystems that host their populations have the potential to increase the yield of adjacent crops that are dependent on insect-mediated pollination. While cereals do not profit from pollination, important fruit, vegetable, nut, spice, and oil crops do [5]. The demand for the pollination service is thus generated by the decision of the farmer to plant crops which depend on or profit from pollination [8]. At this point, wild pollinators deliver economic value which can be measured by assessing the contribution of pollination to total crop yield or by estimating the costs that are saved from replacing wild pollination with a managed form [17-20].

The applied methodology is derived from InVEST<sup>1</sup> which was developed for mapping ecosystem services at local scale. [21] but adapted to fit a continental-scale mapping approach at four essential points [22]:

- (1) different input data were used to model composite indicators for floral availability and nesting suitability,
- (2) a specific land parcel system based on the CAPRI (Common Agricultural Policy Regionalised Impact) [23] was used to estimate the contribution of crops to floral availability and nesting suitability and to estimate the relative benefits derived from pollination,
- (3) an extra module calculated the activity of bee pollinators

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<sup>1</sup> Integrated Valuation of Environmental Services and Tradeoffs (<http://www.naturalcapitalproject.org/InVEST.html>)



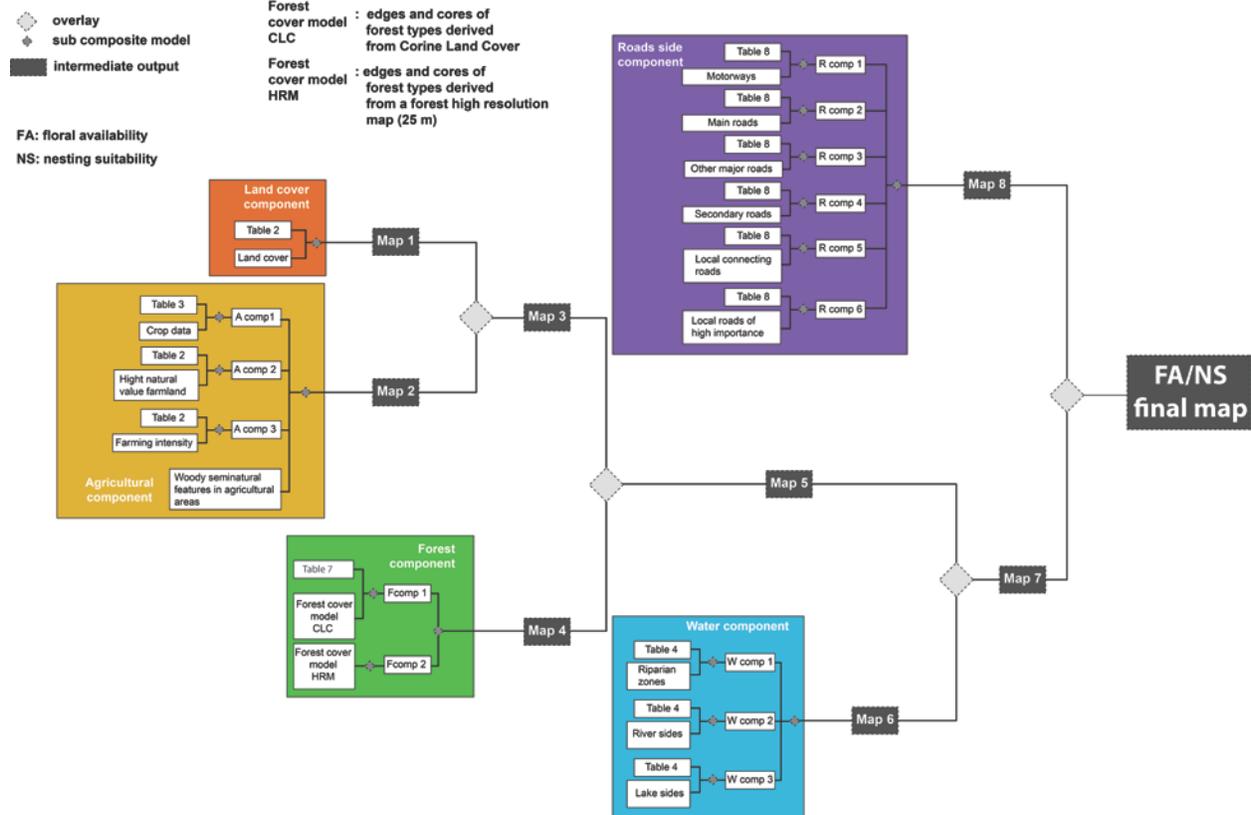
Table 1: Input data for the preprocessing composite models.

Component	Data description	Resolution
Land cover	Corine Land Cover 2000 (CLC2000) raster data - version 13 (02/2010) Source: EEA, 2010 Map of the European environmental landscape based on interpretation of satellite images with land cover types in 44 standard classes.	100 m
Agricultural land use	Crop yield data The CAPRI model results in crop yield statistics for homogeneous clusters of 1 km <sup>2</sup> pixels (HSMU), identified on the basis of the Farm Structure Survey regions (NUTS 2 or 3, depending on the Member State, EUROSTAT 2003), land cover (CLC2000), soil mapping units (European Soil Database V2.0, European Commission, 2004) and slope. Source: ( <a href="http://www.capri-model.org">www.capri-model.org</a> ) [23]	1000 m
	Olive farming data [25]	100 m
	High Nature Value Farmland (HNV) data. HNV is defined as areas in Europe where agriculture is a major (usually the dominant) land use and where that agriculture supports, or is associated with, either a high species and habitat diversity or the presence of species of European conservation concern, or both. Source: JRC [26]	100 m
	Presence of semi-natural vegetation at European scale. Source JRC, unpublished	100 m
Road network	TeleAtlas® MultiNet™ dataset (version 2007.10)	
Water	Riparian zones [27]	25 m
	CCM2 data (river network and small lakes) Source: JRC/EEA	
	CLC2000 data (main lakes) Source: EEA	
Forest cover	CLC2000 data Source: EEA	100 m
	Pan-European Forest/Non-Forest Map 2006, Source: JRC [28]	25 m
Activity index	AGRI4CAST interpolated grid [29]	25 km

Assigning weights to the various spatial attributes was based on literature and involved the opinion of experts following discussions in a workshop. The result was a set of scores per land cover or land use type on a scale between 0 and 1. A score of 0.5 would indicate that 50% of the land cover pixel provides suitable nesting sites and available floral resources [21].

Figure 2 presents a flowchart showing how both composite indicators were derived using several spatial datasets, while several tables of the Supplement to this article provide the scores between 0 and 1 assigned to different land cover and land use types with respect to nesting suitability and floral availability.

Figure 2: Flow chart presenting the data flow used to derive a final map of nesting suitability and floral availability (FA/NS final) (Models A and D in Figure 1).



The base map for the assessment of nesting suitability and floral availability was the Corine Land Cover data for the year 2000 (CLC 2000) (Table 1). The CLC 2000 data were subsequently combined with other datasets in order to improve the initial weights using more accurate spatial data on agricultural land use, forest cover, riparian areas and roadsides (Figure 2, Table 1). These land cover types are assumed to be important suppliers of habitats for wild bee species [14-16,20].

The model to obtain final scores for nesting suitability and floral availability has a cascade structure shown in Figure 2. Starting from a set of initial scores based only land cover (Map 1 in Figure 2), the model was updated at each step with new information using logical expressions and GIS operations to determine values in areas where spatial datasets overlap or where spatial data more accurate than the basic land cover map can be used. Map 2 (Figure 2) assessed nesting suitability and floral availability in agricultural land and updated Map 1 to Map 3. Next, this latter map was overlaid with a forest specific assessment (Map 4) to result in Map 5. In a following step, spatial data on riparian areas (Map 6) were added to construct Map 7. Subsequently, the data on road sides were considered (Map 8). The final result was a map of potential nesting suitability and floral availability (map FA/NS final map).

## LAND COVER COMPONENT

The land cover dataset plays a crucial role. Table 2 presents an example of land cover ranking table where each land cover type has a score from 0 to 1, according to its potential to provide floral and nesting resources. HNV\_F+, HNV\_N+ represent additional scores for FA and NS respectively, on High Nature Value (HNV) farmland.

Table 2: Floral availability (FA) and nesting suitability (NS) scores for the Corine Land Cover (CLC) types.

CLC code	Description	FA	HNV_F+	NS	HNV_N+	
111	Continuous urban fabric	0.05	0	0.1	0	
112	Discontinuous urban fabric	0.3	0	0.3	0	
121	Industrial or commercial units	0.05	0	0.1	0	
122	Road and rail networks and associated land	0.25	0	0.3	0	
123	Port areas	0	0	0.3	0	
124	Airports	0.1	0	0.3	0	
131	Mineral extraction sites	0.05	0	0.3	0	
132	Dump sites	0	0	0.05	0	
133	Construction sites	0	0	0.1	0	
141	Green urban areas	0.25	0	0.3	0	
142	Sport and leisure facilities	0.05	0	0.3	0	
211	Non-irrigated arable land*	0.2	0	0.2	0	
212	Permanently irrigated land*	0.05	0	0.2	0	
213	Rice fields	0.05	0	0.2	0	
221	Vineyards	0.6	0.2	0.4	0.1	
222	Fruit trees and berry plantations	0.9	0	0.4	0.1	
223	Olive groves**	intensive	0.2	0.2	0.4	0.1
		extensive	0.6	0.2	0.6	0.1
231	Pastures	0.2	0.2	0.3	0.2	
241	Annual crops associated with permanent crops	0.5	0.2	0.4	0.1	
242	Complex cultivation patterns	0.4	0.2	0.4	0.1	
243	Land principally occupied by agriculture, with significant areas of natural vegetation	0.75	0.05	0.7	0.1	
244	Agro-forestry areas***	0.5	0.4	1	0	
311	Broad-leaved forest***	0.9	0	0.8	0	
312	Coniferous forest***	0.3	0	0.8	0	
313	Mixed forest***	0.6	0	0.8	0	
321	Natural grasslands	1	0	0.8	0	
322	Moors and heathland	1	0	0.9	0	
323	Sclerophyllous vegetation	0.75	0	0.9	0	
324	Transitional woodland-shrub	0.85	0	1	0	
331	Beaches, dunes, sands	0.1	0	0.3	0	
332	Bare rocks	0	0	0	0	
333	Sparsely vegetated areas	0.35	0	0.7	0	
334	Burnt areas	0.2	0	0.3	0	
335	Glaciers and perpetual snow	0	0	0	0	
411	Inland marshes	0.75	0	0.3	0	
412	Peat bogs	0.5	0	0.3	0	
421	Salt marshes	0.55	0	0.3	0	
422	Salines	0	0	0	0	
423	Intertidal flats	0	0	0	0	

511	Water courses	0	0	0	0
512	Water bodies	0	0	0	0
521	Coastal lagoons	0	0	0.2	0
522	Estuaries	0	0	0	0

\* The values for non-irrigated arable land and for permanently irrigated land of Table 2 are replaced in the model with values based on Table 3 using additional spatial data. Readers who wish to assess floral availability and nesting suitability of these land types using Corine Land Cover data only may use the values suggested in Table 2.

\*\* The land cover type olive groves was scored using additional spatial information. Readers who wish to assess floral availability and nesting suitability of olive groves using Corine Land Cover data only may use an average value.

\*\*\* The values for agro-forestry areas, broad-leaved forest, coniferous forest and mixed forest of Table 2 are replaced in the model with values based on Table 7 using additional spatial data. Readers who wish to assess floral availability and nesting suitability of forests using Corine Land Cover data only may use the values suggested in Table 2.

#### Box 1: data processing for the land use component

1. The land use component makes a spatial join between the Corine Land Cover data and Table 2
2. updates the scores of floral availability (FA) and nesting suitability (NS) with additional spatial information of high nature value farmland (HNVF):
3. Reclassify the CLC data 2000 with the FA and NS values reported in Table 2;
4. Overlay with the olive crop data and adjust values for FA and NS;
5. Intersect with the HNMF data and increase the scores according to Table S1 using raster sum;
6. Set the scores on land cover types with code 211, 212, 244, 311, 312 and 313 to 0 (for replacing with scores based on the agricultural and forest model components).

## CROPLAND

Cropland is a dominant land cover in Europe but the CLC 2000 data does not report agricultural land use in terms of crop productivity or management practices. Therefore, additional data were used to determine nesting suitability and floral availability on arable land.

We worked on cropland at three levels: crop types, management practice and cropland heterogeneity.

### Box 2: Steps for the agricultural component

1. The agricultural component replaces scores for FA and NS on the CLC land cover types with codes 211 and 212 using data from the CAPRI model and using a layer on semi-natural vegetation in agricultural areas (SNV):
2. Set agricultural scores, according with crop shares:
  - a. Extract arable parcels from Corine Land cover (211-212) that intersect with the Homogenous Soil Mapping Units (HSMU) from the CAPRI model;
  - b. Calculate an average score weighted by the crop share according to CAPRI data;
3. Increase the value of agricultural parcels if they overlap with HNV farmland or SNV using the raster sum function.

## CROP YIELD DATA

Not all the crop types need insect pollination or provide forage to sustain insect pollinators and /or are preferred sites for nesting [16,30]. Spatially explicit data on crop types based on the CAPRI model [23] were used to assign specific scores for nesting suitability and floral availability.

### Box 3: procedure for the crop types assessment

Extract arable parcels from CLC (classes 211-212) that intersect the HSMU (spatial units of CAPRI, [www.capri-model.org](http://www.capri-model.org))

compute a weighted average:

$$\text{Score}_{HSMU} = \frac{\sum_{i=1}^n (w_i * score_i)}{\sum_{i=1}^n (w_i)}$$

Where:

$\text{Score}_{HSMU}$  = weighted mean of scores for FA and NS

$W_i$  = the crop share (%) for each HSMU

Score<sub>i</sub> = the crop<sub>i</sub> score

Table 3: Floral availability (FA) and nesting suitability (NS) scores for crops available in the CAPRI model. Dependency of crops on insect pollination (%) \*.

