Supplementary material S2 – Composition and configuration models per ES

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Sediment retention capacity model

Sediment retention capacity was mapped using InVEST (Kareiva et al. 2011). In the InVEST model, sediment retention consists of (i) sediment retention at the cell and (ii) filtration of sediment input from upstream cells. We used the Universal Soil Loss Equation (USLE) to calculate sediment retention per cell:

$$USLE = R * K * LS * C * P \quad (1)$$

Where R is the rainfall erosivity, K is the soil erodibility factor, LS is the slope length-gradient factor, C is the crop/vegetation and management factor, P is the support practice factor. Table S.3 provides an overview of the data sources for all components in equation 1. The crop vegetation factor, C, was calculated based on the approach suggested by van der Knijff et al. (2000), as follows:

$$C = exp\left[-\alpha * \frac{NDVI}{\beta - NDVI}\right] \quad (2)$$

Where we substituted MODIS-derived Enhanced Vegetation Index (EVI) for the Normalized Difference Vegetation Index (NDVI), using the annual average based on weekly time series, and set α = 2 and β =1 To preserve spatial heterogeneity, the range of C estimates were divided in 10 intervals and these were combined with the existing land cover classification, resulting in a total of 240 possible values.

The second step of the sediment retention model calculates the sediment filtration by land cover of sediment transported from upstream cells. The model assumes that the estimated soil loss from USLE is transported to downstream grid cells if the retention capacity of the receiving cell is zero (Sharp et al. 2015). This retention depends on the physical filtration and slowing down of overland flow by vegetation, allowing sediment particles to deposit (Sharp et al. 2015). Per-cell retention is a function of a retention efficiency factor, E_i, and was estimated based on a combination of different sources (May and Place 2005; Sude et al. 2011; Sharp et al. 2015). The sediment retention efficiency factors are salt- and freshwater = 1.0, fen and bog =0.95, heather = 0.9, forest =0.87, grassland = 0.85, cropland = 0.6, urban =0.4, montane = 0.2 and last sediment and rock = 0.05. The mass balance equation for the transport of sediment is then calculated as follows:

$$S_i = \left(\sum_{j \in \{i_{neighbors}\}} S_j\right)(1 - E_i) + USLE_i \quad (3)$$

The left hand side of the equation represent the total sediment input from upstream cells, S_j, multiplied by the sediment filtration efficiency.

In the configuration model, sediment retention capacity for a cell *x*, $ConfSediment_x$, is the sum of the sediment retention at the cell and the filtration capacity of the land cover type *i* as present at cell *x*, specified as:

$$ConfSediment_x = PotSoilLoss_x - ActualSoilLoss_{x,i} + import\_sed_x * \left(1 - filt\_cap_{x,i}\right) \quad (4)$$

See Table S.4 for a description of the individual model components of all ES models. The $PotSoilLoss_x$ is calculated from the USLE, equation 1, and equals the amount of sediment eroded without land cover (C=1). The $ActualSoilLoss_{x,i}$ equals the amount of sediment eroded with the land cover crop factor (C≤1). The difference between the two is the amount of sediment retained by the land cover.. The second part of the equation calculates the sediment retention based on the filtration capacity, $filt\_cap_{x,i}$, which relates to the retention efficiency factor in equation 3,of the land cover and the amount of sediment received from upstream cells, $import\_sed_x$, which relates to the sediment input from upstream cells in equation 3 . The composition model for sediment retention was calculated as:

$$CompSediment_x = PotSoilLoss_x - ActualSoilLoss_{x,i} + \overline{import\_sed_w} * filt\_cap_{x,i} \quad (5)$$

where $\overline{import\_sed_w}$ is the mean amount of sediment input for all cells calculated per watershed, *w*. The only difference between the composition and configuration model for sediment retention capacity is the sediment input. In the composition model, the sediment input equals the average sediment input for the watershed in which the land cover cell is located. Watershed boundaries were obtained from the Scottish Environmental protection agency.

Table S.3: Description of factors and data sources for the sediment retention model in InVEST.