Group	Crop type	CAPRI code	FA	NS	Dependency (%)
Cereals	Soft wheat	SWHE	0.05	0.1	0
	Durum wheat	DWHE	0.05	0.1	0
	Rye and meslin	RYEM	0.05	0.1	0
	Barley	BARL	0.05	0.1	0
	Oats	OATS	0.05	0.1	0
	Paddy rice	PARI	0	0	0
	Maize	MAIZ	0	0.1	0
	Other cereals	OCER	0.05	0.1	0
Oilseeds	Rapeseed	RAPE	0.9	0.1	25
	Sunflower	SUNF	0.9	0.1	25
	Soya	SOYA	0.5	0.1	25
	Olives for oil**	OLIV	0.6	0.6	0
	Other oilseeds	OOIL	0.5	0.1	17.5
Other annual crops	Pulses	PULS	0.7	0.1	5
	Potatoes	POTA	0.7	0.1	0
	Sugar beet	SUGB	0.25	0.1	0
	Flax and hemp	TEXT	0	0	5
	Tobacco	TOBA	0	0	0
	Other industrial crops	OIND	0.5	0.1	0
Vegetables Fruits Other perennials	Tomatoes	TOMA	0.7	0.4	5
	Other vegetables	OVEG	0.75	0.4	0
	Apples, pear & peaches**	APPL	0.9	0.4	65
	Citrus fruits**	CITR	0.9	0.4	5
	Other fruits**	OFRU	0.9	0.4	40
	Table grapes**	TAGR	0.9	0.4	0
	Table olives	TABO	0.5	0.1	0
	Table wine**	TWIN	0.9	0.4	0
	Nurseries	NURS	0	0	0
	Flowers	FLOW	0.9	0.05	0
	Other marketable crops	OCRO	0.5	0.4	0
Fodder production	Fodder maize	MAIF	0	0.1	0
	Fodder root crops	ROOF	0.75	0.1	0
	Other fodder on arable land	OFAR	0.5	0.4	0

\* dependency data from [7].

\*\* in correspondence with Table 2

## MANAGEMENT PRACTISES

The presence of extensive management practices, which is characterized by a small input of labour, fertilizer and capital relative to the land area being farmed, or the presence of organic farming increases the pollination success [31]. It enhances the benefit of crop pollination for yield quantity and quality [32] and determines a favorable condition for the insect activity [20,33]. Therefore, scores of habitat suitability and floral availability were increased in

agricultural areas under extensive farming [25] and areas under High Natural Value Farmland [26], see Table 2 and Box 1.

To determine areas under extensive farming, only data about olive cultures are available at European scale, but the same procedure could be used to add data layers to the model for other crop types as well.

Habitat heterogeneity and the presence of semi-natural habitats in agricultural landscape improve insect activity due to increased nesting sites and floral resources [33-35]. So as a last step we increased again the scores of nesting suitability and floral availability in agricultural areas based on the CLC2000 dataset that intersect a map of the semi natural habitats in Europe (unpublished dataset, source: Joint Research Centre) so as to value e.g. small patches of woodland in agricultural land.

## WATER COMPONENT

Riparian zones, lakes boundaries, levees, rivers and ditches in semi natural zones have a positive impact on insect activity. Table 4 shows scores for the data used for the water component assessment.

Table 4

Table 4: water component scores for floral and nesting

Data source		Scores	
		NS	FA
water	riparian zones	0.8	0.8
	river network	0.5	0.5
	lakes boundaries	0.7	0.7

## RIPARIAN ZONES INPUT DATA

As model of riparian zones at the European level we choose the riparian zonation model from [27]. The model evaluates a set of environments and assigns the belonging to the riparian zone class. The spatial resolution of 25 m represents an optimal trade-off between a computationally and cost efficient approach together with the availability of continental remote sensing based datasets.

Table 5 lists the land cover types covered by the riparian zonation model.

Table 5: CLC classes assessed in the riparian zonation model [27]

CLC CODE	Level 1	Level 2	Level 3	
311	Forest and semi natural areas	Forests	Broad-leaved forest	
312			Coniferous forest	
313			Mixed forest	
321		Scrub and/or herbaceous vegetation associations	Open spaces with little or no vegetation	Natural grasslands Moors and heathland
322				Sclerophyllous vegetation
323				Transitional woodland-shrub
324				Sands, Beaches, Dunes
331				
511	Water bodies	Inland waters	Water courses	

## RIVER NETWORK AND LAKE BOUNDARIES

We assumed a buffer of 25 m along rivers, lakes and wetlands in areas not considered by the European riparian zone model (Table 6).

Table 6: Corine land Cover classes selected to improve the riparian zonation model information for the pollination model

CLC classes	description			
211	Agricultural areas	Arable land	Non-irrigated arable land	
212			Permanently irrigated land	
213			Rice fields	
221		Permanent crops	Vineyards	
222			Fruit trees and berry plantations	
223			Olive groves	
231		Pastures	Pastures	
241		Heterogeneous agricultural areas	Annual crops associated with permanent crops	
242			Complex cultivation patterns	
243			Land principally occupied by agriculture, with significant areas of natural vegetation	
244			Agro-forestry areas	
332		Forest and semi natural areas	Open spaces with little or no vegetation	Bare rocks
333				Sparsely vegetated areas
334	Burnt areas			
335	Glaciers and perpetual snow			
411	Wetlands	Inland wetlands	Inland marshes	
412			Peat bogs	
421		Maritime wetlands	Salt marshes	
422			Salines	
423			Intertidal flats	

### Box 4: GIS steps for the water component

The water component scores land cover parcels if they overlap with a riparian area. It extends the riparian zone model that covers the land class types (Table S4) with land cover types in Table S5:

1. Extract all lakes and river boundaries inside the natural, semi natural and agricultural CLC land class types according to Table S5 (excluding artificial land types);
2. Compute a Euclidean distance at 25 m resolution;
3. Score lakes (W1) and rivers boundaries (W2) according to Table S6;
4. Do the following overlay and map algebra operations:
  - a. Sum the riparian zones (based on the riparian zone model) and the lake sides (W1);
  - b. Sum W1 and the river sides (W2);
  - c. Cut off at a maximum score of 0.8;
5. Aggregate the result to 100 m (using the option AVERAGE).

## FOREST COMPONENT

Forest and woodland provide nesting habitats and floral resources for pollinators. In particular, forest edges adjacent to more open land have a positive impact and small patches are particularly important for insect activity [14,15].

Forests were mapped using the CLC 2000 data in combination with a high resolution forest map [28]. We computed Euclidean distances from the edges to the core of forested patches. For the CLC 2006 data we assigned separate scores to the edge and core areas of different forest types, namely broad-leaved, coniferous and mixed forests (Table 7). The edge area score is constant. The core area score decreases from its edge towards its center, according to a distance decay function based on the average foraging range of pollinators (Table 7). We aggregated the high resolution forest map, which is available at 25 m, to 100 m and calculated the percentage of pixels covered by forests. We then combined the two datasets.

Table 7: scores for the forested patches

Data source	Forest category	Weight rates		
			NS	FA
CLC2000 forest data	Broad-leaved forest	50 m edge	0.9	1
		core forest	0.7	0.9
	Coniferous forest	50 m edge	0.9	0.4
		core forest	0.7	0.3
	Mixed forest	50 m edge	0.9	0.7
		core forest	0.7	0.6

### Box 5: GIS steps for the forest component

1. The forest component replaces scores for FA and NS on the CLC land cover types with codes 244, 311, 312 and 313 using a High Resolution Forest Map (HRFM):
2. Select the CLC forest data types with codes 244, 311, 312 and 313:
  - a. Compute an internal Euclidean distance;
  - b. Mask out the internal edges for CLC forest types;
  - c. Score the edges and cores according to Table 7;
  - d. Weigh the cores using the Euclidean distance layer with values decreasing according to the same function that we are using for the foraging distance ( $\text{Exp}(-\text{distance} / \alpha)$ ) while keeping the edge value unchanged, where distance is the Euclidean distance and alpha is the flight distance;
3. Forest cover Model High Resolution Map (HRM):
  - a. Extract data inside natural, semi natural and agricultural landscapes that do not overlap with Corine Land Cover forest classes;
  - b. Aggregate the result to 100 m using the proportion covered as spatial surrogate;
4. Sum the layers obtained under steps 1 and 2.

## THE ROAD COMPONENT

Marginal habitats, roadsides and field paths in semi natural zones have a positive impact on nesting suitability and floral availability, and may provide suitable bee habitat especially in highly modified landscapes [15,36,37]. In Europe, road sides, although influenced by emissions from traffic, road maintenance or agriculture, are often mowed which is assumed to explain higher plant diversity of road sites relative to other field border sites [37]. Moreover, in several EU countries, particular regulation applies with respect to the dates and frequency of mowing and pesticide use in order to maintain the natural character of road sides. Arguably, we assumed higher nesting suitability and floral availability on road sites. We used TeleAtlas as a model for the road network in Europe. We extracted only roads inside natural, semi natural and agricultural landscapes (excluding all the artificial zones) and we assigned specific scores for NS and FA to a 25 m buffer computed for six road types. The data were then aggregated at 100 m resolution (Box 6). Scores change according to the importance of the road (Table 8).

**Table 8: Roads weights for Nesting suitability and Floral Availability**

category	data	NS	FA
roads	Motorways	0.8	0.8
	Main roads	0.8	0.8
	Other major roads	0.5	0.5
	Secondary roads	0.3	0.3
	Local connecting roads	0.2	0.2
	Local roads of high importance	0.1	0.1

### Box 6: GIS process for roads

1. Extract roads available in the TeleAtlas data inside: all natural, semi natural and agricultural CLC land cover types (excluding artificial land cover types);
2. Take the Euclidean distance at 25 m resolution;
3. Score each road type according to table S7;
4. Now overlay:
  - a. Motorways with Main roads (R1);
  - b. R1 with other major roads (R2);
  - c. R2 with secondary roads (R3);
  - d. R3 with local connecting roads (R4);
  - e. R4 with local roads of high importance (R5);
  - f. Cut off at a maximum score of 0.8;
5. Aggregate the result to 100 m (using the option AVERAGE).

## POLLINATORS ACTIVITY INDEX

Habitats may be suitable to provide nesting sites or forage to pollinators but if the ambient temperature is below a certain threshold, the potential to pollinate approaches zero, as insects will not leave the nest in order to forage. Corbet et al. [24] developed a model to express pollination activities based on the proportion of active bees and bumblebees. This proportion was measured by counting in the field the numbers of individuals that leave the nest for foraging, relative to the peak number of nest leavers that was observed during daily counting. We adapted the relative pollination abundance to account for climatic variation in temperature and solar irradiance by calculating an annual averaged activity coefficient between 0 and 100% representing the pollination activity of solitary bees (Model F in Figure 1).

The activity coefficient  $A$  for solitary bees was calculated as:

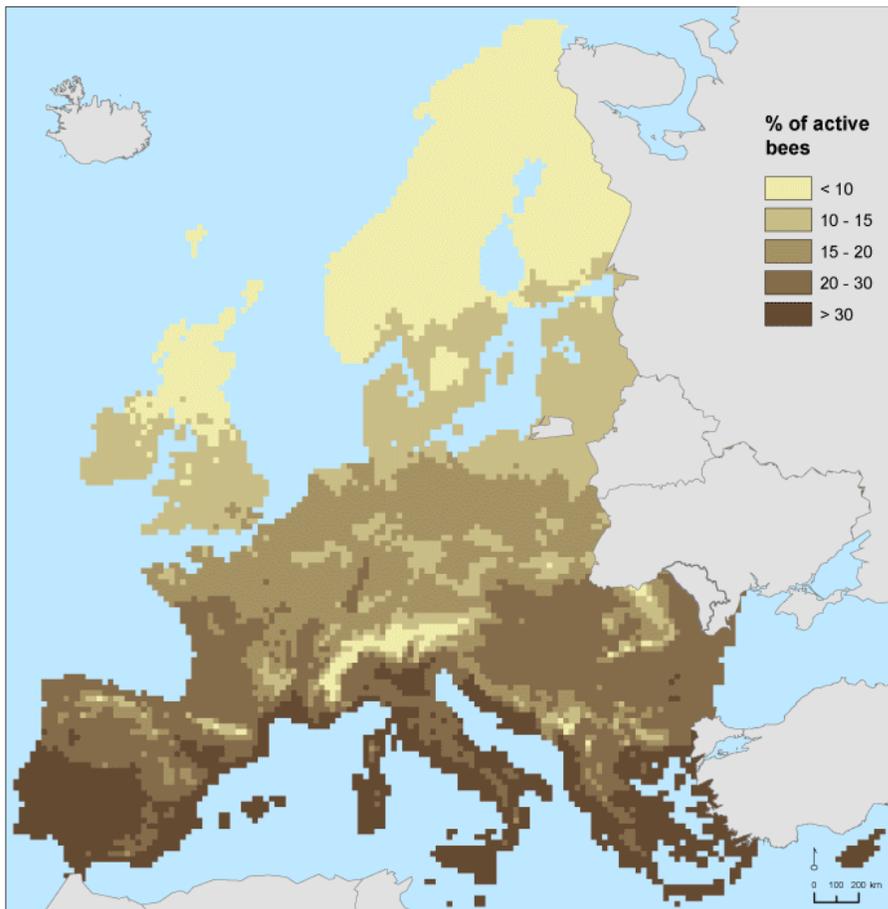
$$A (\%) = - 39.3 + 4.01 \times T_{\text{blackglobe}} \quad (1)$$

Where  $T_{\text{blackglobe}}$  stands for the temperature in a black, spherical model, which simulates the body temperature of an insect. This temperature can be calculated as a function of ambient temperature  $T$  ( $^{\circ}\text{C}$ ) and solar irradiance  $R$  ( $\text{W m}^{-2}$ )[24]:

$$T_{\text{blackglobe}} = - 0.62 + 1.027 \times T + 0.006 \times R \quad (2)$$

Activity coefficients that were  $< 0\%$  or  $> 100\%$  were adjusted to  $0\%$  and  $100\%$ , respectively. This assessment was performed at  $25 \text{ km}$  resolution using the JRC MARS climate database [29] which contains meteorological data for Europe. The database reports solar irradiance in units  $\text{kJ m}^{-2} \text{ day}^{-1}$ . To convert to  $\text{W m}^{-2}$ , we calculated the hours of daylight as a trigonometric function of latitude.

Figure 3: solitary bees activity in Europe (%)



### THE FORAGING RANGE

Land parcels which are suitable to support nesting are connected to crops that need to be pollinated by the flight distance of pollinating insects (Model B in Figure 1). Wild bees can pollinate crops insofar as the distance between their nests and the crops that provide foraging resources does not exceed the foraging range. Furthermore, foraging is assumed to decline exponentially with distance [38-40]. Average foraging distances are species specific and vary between a few meters to several kilometers. Based on data of expected foraging distance of different bee species [21], we selected a distance of 200 m to represent short flight distance species, using solitary bees as a model [38]. This distance was used to simulate the potential foraging sites (Model C in Figure 1) and the relative pollination potential (Model H in Figure 1) using the same equations as the InVEST model [21].

### Box 7: the distance matrix parameters

The distance matrix is used as kernel file in a moving window (Focal statistic, option SUM).

The matrix depends on:

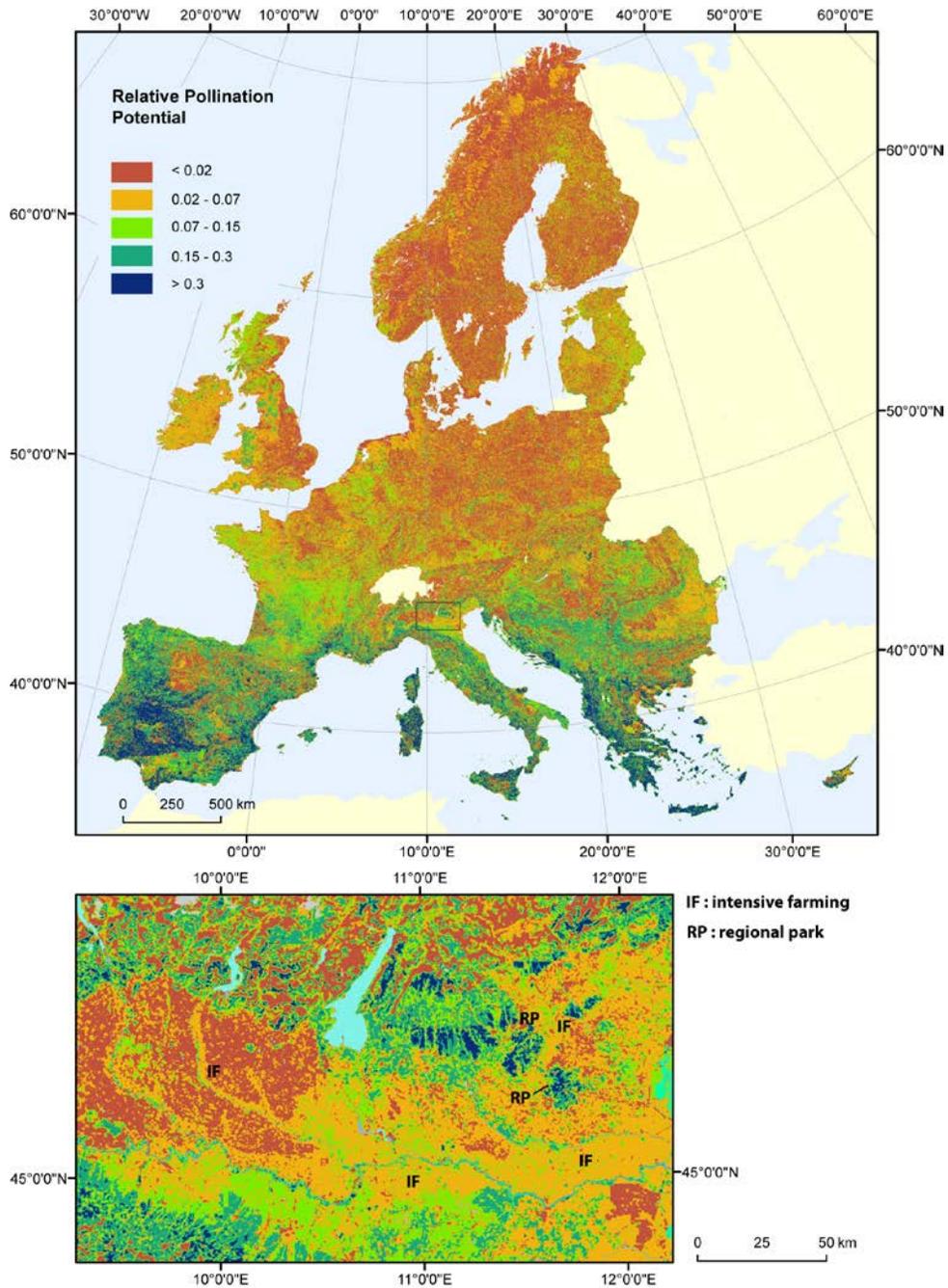
1. Data Resolution
2. Neighborhood
3. Average distance (alpha)

Distance function  $Y = \exp(-\text{distance} / \text{alpha})$

# THE RELATIVE POLLINATION POTENTIAL

An EU-wide map of relative pollination potential (RPP) is presented in Figure 4.

Figure 4: relative pollination potential in Europe.



This map depicts the potential of land cover cells to provide crop pollination by wild bee species on a relative scale between 0 and 1. It is based on the input information that is presented in Figure 1 including the relative suitability of land cover cells to host pollinator populations, the availability to provide floral resources and the average activity of bees as a result of climatic variation. The general pattern of the RPP is an increase of pollination potential along a north-south gradient in southern direction following the temperature gradient in Europe, corresponding to the modeled activity rate of bees.

Given temperature, RPP is low in areas where the dominant land use is arable land used for the production of cereals. This is the case for the east of the United Kingdom, areas in France surrounding the capital, areas in central Spain, the Po plain in Italy, areas in northern Germany, Poland and Slovakia and the along the borders of the Danube in Bulgaria and Romania. These areas are assumed to have a relatively low nesting suitability and to offer limited resources for foraging due to lower abundance of plants with flowers carrying nectar.

The inset in Figure 3 demonstrates the modeled effect of semi-natural and natural areas on pollination potential. The inset covers a large part of the Po Valley in North Italy with Lake Garda as clear land mark in the middle of the map. Areas in orange correspond to intensively used agricultural land where RPP is low, indicated by IF (intensive farming). Different elements but in particular the riparian area along river Po (flowing from the west to the east) and regional parks (RP on the map) increase the pollination potential of the landscape.

## LOCAL POLLINATION DEFICIT

The map of relative pollination potential was used in two regions in Europe (Veneto, Italy and Midi-Pyrénées, France) to visualize better where areas exist with a pollination deficit or a gap in the supply of the service. Pollination deficits were mapped as the difference between 1 and the regional relative pollination potential. This latter quantity is the relative pollination potential which is normalized between 0 and 1.

As an example we demonstrated for two regions how the map of relative pollination potential can be used to assess at landscape scale gaps in the potential supply of pollination services. Both regions, the Midi-Pyrénées in the south of France and Veneto in the northeast of Italy, have significant agricultural activities where 27% and 41% of the land, respectively, is used for crop production. Figure 5 maps the pollination deficit for the two regions while Figure 6 maps the share of crops which is dependent on insect pollination.

In Veneto 80% of land is characterized by a medium to high or high pollination deficit, with 50% of this land concentrated in agricultural areas with intensive farming (1A, Figure 5), where soybean is one of the most dominant crop types dependent on insect pollination (1A, Figure 6). In contrast, a medium to low gap is detected in the province of Verona (2A, Figure 5), in the area of the Colli Euganei Regional park (3A, Figure 5), and in the Treviso province (4A, Figure 5). Agricultural activities in the area around Verona are dominated by cultivation of fruits, olives and soya (2A, Figure 6).

In the Midi-Pyrénées almost 40 % of the land has a low pollination deficit; 42% has a medium to high gap while almost 20% has a high gap. The latter areas are, similarly to the Veneto region, characterized by agricultural areas with an intensive farming practice where 15% of crops are dependent on insect pollination. In particular, these are soya and pulse in the department of Gers (1B, Figure 6), rape and sunflowers in the department of Haute-Garonne (2B, Figure 6), and sunflowers in the department of Tarn (3B, Figure 6).

Figure 5: Pollination deficit for two regions in Europe (A. Veneto northeast Italy; B. Midi-Pyrénées, southern France). Color codes on the map correspond with areas of low, medium, medium to high and high gaps in the potential supply of pollination. Pie charts present the relative share of each gap for the entire region. See text for explanation of the codes on the maps.

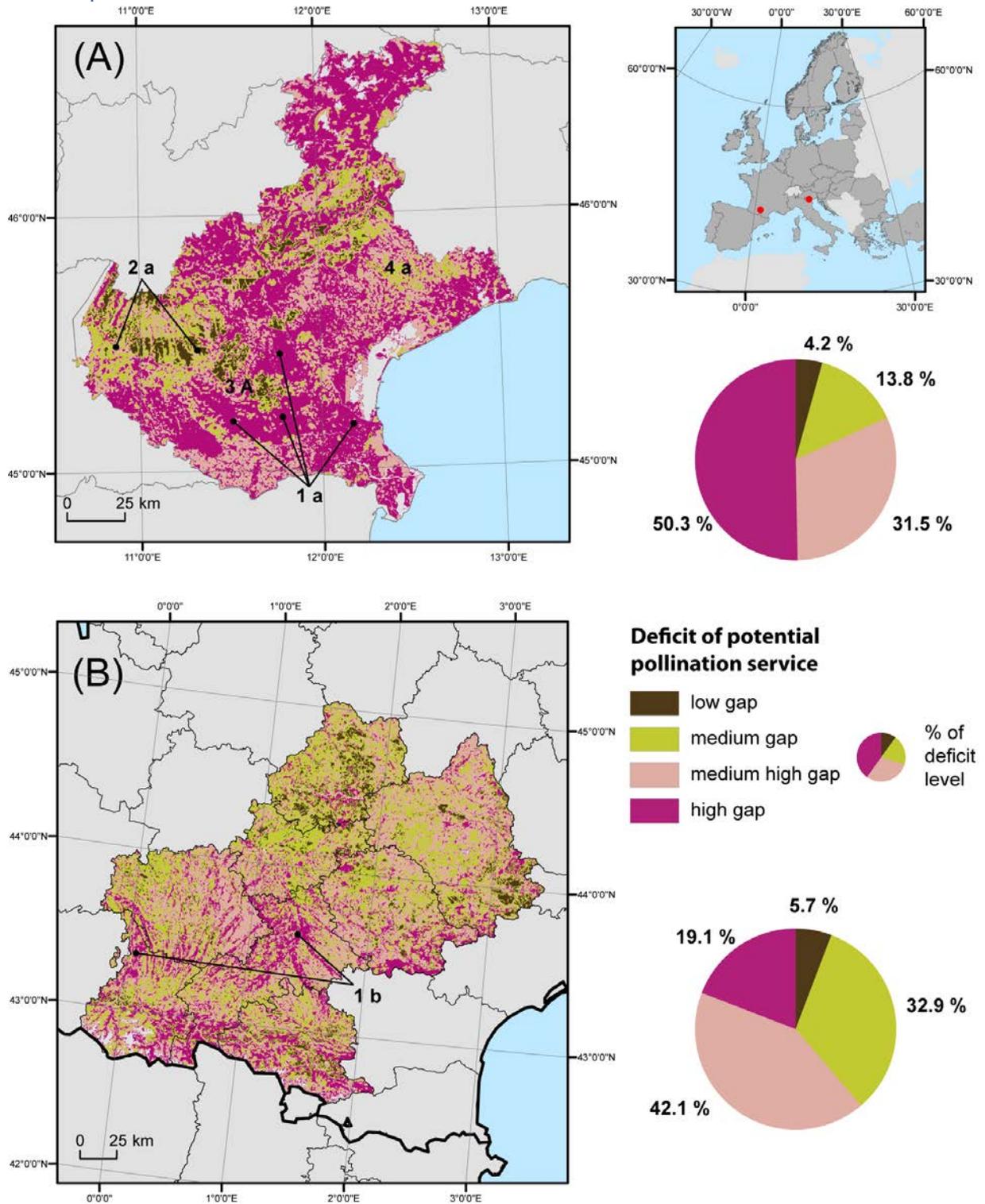
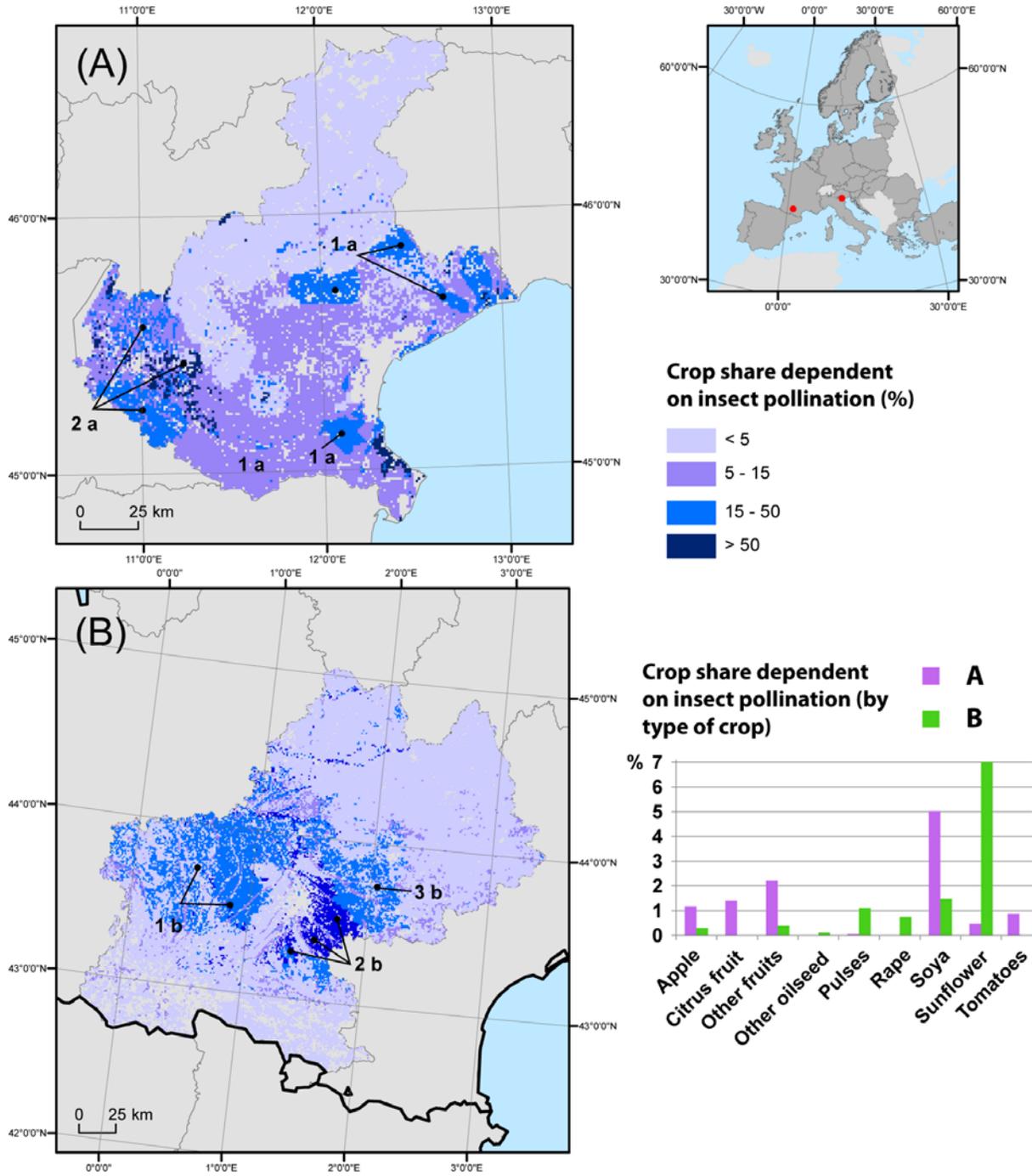