Factor	Description of method/data source
R	calculated as function of the kinetic energy and intensity of rainfall, KE *I30 (Davison et al. 2005). The intensity of rainfall is calculated based on rainfall intensity data from the UK meteorological office from 1961-1990 (UKmetoffice 2015). Because precipitation in Scotland is quite even we estimated I30 = 2*(ARI)/24 where ARI is the annual rainfall intensity. Following Davison et al. (2005) kinetic energy is calculated as $KE\ (J/m^2) = 3.756 * AR^{1.1445}$ Where AR is the mean annual rainfall based on precipitation data from the UK meteorological office from 1961-1990.
K	Obtained upon request from the EU Joint Research Centre. See: http://eusoils.jrc.ec.europa.eu/library/themes/erosion/Erodibility/
LS	Computed by InVEST using the Digital Terrain Model based on the Ordnance Survey terrain map for the UK (OrdnanceSurvey 2015)
C	the crop factor was calculated based on the approach by van der Knijff et al. (2000).
P	We assumed no difference in management for land cover types (P=1)

Flood control capacity model

In the composition model, flood control capacity was quantified using land cover proxies for flood protection from Burkhard et al. (2012). The land cover proxies combine flood control potential for river and coastal floods. Here we focussed on river flooding and therefore, the coastal land cover classes were assigned the lowest value for “no flood control potential”. In the composition model, flood control capacity at cell *x*, $CompFlood_x$, is equal to the ES potential value of the land cover type *i* as present at cell *x*, specified as:

$$CompFlood_x = FloodCap_{x,i} \quad (6)$$

In the configuration model, flood control capacity of a cell additionally depends on the location of a cell in a watershed with respect to the flow path and the stream, thereby accounting for configuration. We calculated the flow accumulation value (FACC), as the number of upstream cells potentially transporting water into a particular cell. The FACC accounts for the position of the land cover within a watershed relative to the flow path. Chan et al. (2006) previously used flow accumulation for mapping flood control capacity. For each watershed we calculated the average FACC value of all cells in the watershed. The FACC value of a cell was scaled relative to the average FACC of the watershed to which the cell belonged, indicating that cells with a high amount of upstream area contribute more to flood control:

$$ConfFlood_x = FloodCap_{x,i} * \frac{FACC_x}{FACC_w} \quad (7)$$

Modelled effect of landscape composition and configuration do not apply under conditions of full soil saturation.

Landscape aesthetics capacity model

In the composition model landscape aesthetic capacity was quantified using land cover proxies for "landscape aesthetics and inspiration" from Burkhard et al. (2014). Landscape aesthetics capacity of a cell *x*, $CompAesthetic_x$, is equal to the ES potential value of the land cover type *i* as present at cell *x*, specified as:

$$CompAesthetic_x = AesthCap_{x,i} \quad (8)$$

Land cover diversity assigned to a cell was determined by two factors: the landscape type surrounding a cell, and the land cover diversity within that landscape type. First, we assigned each cell to one of three generic landscape types: natural dominated landscape, agricultural dominated landscape or mosaic landscape. The landscape type was calculated within a view shed of 200 meters following Casado-Arzuaga et al. (2013). Agricultural dominated landscapes had > 50% agricultural land cover in the view shed, whereas natural dominated landscapes had >50% natural land cover in the view shed. Only cells surrounded by 50% natural vegetation and 50% agricultural land are assigned to mosaic landscape types. Only considering an equal share of natural and artificial land cover as a mosaic landscape is a conservative approach to not overestimate the effect of accounting for configuration on landscape aesthetics capacity. The land cover classes arable land, pastures, suburban and urban were assigned to artificial land cover and all other land cover classes were assigned to (semi-)natural. We obtained landscape preference scores per landscape type from a meta-analysis for European agricultural landscapes (van Zanten et al. 2014). The landscape preferences were in the order mosaic (0.684), natural (0.466) and agricultural (0.388) (van Zanten et al. 2014). Each cell was assigned a landscape preference score based on the landscape type it belonged to.

Second, within each landscape type we calculated for each cell the diversity of land cover using Shannon diversity index (SHDI), again within a view shed of 200 meters. We then combined the landscape type scores with the SHDI values as follows:

$$LandDiv_x = p_x - \left(\frac{0.684 - p_x}{maxSHDI_x} * SHDI_x\right) \quad (9)$$

Where *p* is the preference score of the landscape type at cell x. The constant, 0.684, is the reference maximum score for mosaic landscapes indicating that mosaic landscapes always receive the maximum LandDiv score of 0.684. Agricultural and forest dominated landscapes receive a relatively lower score depending on the Shannon diversity index. The SHDI value of a cell is scaled relative to the maximum SHDI value for Scotland. The higher the SHDI value the closer the resulting land cover diversity score will be to the land cover diversity score for mosaic landscapes.