Figure 6: Crop share (%) dependent on insect pollination (A. Veneto northeast Italy; B. Midi-Pyrénées, southern France). Source: [23].



## RECREATION

Cultural ecosystem services are recognized as “non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experience” [41]. Examples of cultural ecosystem services are: appreciation of natural scenery; opportunities for tourism and recreational activities; inspiration for culture, art and design; sense of place and belonging; spiritual and religious inspiration; education and science [42].

We propose a framework for a spatially explicit assessment of local nature-based recreation. Outdoor recreation and tourism represent an important service that interest millions of people and contributes to connect them to nature. While tourism is an occasional activity, local outdoor recreation affects the daily life of people.

Public, local, nature-based outdoor recreational activities include a wide variety of practices ranging from walking, jogging or running in the closest green urban area or at the river/lake/sea shore, riding a bike in nature after work, picnicking, observing flora and fauna, organizing a daily trip to enjoy the surrounding beauties of the landscape, among a myriad of other possibilities. These activities have an important role on the human well-being and health, since they provide physical, aesthetic, cultural benefits and offer an opportunity to experience directly a relationship with nature. In addition, fruition of nature-based recreational activities may induce people’s support for ecosystem protection.

## THE MODEL

The model focuses on modeling recreational opportunities provided by nature at a local level and it is framed in the ecosystem services cascade [4].

It covers three main aspects:

- The potential opportunities, provided by the ecosystem for recreational activities, (RP Map, A, in Figure 7)
- The flow of service, which combines the potential provision map (RP) with proximity map (P) (ROS Map, B, in Figure 7).
  - The Proximity to population is considered to be one of the main drivers of fruition: people have to reach recreational sites and opportunities by transportations infrastructures
  - The Recreation Opportunity Spectrum (ROS), originally developed as a tool for inventorying, planning, and managing recreation opportunities [43], is adopted for a reclassification of the land cover according to the range of opportunities available and the proximity to the potential users.
- The assessment of potential benefits: which evaluate the percentage of potential trips for each ROS category (% PPB, B, in Figure 7).

Figure 7 shows the rationale of the model. In a first part, it assesses the potential capacity of a group of identified landscapes to provide opportunities for local outdoor recreation (D). It varies according to the presence of three key aspects: the degree of naturalness (A), the presence of natural areas (B) and the presence of water (C). In a second step it computes Euclidean distances from urban (E) areas and from roads (F). The two maps are then combined to derive a proximity map (H), which depends on specific proximity parameters (G). A final map of recreation opportunities (ROS) (D) is then computed by a cross tabulation between the RP (D), the Proximity Map (H) using a second set of parameters (I) with thresholds for the degree of recreation opportunities provided by nature and the degree of proximity and remoteness. Parameters (G and I) are derived from a literature review.

Table 9 lists input data used for the computation of the model at European scale.

Figure 7: rationale of the recreation model

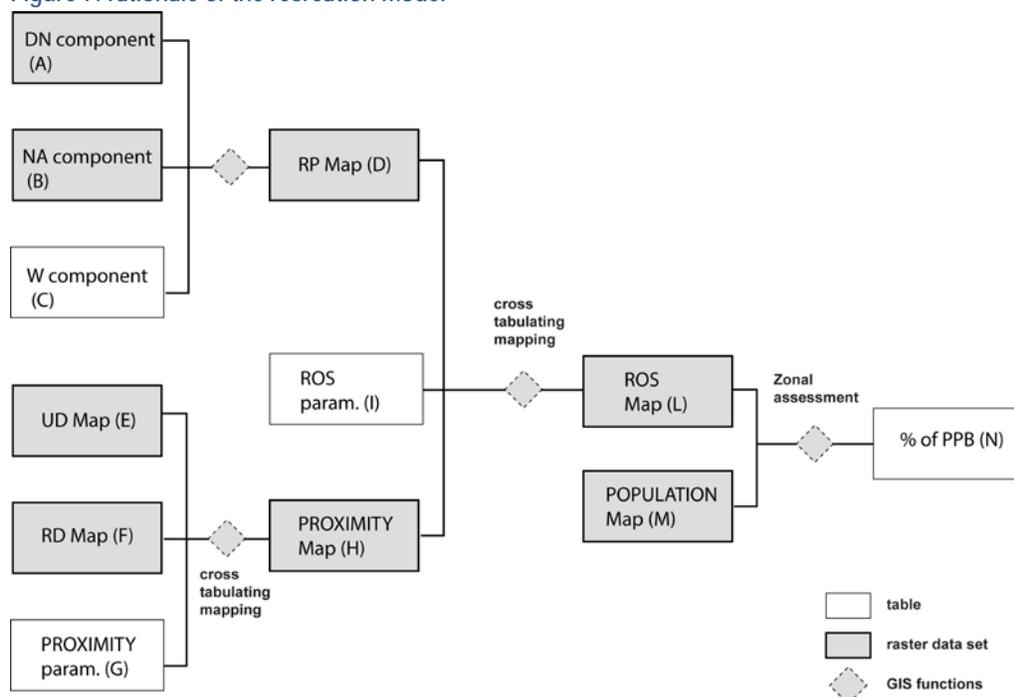


Table 9: input data for the recreation model

Data description	
Land cover	Corine Land Cover 2000 (CLC2000) raster data - version 13 (02/2010) Source: EEA, 2010
	Map of the European environmental landscape based on interpretation of satellite images with land cover types in 44 standard classes. Degree of naturalness: hemeroby index [44]
Natural areas	Natura 2000 database Source: EEA <a href="http://ec.europa.eu/environment/nature/natura2000/db_gis/index_en.htm">http://ec.europa.eu/environment/nature/natura2000/db_gis/index_en.htm</a>
	Common Database on Designated Areas (CDDA). (EEA), <a href="http://www.eea.europa.eu/data-and-maps/data/nationally-designated-areas-national-cdda-6">http://www.eea.europa.eu/data-and-maps/data/nationally-designated-areas-national-cdda-6</a> .
	UNESCO natural sites in Europe (JRC).
Water component	Bathing water quality (EEA)
	Coastal line (extracted from CLC 2000)
	Lakes (extracted from CLC 2000)
Proximity	Road network TeleAtlas® MultiNet™ dataset (version 2007.10)
	Urban areas (extracted from CLC 2000)
Benefits	Population density at 100 m resolution [45] <a href="http://www.eea.europa.eu/data-and-maps/data/population-density-disaggregated-with-corine-land-cover-2000-2">http://www.eea.europa.eu/data-and-maps/data/population-density-disaggregated-with-corine-land-cover-2000-2</a>

## THE RECREATION POTENTIAL

According to the findings from surveys and from literature, recreation potential is mapped through components that have a specific relation with people's behavior.

An overview of some common features of recreational preferences in Europe was drawn by analyzing three visitor surveys, namely the Finnish National outdoor recreation demand inventory (LVVI2) [46], the Danish national household survey and national on-site recreation survey [47] and the English Monitor of Engagement with the Natural Environment Survey (MENE)[48,49]. In addition, a number of other studies cited in literature was explored. The variables representing ecosystem functions and the effect of human infrastructure and accessibility on the recreation ecosystem service (cf. Fig.1) used in the model were selected based on the above-mentioned studies [50].

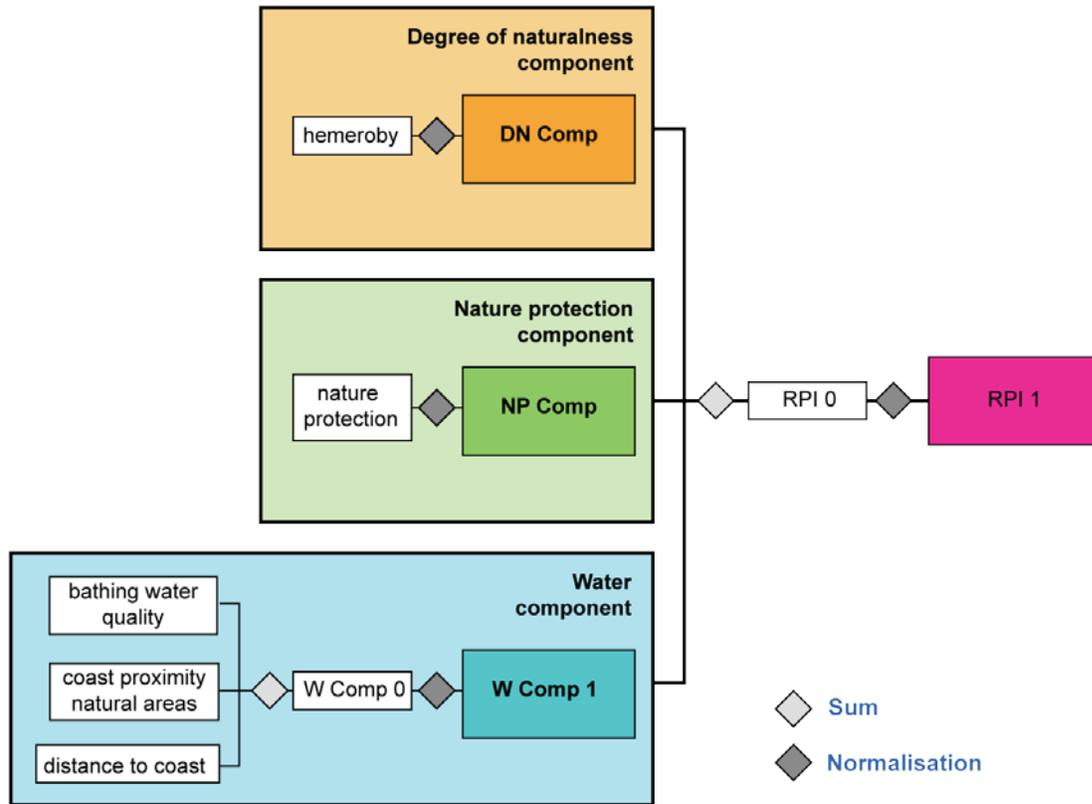
Though habits of people related to local recreation vary with culture, latitude, type of environment, age, social status, etc. the following commonalities arisen from surveys and literature review:

- distance travelled is relatively short: close-to-home visits take place within ca. 8 km from the starting point, which, in most cases, is the respondents' home;
- water exerts a specific attraction for recreational visits;
- people are keen to travel longer distances to reach more natural habitats;
- arable land is not recorded as being particularly attractive for recreation in nature, while grassland, especially if extensive, is listed among recreation sites;
- forests are generally considered attractive recreation sites;
- overall, sites that are more natural appear to be more attractive than areas of higher anthropic influence.

In the analysed studies there is not any particular information on the role that protected areas specifically plays in attracting people (no specific questions in the surveys). However, their role can be derived from the Finnish survey [46], where regions of outstanding natural value, like the Northern parts of Lapland, are the destination of a share of trips to state-owned land (comprising protected sites, wilderness areas, and large hiking areas) higher than all other more populated regions together [51].

The key points have been divided in three modules: the first relates to the degree of naturalness identified as a proxy for people preferences for more natural areas; the second concerns protected areas as public recreation areas; the third concerns water attractiveness, see Figure 8.

Figure 8: Flow chart presenting the data flow used to derive a final map for recreation potential.



## DEGREE OF NATURALNESS

The natural value is modeled through the "*Hemeroby*" index (or degree of naturalness), that measures the human influence on landscapes and flora; the European Hemeroby map [44] was obtained by combining a component derived from the land use map (1), a component which represents the management practices and one representing the type of forest. (3). The main steps are the following :

1. attributing to each CORINE land cover class its average degree of naturalness on the basis of literature [52-54]
2. reclassifying agricultural and forested areas according to the management practices, such as data on nitrogen input and livestock density provided by the CAPRI model ([www.capri-model.org](http://www.capri-model.org)) [23].
3. reclassifying the tree species database of the JRC (AFOLU), [55]

The hemeroby scale ranges from 1 (natural) to 7 (artificial). In order to be used in the composite model for recreation:

- Null data have been set as 0
- The index has been inverted and scaled from 0 to 1

## NATURAL AREAS COMPONENT

Public recreation areas were mapped using the Natura 2000 database, the Common Database on Designated Areas (CDDA) and a list of UNESCO natural sites in Europe (JRC). The Natura 2000 database contains sites designated under the Birds Directive (Special Protection Areas, SPAs) and the Habitats Directive (Sites of Community Importance, SCIs, and Special Areas of Conservation, SACs).

The CDDA holds information about protected sites and the national legislative instruments, which directly or indirectly create protected areas (European Environment Agency). Table 10 shows the CDDA classification (IUCNAT field) and the grouping used for the indicator.

**Table 10: Nationally designated areas classification and score for the recreational purposes.**

IUCNAT	case number	Category definition	grouping	score
Ia	3874	Strict Nature Reserve: protected area managed mainly for science	1	0
Ib	1283	Wilderness Area: protected area managed mainly for wilderness protection	2	1
II	317	National Park: protected area managed mainly for ecosystem protection and recreation	3	0.8
III	2790	Natural Monument: protected area managed mainly for conservation of specific natural features	2	1
IV	17111	Habitat/Species Management Area: protected area managed mainly for conservation through management intervention	3	0.8
V	10618	Protected Landscape/Seascape: protected area managed mainly for landscape/seascape conservation and recreation	3	0.8
VI	1009	Managed Resource Protected Area: protected area managed mainly for the sustainable use of natural ecosystems	3	0.8
N/A	17640	Not classified	3	0.8

The natural areas have been classified focusing on their importance for recreational purposes, see Table 10. The score varies between 1 (for protected area with the highest natural value) to 0.8 for sites managed for different purposes. Sites Very high in natural value, classified as “Strict Nature Reserve: not accessible for recreation purposes” have been excluded from the processing because access of people is forbidden

### Box 8: Natural areas processing

1. Overlay between CDAA and Natura 2000 conditions:
  - a. CDDA = 1 AND Nat2000 = 8 cod = 1
  - b. CDDA = 0 or CDDA = 2 or CDDA = 3 CDDA = 4 CDDA = 5 CDDA = 6 CDDA = 7 AND Nat2000 = 8 cod = 2
2. Union with UNESCO, Condition:
  - a. CDDA = 0 AND UNESCO = 9 cod=3

## WATER COMPONENT

The current exercise focuses on in land ecosystems. Nevertheless sea coastal areas and inland water bodies play an important role for recreational purposes [43,56,57]. There are many factors driving water attractiveness (i.e. coastal morphology, water quality, protected areas, presence of infrastructures such as harbors, piers and equipped beaches), three of which are considered in the present approach:

- The bathing water quality
- The distance from the coasts
- The coast in the proximity of inland protected natural areas

### BATHING WATER QUALITY

Data on bathing water quality are annually collected by the European Environment Agency, as measured under the EU Bathing Water Directive (76/160/EEC). The information is used to assign a value to a 1 km coastal buffer around the sampling point, in function of water quality for bathing purposes, assuming that it affects destination choices (Vesterinen et al., 2010). In the current application, points are selected where good or sufficient water quality status is achieved, see Table 11 for the scoring.

**Table 11: Bathing Water Quality classification and score for the recreational purposes.**

Original types		Quality descriptions	score
CG	Compliant with the guide values	Compliant with guide and mandatory values achieves good water quality status	3
CI	Compliant with the mandatory values	Compliant with mandatory values only achieves sufficient water quality status	2
B	Prohibited throughout the entire bathing season		0
NC	Not compliant with the mandatory values	Noncompliant with mandatory values equates to poor water quality status	0
NS	Not sampled		excluded
NF	Insufficiently sampled		excluded
Others or blank	Unknown.		excluded

---

## THE DISTANCE FROM THE COASTS

Data on outdoor recreation facilities are not available EU-wide, therefore it is assumed that water attractiveness decreases as the distance from the coast increases, being high in the proximity of water. Such distance in the present work is set at 2000 m. Coastlines of sea and lakes have been extracted from CLC2000 dataset, and an S-shaped impedance function has been used to calculate attractiveness (Kwan, 1998; Geurs and Ritsema, 2001). The following inverse logistic function (1) has been applied to all coastlines:

$$f(d) = \frac{1 + K}{K + e^{\alpha \cdot d}} \quad (1)$$

where:

$d$  is the distance from coast,  $\alpha$  and  $K$  are the size and shape parameters of the function respectively set at 3.50E-03 and 150 in a way that attractiveness is halved at mid-distance. Ad hoc surveys are needed for specific fine-tuning of the function.

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## THE COAST IN THE PROXIMITY OF INLAND PROTECTED NATURAL AREAS

Coastline included in inland protected areas has been identified as adding value to recreation provision, in this case the impedance factor is not applied and the weight of the 2 km buffer equals 1.

## THE RECREATION OPPORTUNITY SPECTRUM

People can benefit from the opportunities provided by nature for recreational activities if they are able to reach them. The Recreation Opportunity spectrum was chosen as a method to map different degrees of service available according to their proximity to the people.

Remoteness and proximity have been addressed in the second step of the analysis, in order to assess how the benefit (recreation) can be delivered to people. The proxy that has been identified couples information on both variables and has been mapped by classifying the EU into zones of proximity versus remoteness. From the ROS perspective this part takes into account remoteness and to some extent expected social experience. Distance from roads and residential areas have been used as inputs. The information on the road network is provided by the TeleAtlas database, and covers all paved roads in Europe. Gravel roads have been discarded to ease the processing. Residential areas are extracted from CORINE land cover classes "continuous urban fabric" and "discontinuous urban fabric", therefore, all urban patches larger than 25 ha are considered in the mapping. In the current exercise there was the necessity to adapt overseas experiences to the peculiarities of the European continent, especially considering that the EU does not contain large wilderness areas like other continents. Therefore, the concepts of remoteness and proximity have to be tuned to the experience of EU citizens. In order to do so, a panel of ten European experts of different nationalities was asked to fill out a table in which they had to

define thresholds for distances from roads and urban, and assign each combination a label among the following five: neighborhood, proximity, far, remote, very remote. Table 12 shows the cross tabulation parameters for the proximity index computation.

Table 12: proximity parameters (A in Figure 7).

		Distance from road (km)					
		< 1	1-5	5-10	> 10		
Distance from urban areas (km)	< 5	1	2	2	4	1	Neighborhood
	5-10	2	2	2	4	2	Proximity
	10-25	3	3	3	4	3	Far
	25-50	3	4	4	4	4	Remote
	> 50	4	4	4	5	5	Very Remote

The final ROS has been computed by a cross tabulation between the RPI and the zoning for the EU in terms of remoteness and accessibility. The potential for recreation has been classified in three classes of high-medium-low provision by defining thresholds derived from the analysis of data distribution of the RPI, and aggregating the information on remoteness and accessibility in three classes (Table 13). The RPI classes identify areas with low-medium-high recreation provision: low provision is characteristic of intensively managed areas (i.e. a great part of the EU arable land), medium provision is characteristic of permanent vegetation (i.e. pastures, permanent crops, managed forests), high provision is mostly typical of protected areas (with no habitat distinction) and forests characterized by a high degree of naturalness.

Table 13: parameters for the Recreational Opportunity spectrum (I)

			Recreation Potential				
			1	2	3		
			< 0.19	0.19-0.25	> 0.25		
Remoteness/ Accessibility	1	Neighborhood	1	4	7	1	Low provision - easily accessible
	2	Proximity	1	4	7	2	Low provision - accessible
	3	Far	2	5	8	3	Low provision - not easily accessible
	4	Remote	3	6	9	4	Medium provision - easily accessible
	5	Very Remote	3	6	9	5	Medium provision - accessible
						6	Medium provision - not easily accessible
						7	High provision - easily accessible
						8	High provision - accessible
						9	High provision - not easily accessible