Finally, in the configuration model, landscape aesthetics capacity of cell *x*, $ConfAesthetics_x$, is a combination of the land cover proxy for landscape aesthetics and on the surrounding land cover diversity value of a cell. The land cover diversity of a cell is scaled relative to the mean land cover diversity for all cells in Scotland, $\overline{LandDiv_S}$, as specified:

$$ConfAesthetics_x = AesthCap_{x,i} * \frac{LandDiv_x}{\overline{LandDiv_S}} \tag{10}$$

The preference scores from the meta-analysis by van Zanten et al. (2014) apply to European agricultural landscapes. Due to a lack of other data sources on the effect of land cover diversity on landscape aesthetics potential, we applied the same methodology to all landscapes in Scotland.

Pollination capacity model

Pollination capacity per cell was quantified with land cover proxies from Zulian et al. (2013), who present separate land cover proxies for nesting suitability and floral resource availability for bees per CORINE land cover type. In the composition model, pollination capacity of cell *x*, $CompPollination_x$, is equal to the ES potential values from Zulian et al. (2013) for nesting suitability of the land cover type *i* as present at cell *x*, specified as:

$$CompPollination_x = nest\_suitability_{x,i} \tag{11}$$

Following Lautenbach et al. (2011) we did not assign nesting suitability values to the land cover class “arable land”.

In the configuration model, pollination capacity was quantified using the InVEST pollination model (Lonsdorf et al. 2011). In InVEST, pollination capacity of a cell depends on the nesting suitability of a cell, floral resource availability within the surroundings of nesting cells, and the distance between nesting cells and cropland. Land cover proxies for floral resource availability were obtained from Zulian et al. (2013). Floral resource availability values were assigned to arable land. Compared to the InVEST model, three adjustments were made. First, following Zulian et al (2013) we accounted for edge effects by assigning separate values for nesting suitability and floral resource availability to forest interior and edge cells. Forest edge cells were defined as those cells within 50 meters from other land cover types. Second, in InVEST the effect of floral resource availability on pollination capacity declines with distance (Lonsdorf et al. 2011). We applied a maximum bee flight distance of 500 meters following Lautenbach et al. (2011). The distance dependent effect of floral resource availability was calculated as follows. Floral resource availability depends on the distance, *d*, between the nesting cell, *n*, and the cell with floral resources, *f*, as well as the flight distance of the bee species, *α*, as specified:

$$floral\ distance\ decay = e^{\frac{-d_{nf}}{\alpha}} \tag{12}$$

The effect of distance on floral resource availability using the distance decay function from InVEST is then summed for all floral resource cells within the flight distance, *F*, specified as:

$$floral\_resources_x = \frac{\sum_{f=1}^{F}(floralpotential_{x,i}+edgef_{x,i})*e^{\frac{-d_{nf}}{\alpha}}}{\sum_{f=1}^{F} e^{\frac{-d_{nf}}{\alpha}}} \quad (13)$$

For each cell, we additionally calculated the average floral resource availability within a 500-meter radius from the nesting cell without accounting for distance decay or edge effects, $\overline{floral}_x$. We adjusted the InVEST model by scaling he floral resource availability per nesting cell, after accounting for distance decay and edge effects, relative to the average floral resource availability. In the configuration model, nesting quality for a cell, $NestingQuality_x$, is then a combination of the nesting suitability, edge effects and the surrounding floral resources, where floral resource availability values were scaled relative to the mean floral resource availability value within 500 meters of a nesting cell, as specified:

$$NestingQuality_x = \left(nest\_suitability_{x,i} + edgen_{x,i}\right) * \frac{floral\_resources_x}{\overline{floral}_x} \quad (14)$$

We have so far accounted for (i) edge effects and floral resource avaialability (ii) on nesting quality of a cell. We then accounted for (iii) the distance between cropland and bee nesting cells on pollination capacity. In InVEST pollination capacity of a cell declined with increasing distance from cropland cells (Lonsdorf et al. 2011). We applied the same distance decay function as specified in equation (12), with the sole exception that the distance is now calculated between nesting cells and cropland cells, c, instead of floral cells, as specified:

$$cropland\ availibility = e^{\frac{-d_{nc}}{\alpha}} \quad (15)$$

In contrast to InVEST, we assigned pollination capacity scores to the nesting cells and not to cropland cells. The cropland availability for each nesting cell was scaled relative to the average cropland availability, as specified:

$$average\ cropland\ availibility = e^{\frac{-\alpha/\sqrt{2}}{\alpha}} \quad (16)$$

The average cropland availability represents the distance decay effect if cropland cells would be evenly distributed in the 500 meter radius surrounding a nesting cell. If the 500 meter radius, α, would be split at 353.55 meter, $\alpha/\sqrt{2}$, the area of the inner and outer circle would be equal and both circles could potentially hold the same amount of cropland cells. The average distance decay effect is therefore calculated as the distance decay effect at 353.55 meter. The effect of distance to cropland per cell was scaled relative to the average distance decay effect.