RESULTS

Figure 9: recreation potential indexes for Europe

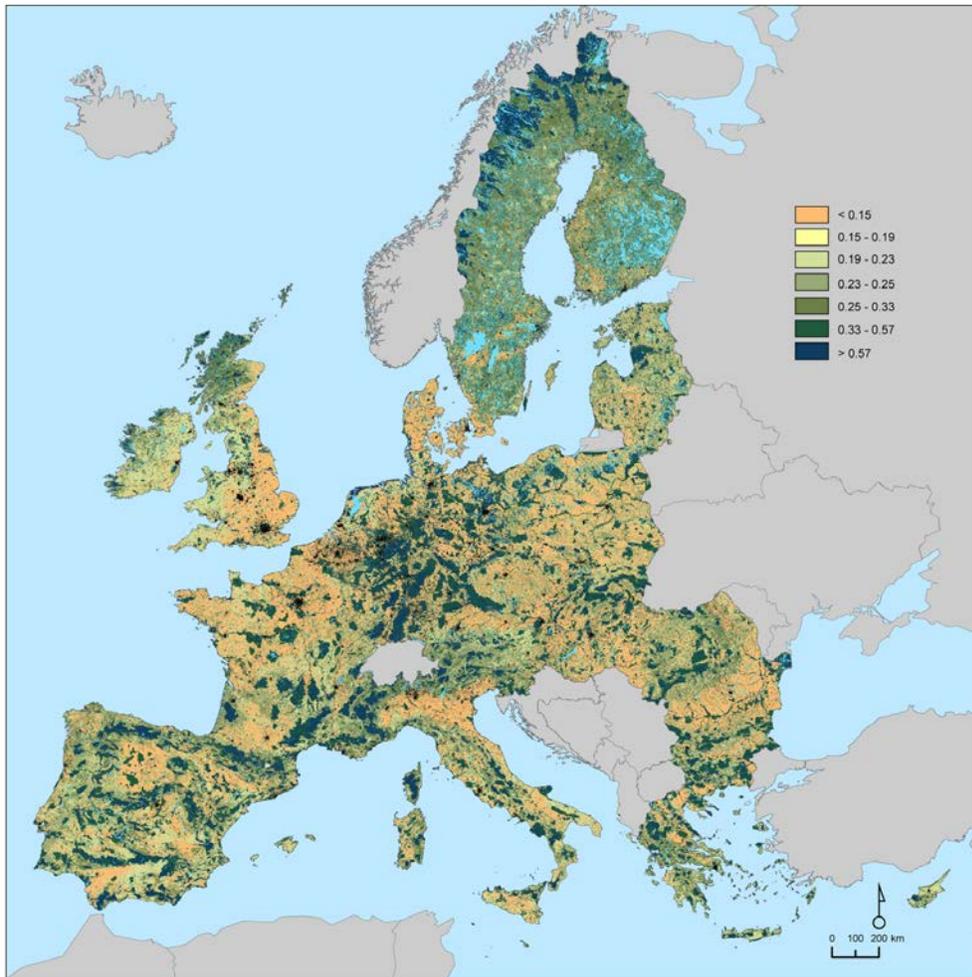


Figure 10: Proximity map

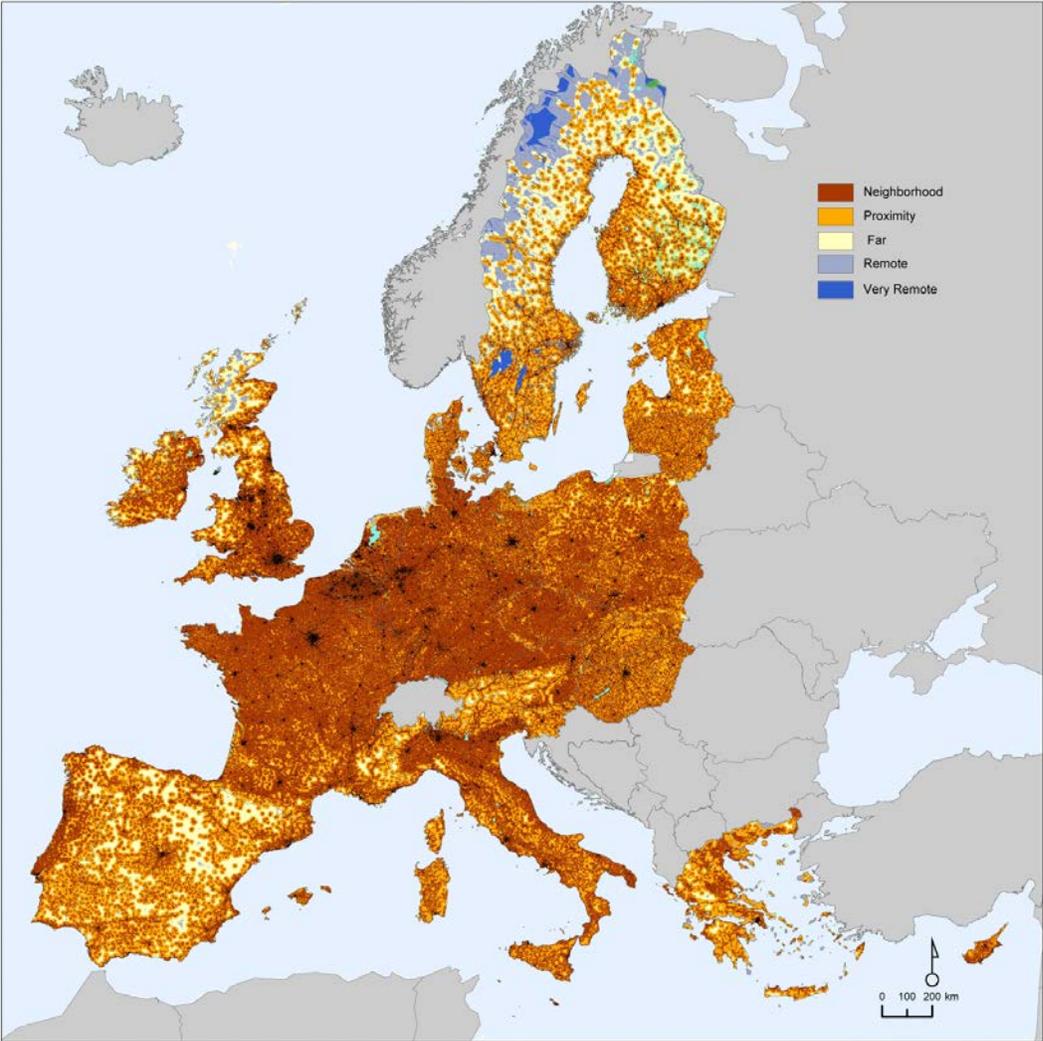
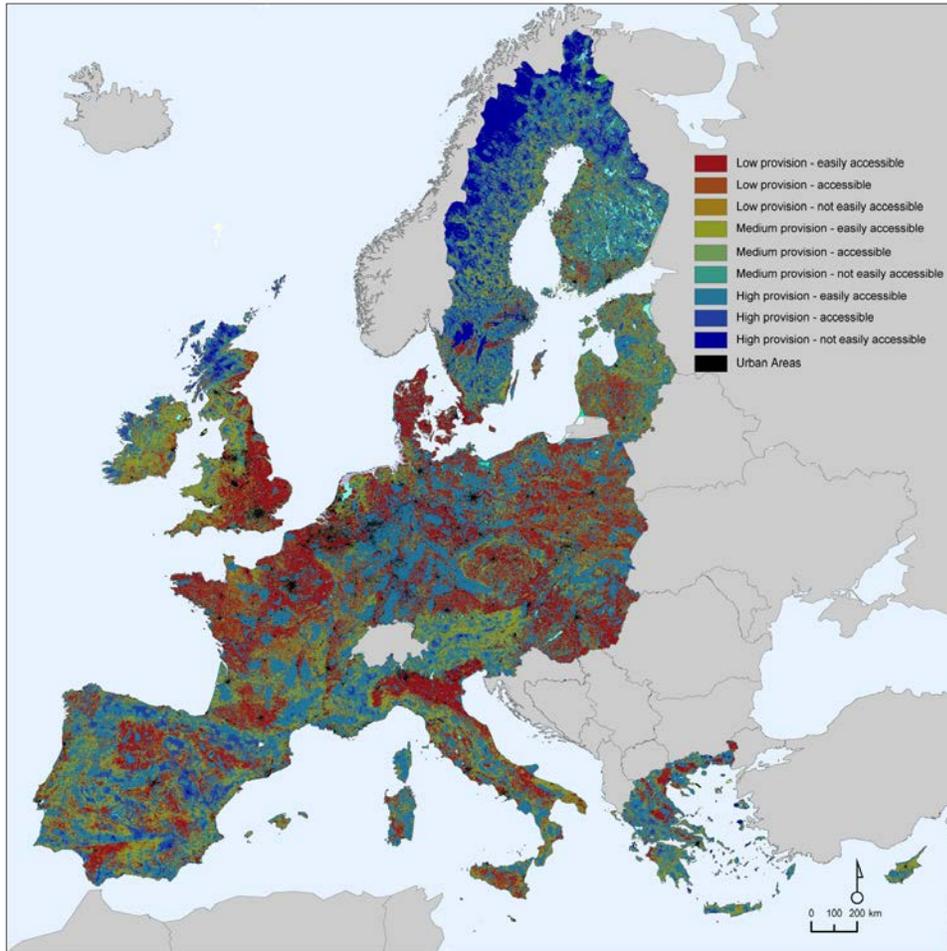


Figure 11: Recreation Opportunity Spectrum



**THE ASSESSMENT OF BENEFITS**

The potential flow of the service to visitors can be estimated by computing the share of potential trips that can theoretically be done in order to reach the different ROS zones. As mentioned above, the present study addresses daily recreation, therefore according to the surveys two reference distances were identified for close-to-home and daily maximum travelled distance: 8 and 80 km. The map of EU population density at 100 m resolution [45] has been used as a source of information on population distribution in Europe. The smoothing function (1) has been applied to describe how far people travel to reach destinations for recreation. Surveys indicate that travelled distance can be modelled using (1), in fact the highest percentage of trips is done in the vicinity of travel origin [58-60]. The function assumes that the average citizen has higher probabilities to travel to sites that are closer compared to those that are farther away. The value of each cell of the resulting layer corresponds to the number of inhabitants who can reach the cell from the surrounding 8 or 80 km, given the impedance described in function (1). Such value is the result of the weighted sum (2):

$$P_{cell} = \sum_{x=1,D}^{-D} \sum_{y=1,D}^{-D} f(d_{x,y}) * P_{x,y} \quad (1)$$

where:

D is the maximum travelled distance

x, y are the coordinates of each cell with respect to the processed cell

d is the distance of each cell from the processed cell

P is the population living in the x, y cell

f is function (1)

The values of  $\alpha$  and K in the two cases are reported in Table 14. The shape of the function shows that the probability of traveling beyond 4 km (close to home trips) and 30 km (daily trips) decreases below 0.5.

**Table 14: Parameters of the cumulated population model**

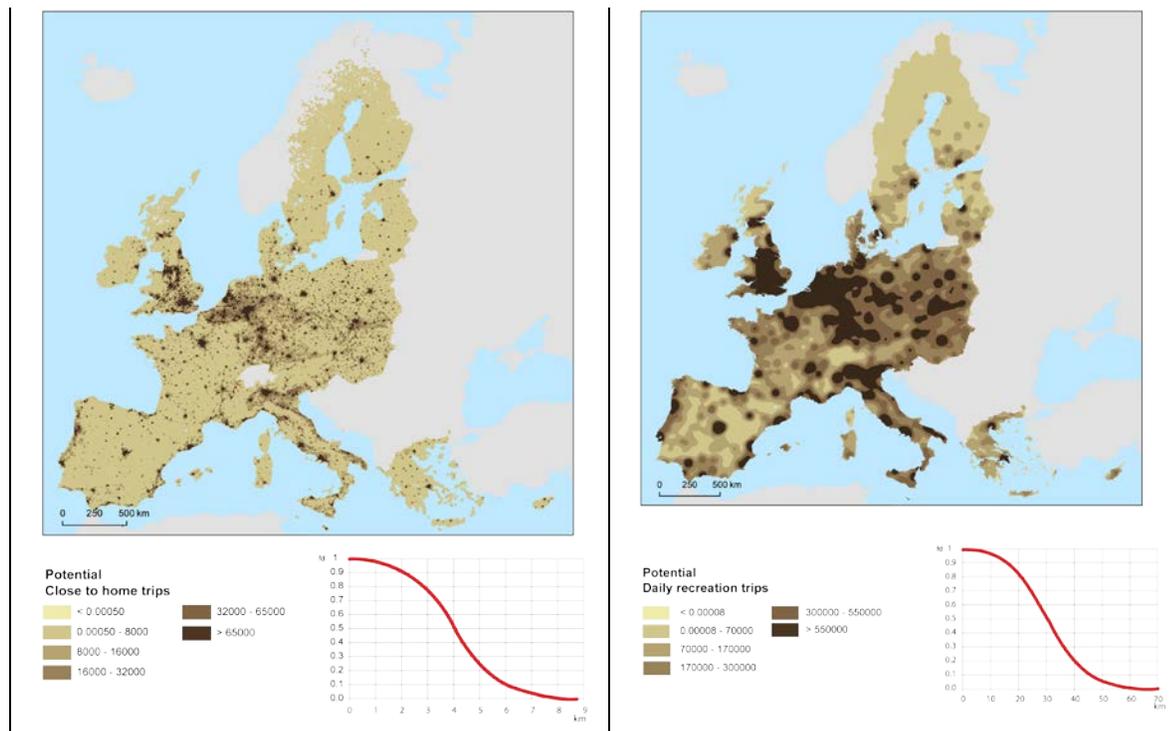
MOBILITY MODEL	PARAMETERS	
Long distance function 80 km	$\alpha$	1.12E-04
	K	27.95793
Short distance function 8 km	$\alpha$	1.13E-03
	K	450

Table 15: ROS Categories in Europe.

ROS Categories	EUROPE	%
1	low provision - easily accessible	24.00
2	low provision - accessible	0.52
3	low provision - not easily accessible	0.04
4	medium provision - easily accessible	25.25
5	medium provision - accessible	2.18
6	medium provision - not easily accessible	0.48
7	high provision - easily accessible	37.81
8	high provision - accessible	6.44
9	high provision - not easily accessible	3.30

The maps of potential population distribution on close-to-home and daily trips are shown in Figure 12. In practical terms the map is a density distribution of potential users, assuming that every cell can be reached by all residents in their respective surroundings according to (1).

Figure 12: Potential population pressure on ecosystems assuming a 80 km travel for daily trips (by car) and 8 km for short trips (e.g. walking, running, cycling)



Results allow calculating what type of recreation provision EU citizens potentially have access to, and this corresponds to the ecosystem service flow, or the benefit that population can - on average - draw from recreation in the different ROS zones.

The maps in Figure 6 can also be interpreted as the density of potential trips of EU residents in their respective surroundings (whether 8 or 80 km) counted on a 100 m grid. Therefore, the percentage of potential trips per ROS zone can be calculated by dividing the sum of potential trips per ROS zone by the total of all possible trips. Results are reported in Table 16.

**Table 16: potential trips per ROS zone**

	ROS classes	% trips 8 km	% trips 80 km
Europe	1 - Low provision- easily accessible	36,70	35,54
	2 - Low provision- accessible	0,06	0,14
	3 - Low provision- not easily accessible	0,04	0,01
	4 - Medium provision- easily accessible	27,35	25,34
	5 - Medium provision- accessible	0,11	0,35
	6 - Medium provision- not easily accessible	0,01	0,02
	7 - High provision- easily accessible	35,43	37,61
	8 - High provision- accessible	0,21	0,88
	9 - High provision- not accessible	0,09	0,11

## COASTAL PROTECTION

For the purpose of this study, Coastal Protection (CP) is defined as the natural defence of the coastal zone against inundation and erosion from waves, storms or sea level rise. In the same context, protection refers to the physical defence of any asset present in the coastal zone (e.g. property, people) [61].

Using the ecosystem services cascade model as a framework (Figure 13) this study defines three indicators for CP:

- Capacity ( $CP_{cap}$ ): The natural potential that coastal ecosystems have to protect the coast against inundation or erosion. This is based on geological and ecological characteristics. This indicator links to the potential supply of the service and, thus, to the upper compartment of the cascade scheme (i.e. biophysical structure and process). This indicator is defined as:

$$CP_{cap} = 0.33 \cdot G + 0.25 \cdot S + 0.21 \cdot SH + 0.21 \cdot LH$$

Where G is the ranked coastline geomorphology, S is the mean inland slope of the coastal zone (i.e. coastal topography), SH are the ranked seabed habitats, and LH are the ranked land habitats or land cover in the coastal zone. The qualitative variables G, SH and LH are ordered in a meaningful sequence corresponding to their influence for coastal protection and transformed to ranks (numbers) based on expert opinion (a questionnaire filled by 20 international experts, see more details in [61]).

- Natural exposure ( $CP_{exp}$ ): The predicted need of CP based on the climatic and oceanographic conditions of each area. It is estimated as:

$$CP_{exp} = 0.29 \cdot W + 0.29 \cdot SS + 0.22 \cdot SL - 0.19 \cdot T$$

Where W is the wave regime represented by the maximum wave significant height, SS is the storm surge height for a 100 yr return period, SL is the relative sea level trend, and T is the tidal amplitude.

$CP_{exp}$  together with  $CP_{cap}$  give an indication of the service flow (middle box in the cascade scheme) from a natural perspective, i.e. the use of the service will be higher where the coastal systems are exposed and have protection capacity.

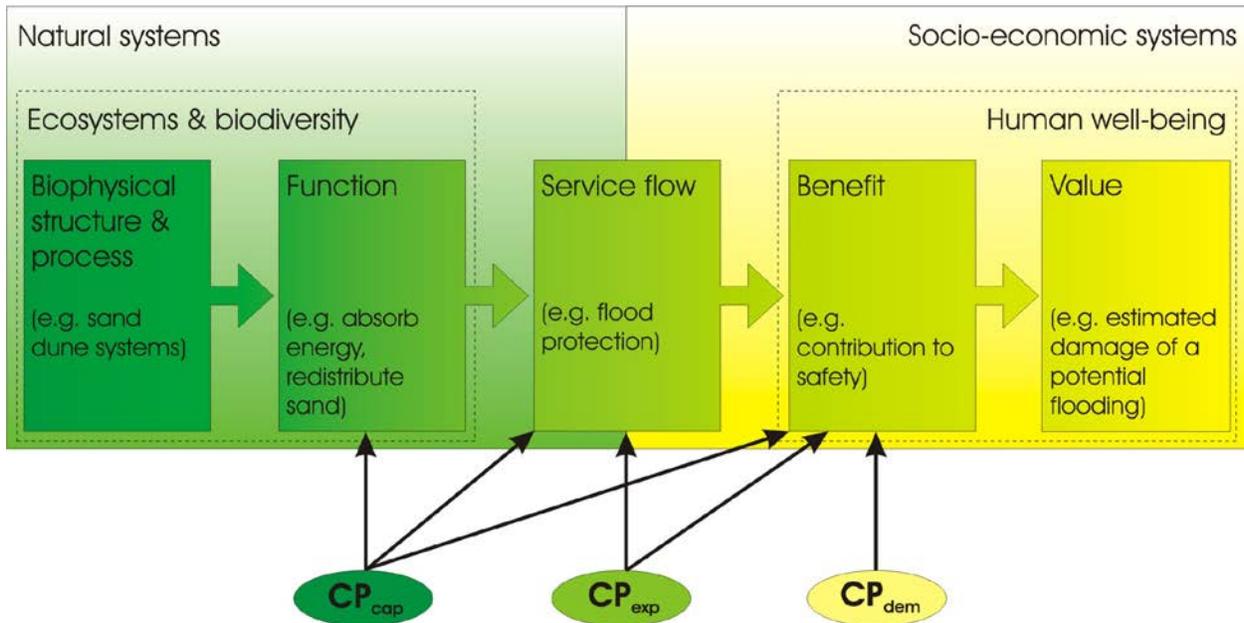
- Human demand ( $CP_{dem}$ ): The estimated necessity of protection of the coastal populations based on the presence of residents and assets in the coastal zone. It is calculated as:

$$CP_{dem} = 0.35 \cdot P + 0.20 \cdot AS + 0.30 \cdot R + 0.15 \cdot U$$

Where P is the population density in the study area, AS is the percentage of artificial (constructed) surfaces, R represents the presence of infrastructures (in this case the roads density), and U indicates the presence of major historical, religious or cultural sites (in this case Unesco world heritage sites).

After analysing  $CP_{cap}$  and  $CP_{exp}$  this indicator helps connecting with the 'benefit' compartment of the cascade scheme (Figure 13). The coefficients of the formulae (i.e. the relevance of each factor for CP) for the calculation of  $CP_{exp}$  and  $CP_{cap}$  are based on a questionnaire to 20 worldwide experts on coastal dynamics (see [61]). For the  $CP_{dem}$  indicator, weighting depend on the relative importance of the variables and the distribution of values across Europe.

Figure 13: Coastal protection framework based on the ecosystem service cascade model.



Main steps of the procedure:

- Study area delimitation and definition of operational units
- Run of processing models
- Run of Coastal Protection Model

Table 17 lists the variables and data sources considered in this study and their corresponding use for building indicators and for assessing CP ecosystem service [61].

Table 17: List of variables and data sources for computing coastal protection.

Variable	Data source	Use for indicators	Use for ecosystem service assessment
Bathymetry	GEBCO global bathymetric data with a resolution of 30 arc-seconds [62]	Delimitation of the study area	Assessment units
Topography	Global digital elevation data based on the NASA Shuttle Radar Topographic Mission (SRTM) of 3 arc-second resolution [63]		
	Digital topographic maps for Scandinavian countries at different resolutions, [64]		
Slope	Same as Topography	CP Capacity	Capacity, flow and benefit
Geomorphology	EU coastal geomorphology data and defence works at approx. 1:100 000 resolution [65]		
Submarine habitats	Modelled seabed habitat maps from the Baltic Sea, the Celtic Sea, the North Sea, and the Western Mediterranean from the EUSeaMap <a href="http://jncc.defra.gov.uk/page-5020">http://jncc.defra.gov.uk/page-5020</a> JNCC (2010)		
	Modelled seabed habitat maps from the Brittany and Pays de la Loire French regions MESH (Mapping European Seabed Habitats), 2010. Combined EUNIS Habitats v3.2. Information derived from MESH Consortium webGIS data ( <a href="http://www.searchmesh.net">http://www.searchmesh.net</a> ) which received funding from the INTERREG IIIB NEW programme ( <a href="http://www.nweurope.org/">http://www.nweurope.org/</a> ).		
Emerged habitats	EU Corine Land Cover (CLC) dataset v.15 from the year 2000 with a resolution of 100 m, EEA (2011)	CP Exposure	Flow and benefit
Wave regime	Modelled data of maximum significant wave height estimated with the WAM "WAVE prediction Model" cycle 4.5 as implemented at the European Centre for Medium range Weather Forecasting. WAM is a continually updated spectral wave model specifically designed for global and shelf sea applications (for deep or shallow waters). It predicts directional spectra and wave characteristics of both wind sea and swell. The values used in this study represent the average of 10 years model run [66,67].		
Tidal range	Tidal amplitude from the principal constituent of tide, in this case the M2 or lunar semi-diurnal wave at 1/8 of a degree resolution extracted from the FES2004 global tidal atlas [68].		
Relative sea level	Global grid of mean sea level trends measured from satellite altimetry between 1992 and 2010 with a resolution of 1/3 of a degree. The altimeter products are produced by Ssalto/Duacs and distributed by Aviso with support from Cnes [69] ( <a href="http://www.aviso.oceanobs.com/duacs/">http://www.aviso.oceanobs.com/duacs/</a> )		

Storm surge	Global storm surge height data extracted from the Dynamic Interactive Vulnerability Assessment (DIVA) database ( <a href="http://www.diva-model.net/">http://www.diva-model.net/</a> )<comma> which collects the output data from the Storm Surge Model Systems of Delft Hydraulics. The variable used in this study is the surge height for a 1:100 year return period [70]		
Population density	EU population density disaggregated with CLC 2000 at 100 m resolution [45]	CP Demand	Benefit
Infrastructures	Main infrastructures in the coastal zone represented here by the road network MapCruzin, 2011. Free European Continent ArcGIS Shapefile Map Layers. Data derived from the OpenStreetMap community, The Free Wiki World Map. <a href="http://www.mapcruzin.com">http://www.mapcruzin.com</a> <a href="http://www.openstreetmap.org">http://www.openstreetmap.org</a> .		
Artificial surface	Presence of artificial surface (land dedicated to urban and industrial areas) in the coastal zone extracted from CLC 2000, EEA (2011)		
Main cultural sites	Main historical - religious and cultural sites broadly represented by the UNESCO World Heritage List, [71] <a href="http://whc.unesco.org">http://whc.unesco.org</a>		

**THE MODEL**

**THE STUDY AREA DELIMITATION**

The coastal zone considered in this study embraces the area potentially affected by extreme hydrodynamic conditions. This area is delimited in general by the 50 m depth isobath and the 50 m height contour line, although a minimum width of 1 nm offshore and 1 km inland from the coastline are also established. These minimum limits avoid the total exclusion of some coastal areas due to relatively low data resolution or due to the presence of very steep areas. Besides, a maximum extent of 50 km landwards from the shoreline is fixed to avoid identifying far inland habitats and populations as 'coastal' (Figure 14, Figure 15).

Once this coastal zone is delineated, we need to split it into operational units or blocks through the intersection with a vector dataset called preblocks (

Figure 15). For the European analysis, we delineated 1414 blocks, approximately 30 km long perpendicular to the coast and the main topographic and bathymetry trends. Territorial borders inland and EEZ limits offshore were respected to allow for national aggregation.

Figure 14: Example of coastal zone delimitation and division in operational units around the Balearic Islands (NW Mediterranean). Blocks, comprising both land and sea zones, are the grey shaded areas delimited by black lines.

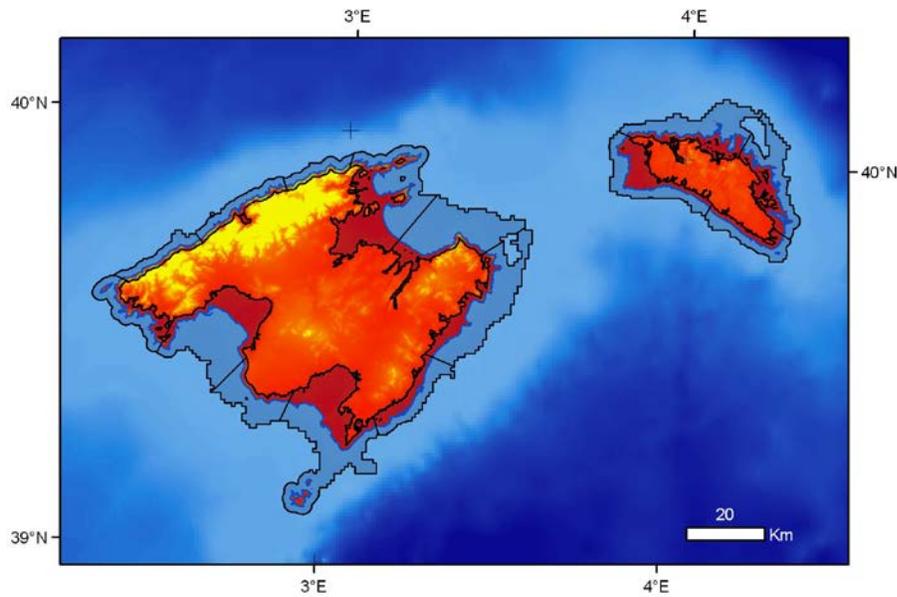
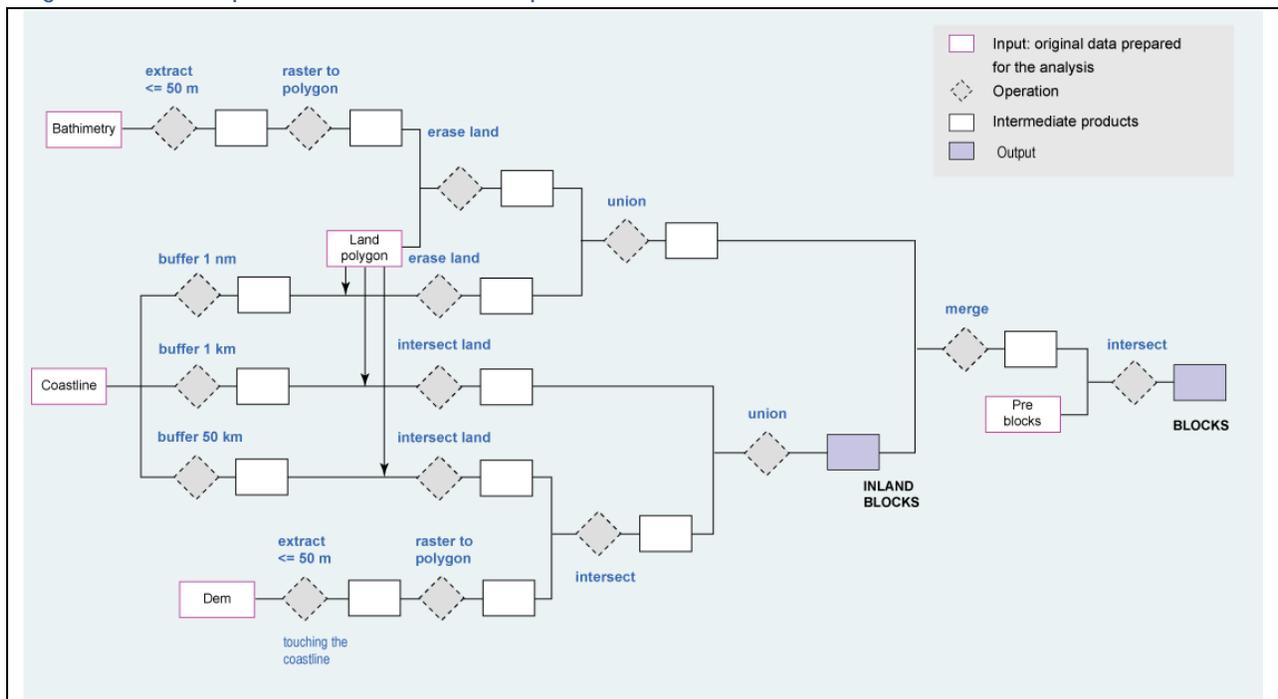


Figure 15: Main GIS processes to construct the operational units



## DATA EXTRACTION AND AGGREGATION

The spatial and statistical operations performed depend on the nature and format of the input data. The aim of data extraction is getting an average value of each input variable per block or operational unit. Table 17 and Figure 16 show the quantitative data processing steps. Wave, tide and sea level data have a relatively low resolution raster format. They are geographically averaged to extract the mean values at coastal locations. A similar procedure is followed with the slope values derived from the original DEM, and with the population density data extracted only from the land side of the blocks. Road data (in vector format) are intersected with the land blocks, their total length is added per block, and the road density is estimated to make results comparable. Storm surge data (polylines) and the location of UNESCO sites (points) are both extracted by block and their value is averaged in the former and added in the latter.