In the configuration model, pollination capacity of cell *x*, $ConfPollination_x$, was then calculated based on the nesting quality of the cell, equation 14, and the cropland availability. The calculation is summed for all cropland cells, *C*, within flight distance of the nesting cell, as specified:

$$ConfPollination_x = \sum_{c=1}^{C} NestingQuality_x * \frac{cropland\ availability_x}{average\ cropland\ availability} \quad (17)$$

In both the composition and configuration model, pollination capacity is only assigned to nesting cells within 500 meters from cropland.

Mapping ES capacity in Scotland

We mapped ES capacity for mainland Scotland, as the sediment retention capacity model is not calibrated well for the surrounding islands. Sediment retention and flood control capacity were assigned to all cells except water courses and bodies. Overland flow is the dominant process for both flood control and sediment retention models, which are affected by land cover composition and configuration. When water or sediment enters a water body overland flow is not the main mechanism of transport from one cell to another. Therefore, land cover composition and configuration has little to no effect on flood control and sediment retention at these locations. Water courses and bodies were identified in two ways. First, the larger water bodies were identified based on the land cover classes salt water and fresh water. Second, we used the FACC value to identify water courses that were not classified as fresh water. All cells to which at least 1000 upstream cells flowed into, according to the FACC, were identified as water courses. The value of 1000 is the default value suggested for the InVEST model to identify the stream network (Sharp et al. 2015). The landscape aesthetics and pollination capacity of land cover are affected by the surrounding vegetation up to respectively 200 and 500 meters. Therefore, to account for edge effects we incorporated land cover types passing the Scottish-English border for 500 meters.

TABLE S.4: Description of the components and subscripts of the composition and configuration model per ES.

Sediment Retention Capacity			
PotSoilLoss	The amount of sediment eroded calculated with the USLE when the cell has no land cover	*Filt_cap*	The sediment filtration value of a land cover type
ActualSoilLoss	The amount of sediment eroded with the current land cover	$\overline{Import\_sed}$	The mean amount of sediment received from upstream cells calculated for all cells within a watershed
Import_sed	The amount of sediment received from upstream cells		
Flood Control Capacity			
FloodCap	The ES potential value for flood control assigned to each land cover type	$\overline{FACC}$	The mean number of upstream cells that flow into a single cell
FACC	The number of upstream sites that flow into a single cell		
Landscape aesthetics Capacity			
AestCap	The ES potential value for landscape aesthetics assigned to each land cover type	*maxSHDI*	The maximum Shannon Diversity Index calculated for all cells in Scotland
p	Landscape preference score per landscape structure	*LandDiv*	land cover diversity score for a cell *x*

SHDI	The Shannon Diversity Index calculated for the land cover within a view shed of 200 meters of each cell	$\overline{LandDiv}$	The mean land cover diversity score for the whole of Scotland
Pollination capacity			
d	The Euclidean distance between two cells	*Floral _resources*	Floral resource availability in the surrounding cells of a nesting cell
Nest_suitability	The ES potential value for nesting cells	$\overline{floral}$	Mean floral resource availability within 500 meter radius of a nesting cell, without accounting for distance and edge effects
α	Flight distance of bee species	*Nesting Quality*	Nesting quality of a cell in configuration model
floralpotential	The ES potential value for floral resource availability	*Cropland _availability*	Effect of distance between nesting cell and cropland on pollination capacity
Edgen	Binary value indicating whether the nesting cell is located at a forest edge	*Average Cropland Availability*	The effect of distance between nesting cell and cropland on pollination capacity when cropland cells are evenly distributed in the surrounding of a nesting cell
Edgef	Binary value indicating whether the floral resource cell is located at a forest edge		
Indices			

i	land cover type	*c*	Cropland cell
x	focal cell	*n*	Bee nesting cell
w	watershed	*f*	Floral resources cell
S	Scotland		

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