**Table 18: quantitative data processing**

Dataset		Main Processing operations	Units of [O_ ] field in the tables
Sea	wave	<u>Focal statistic</u> (rectangle, 3x3 cell, mean, ignore null data) = ras1 <u>Raster calc.</u> (Int ("%wave1%"*100) = ras2 <u>Raster to polygon</u> = ras.shp	Maximum significant wave height (*100 m)
	tide	<u>Spatial Joint</u> [O_ ] : mean	Tidal range (cm)
	sea level	[ON_ ] : normalized mean For missing values the value of the nearest block in 150 km radius is chosen	Sea level rise (*100 mm/yr)
Land	DEM	<u>Slope</u> (degree, z = 1) Calculate the mean for each block [O_ ] : mean [ON_ ] : normalized mean No missing values	Land slope (degrees)
	population	Extract by mask (on Bland.shp) Calculate inland population density [O_ ] : population density [ON_ ] : normalized population density For missing values the value will be 0	Population density (inhab/km <sup>2</sup> )
Lines	Roads	<u>Intersect Roads and Bland</u> Calculate inland road density ( $[\text{SUM\_Shape\_leng}] * 1000 / [\text{Shape\_Area}]$ ) [O_ ] : road density [ON_ ] : normalized road density For missing values the value will be 0	Roads density (km/km <sup>2</sup> )
	Surge	<u>Spatial join</u> (match options: intersect) O_ : mean ON_ : normalized mean For missing values the value of the nearest block in 150 km	Height (m) of the storm surge with a 100 yr return period
Points	Unesco	<u>Spatial join</u> (match options: intersect) O_ : sum of points per block ON_ : normalized sum of points per block For missing values the value will be 0	Number of sites

Figure 16: quantitative data processing models

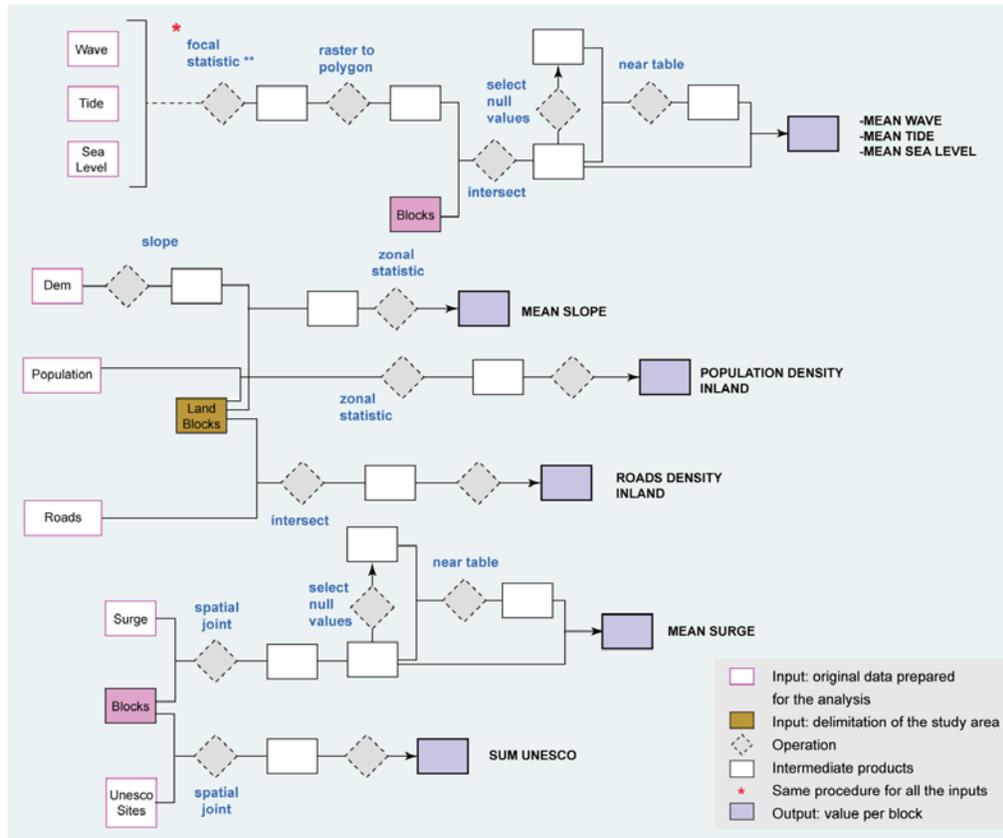


Figure 17 and Table 19 show the qualitative data processing steps. Land cover was divided into artificial land (which is used for the estimation of the CP<sub>dem</sub> indicator) and natural land cover. Natural land cover, natural coastal geomorphology and seabed habitats are ranked from 1 to 5 depending on their protective role against coastal erosion and inundation. Details about the ranking procedure based on expert opinion can be found in [61]. Finally we calculate a weighted average of each variable per block based on the coverage (for polygons) or length (for polylines) of each rank category.

Where necessary, data gaps were filled with (a) the nearest value for the oceanographic variables (wave, tide, sea level, surge), (b) zeros for the absence of a particular feature (roads, UNESCO sites, artificial land), and (c) the mean value for the large gaps in geomorphology and seabed habitats. All the results (the value per block for each variable) were normalised based on minimum and maximum values. The aggregation of all these data follows two steps. In the first one we estimate the three CP indicators (CP<sub>cap</sub>, CP<sub>exp</sub> and CP<sub>dem</sub>) following the formulae described at the beginning of this chapter. In the second step we aggregate those indicators to inform about the different compartments of the ecosystem services cascade model, namely capacity or function, flow and benefit (see Table 17).



In the CP model we calculate the final indicators. It creates a table with the following structure:

**Table 20: structure of the Final output table**

Output Fields:	
BID	Block code
CNTR	Country code
CPcap	Coastal Protection capacity
CPexp	Coastal Protection exposition
CPdem	Coastal Protection demand
CPcapr	Coastal Protection capacity reclassified using the 33 and 66 percentiles (1=low, 2=medium, 3=high)
CPexpr	Coastal Protection exposition reclassified using the 33 and 66 percentiles (1=low, 2=medium, 3=high)
CPdemr	Coastal Protection demand reclassified using the 33 and 66 percentiles (1=low, 2=medium, 3=high)
CPflow	Flow of Costal Protection (see table 5) (1=low, 2=deficient, 3=high)
CPben	Benefit from Costal Protection (see table 6) (1=low, 2=covered, 3=deficient, 4=high)

Once these values are estimated,  $CP_{cap}$ ,  $CP_{exp}$  and  $CP_{dem}$  are reclassified into low, medium and high using the 33 and 66 percentiles. These classes are the input for the cross tabulations that define the two final indicators: CP flow and CP benefit (Table 21 Table 22).

**Table 21: cross tab for CP flow, where red is Deficient flow, yellow is Low flow and blue is High flow.**

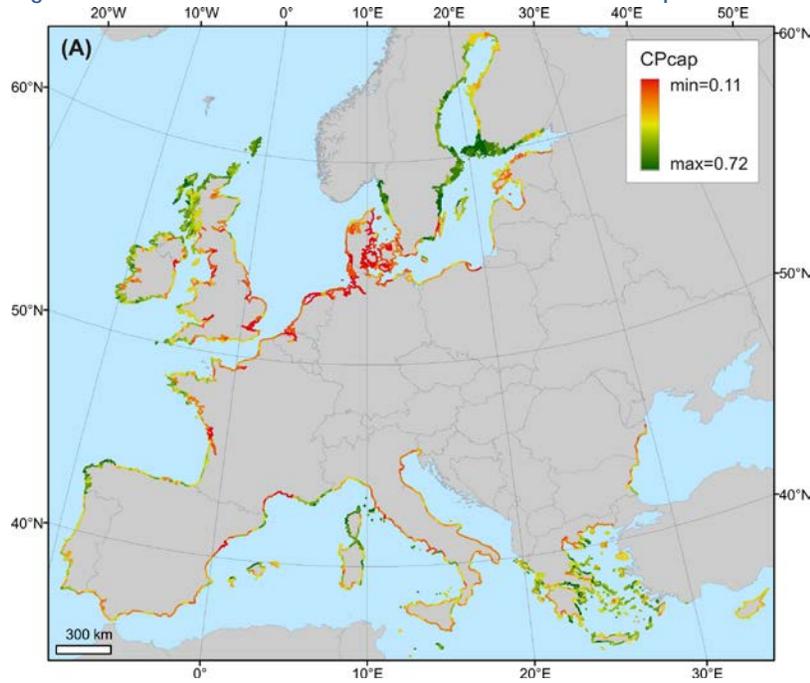
		CP <sub>exp</sub>		
		Low=1	Medium=2	High=3
CP <sub>cap</sub>	Low=1			
	Medium=2			
	High=3			

**Table 22: cross tab for CP benefit, where red is Deficient, yellow is Low, green is Covered and blue is High benefit.**

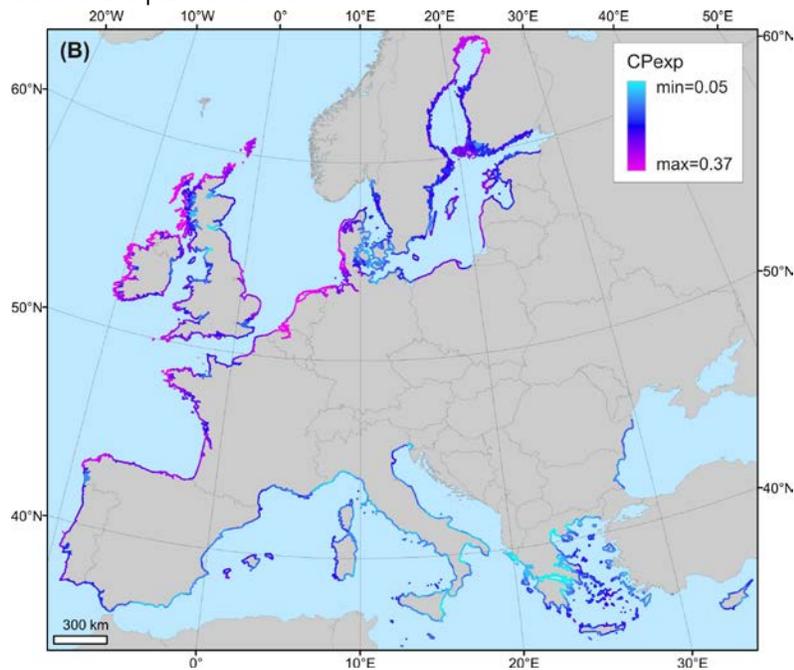
		CP <sub>dem</sub>		
		Low=1	Medium=2	High=3
CP flow	Low=1			
	Deficient=2			
	High=3			

# RESULTS

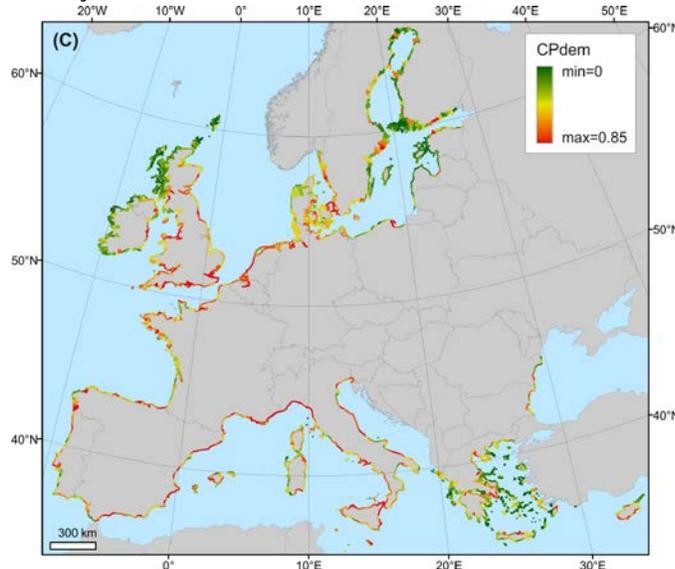
Figure 18: main results for the Coastal Protection index for Europe



Relatively low CP<sub>cap</sub> is present in the shores of Denmark, Germany, The Netherlands, some UK estuaries and the Gulf of Lion; while relatively high values are observed in Scandinavian mid-latitudes, Scotland, Ireland, Galicia, Corsica and parts of Greece.



$CP_{exp}$  is especially low in the most enclosed shores of Greece and southern Italy, the Ligurian Sea, SE Spain, the uppermost sector of some UK estuaries, and the Bay of Mecklenburg (SW Baltic Sea).  $CP_{exp}$  shows the highest values along the Bothnian Bay, Eastern coast of the North Sea, Western coasts of UK and Ireland, and French Brittany.



Regarding  $CP_{dem}$ , the highest values are found near densely populated or constructed areas, in particular Dublin, London, Bilbao, Malaga, Barcelona, Nice, Genoa, Patra and Athens.  $CP_{dem}$  shows minimum values around the Baltic Sea, Western coasts of UK and Ireland, Greece and NE Cyprus.

#### FLOW MAP:

The lowest CP service flow is mostly concentrated in the Mediterranean and Black Seas; the highest values tend to be located in Mediterranean islands, in Atlantic coasts and in Baltic shores; and a deficient service flow is found widespread across EU.

#### BENEFIT MAP:

Low CP benefit values are concentrated around the Baltic Sea, along the Eastern Scottish and Irish coasts, and in Greek islands; high benefit values are mostly present in Atlantic and Northern Baltic shores; the demand could be covered with the flow mainly in a few sectors around the Mediterranean and Black Seas; and, on the contrary, the benefit seems deficient for human needs in most of the North Sea and (in) one fourth of the Mediterranean and Black Seas.

Concerning the study of the coastal zone in EU, there are some key aspects that could improve the quality of this or similar studies, namely:

- a) The update and extension of the EuroSION database, which covers basic aspects such as geomorphology, geology of the coast, erosive trends and presence of man-made structures. The dataset became public in 2005 but some data date back to 1990. Shorelines from Cyprus, Bulgaria and Romania are only covered around 20%.
- b) The extension (and plan for future updates) of the EU sea habitat maps to cover the full NE Atlantic region (Bay of Biscay and Iberian Peninsula, where the MESH-Atlantic project is presently working), Eastern

Mediterranean and Western Black Sea. To reach this kind of model outputs a lot of effort should be invested in experimental benthic habitat mapping, especially in the busy and productive continental shelf.

- c) The development (or compilation) of a European bathymetry map at higher resolution than the global datasets presently available.
- d) The development of spatially explicit socio-economic datasets at least to a level that could be comparable to the available environmental data. This could improve the quality and adequacy of the data input for the assessment of human demand and benefit.

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#### Abstract

Mapping, visualization and the access to suitable data as a means to facilitate the dialogue among scientists, policy makers and the general public are among the most challenging issues within current ecosystem service science and application.

Recently the attention on spatially explicit ways to map ecosystem services, at local, regional and global scale is increasing. This report presents ESTIMAP: a suite of models for a spatially explicit assessment of three ecosystem services (recreation, pollination and coastal protection) at continental scale. The main objective of the models is to support EU policies with information on ecosystem services.

As the Commission's in-house science service, the Joint Research Centre's mission is to provide EU policies with independent, evidence-based scientific and technical support throughout the whole policy cycle.

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