PBL Netherlands Environmental Assessment Agency

INDICATORS AND MODELLING OF LAND USE, LAND MANAGEMENT AND ECOSYSTEM SERVICES

Methodological documentation

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December 2016

VU UNIVERSITY AMSTERDAM

Faculty of Earth and Life Sciences

WAGENINGEN UNIVERSITY & RESEARCH

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Indicators and modelling of land use, land management and ecosystem services. Methodological documentation.

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The Hague, 2016
PBL publication number: 2386

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Acknowledgements
The authors would like to thank Arjen van Hinsberg, Anne Gerdien Prins and Henk van Zeijts (PBL) for the project coordination, and Sandy van Tol (PBL) and Jan Clement (Wageningen Environmental Research) for the assistance in the GIS work.

Graphics
PBL Beeldredactie

Production coordination
PBL Publishers

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Contents

1 Introduction

Background

Ecosystems provide numerous benefits to people by supplying food, fresh water, fertile soils, timber and recreation opportunities, among others. Generally, ecosystem services can be classified into provisioning (e.g. food, drinking water, wood fuel) regulating-maintenance services (e.g. climate regulation, erosion control, pollination) and cultural services (e.g. aesthetic information, recreation, educational value). Changes in land use and its intensity are main drivers of ecosystem services change. Land conversion and land-use intensification have led to the degradation of ecosystems, biodiversity and ecosystem services across the globe (MA, 2003, 2005; Petz, 2014).

Ecosystem services have been assessed increasingly from national to European and international levels, over the last decades. The first international policy assessment with a comprehensive overview of the consequences of ecosystem change for human well-being was the Millennium Ecosystem Assessment (MA, 2003, 2005). This was later followed by the study on The Economics of Ecosystems and Biodiversity (TEEB, 2008, 2010), which gave an insight into the economic significance of ecosystems. Currently, a new standardised classification system, the Common International Classification of Ecosystem Services (CICES), is being developed by the European Environment Agency. The CICES classification builds on the existing classifications (MA, TEEB) and is aimed at a better understanding of how ecosystem services relate to particular economic activities or products and facilitate ecosystem accounts (Haines-Young and Potschin, 2011, 2013). Mapping and assessing biodiversity and ecosystem services[1] is at the core of the EU Biodiversity Strategy to 2020 (European Commission, 2011).

Ecosystems and the services they provide are being degraded across Europe. The EU has set targets for 2020 to halt the loss of biodiversity and improve the state of ecosystem services. The EU Biodiversity Strategy formulates this as follows: *'Halting the loss of biodiversity and the degradation of ecosystem services in the EU by 2020, and restoring them in so far as feasible, while stepping up the EU contribution to averting global biodiversity loss'* (European Commission, 2011).

Aim of the report

This report provides background information on modelling of land use, land management and ecosystem services (Figure 1.1). This work was carried out in close collaboration with the VU University Amsterdam and Wageningen Environmental Research. The main drivers of ecosystem services change were considered to be land cover/land use (Chapter 2), agricultural intensity, forest management and the presence of green landscape elements (Chapter 3). These drivers feed into the ecosystem services models (Chapter 4). These models are suitable for conducting large-scale simulations and for answering policy-relevant questions, such as 'How could changes in land use influence ecosystem services, such as soil erosion prevention and recreation capacity of the landscape in Europe?'.

The models described here, were, among others, used in the Nature Outlook project of PBL Netherlands Environmental Assessment Agency (Van Zeijts et al., forthcoming) to assess the

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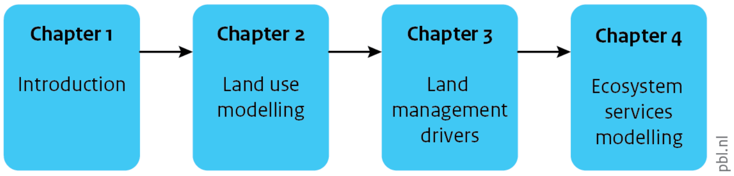
[1] The MAES (Mapping and Assessment of Ecosystems and their Services) project coordinated by the JRC Institute of Environment and Sustainability focuses on the Europe-wide mapping and assessment of ecosystem services: http://biodiversity.europa.eu/maes

effects of a *Trend scenario*. The results of the model runs are reported in detail in *Perspectives on the future of nature: impacts and combinations* (Prins et al., forthcoming).

Figure 1.1.

Set-up of the report



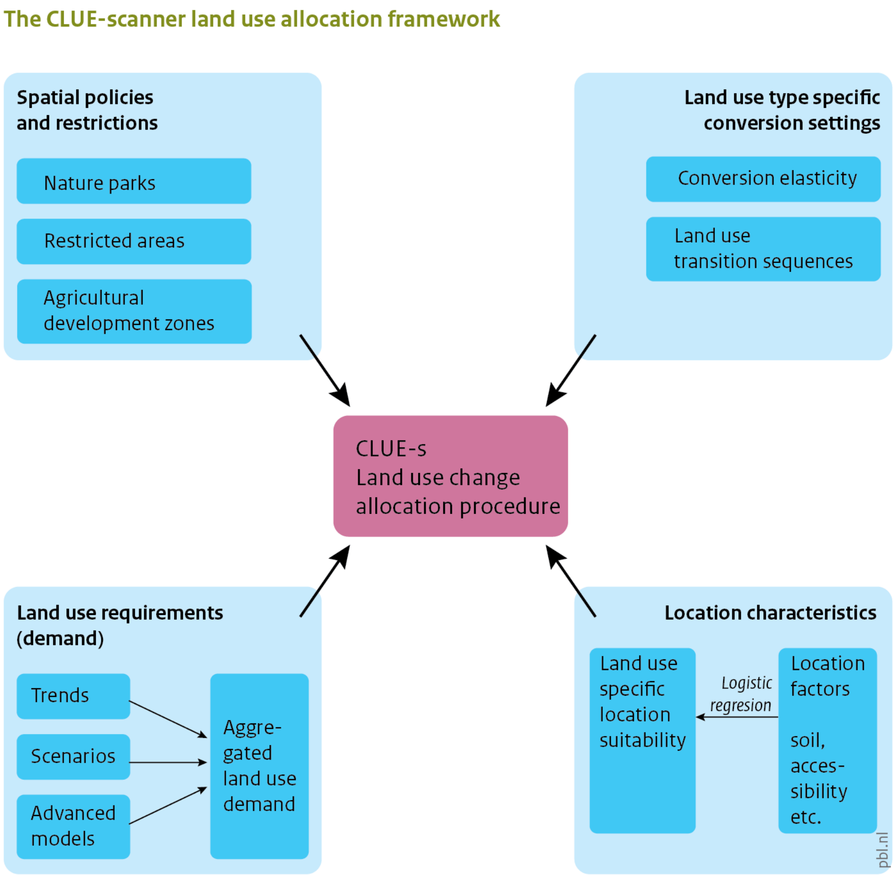
Source: PBL

2 Land-use modelling

2.1 CLUE land-use-change simulations

Land-use changes are modelled with a CLUE-scanner (Pérez-Soba et al., 2010; Verburg et al., 2012; Verburg et al., 2011), a multi-scale, multi-model framework that combines various sector models, a land-use-allocation model and indicator models, connecting analyses on global and European scales to local environmental impacts (Figure 2.1).

Figure 2.1.



Source: Perez-Soba et al. (2010)

The Dyna-CLUE model, implemented in the CLUE-scanner, simulates competition between land uses, combined with spatial allocation rules that define location suitability for land-use types, conversions between land-use types, impact of spatial policies, and neighbourhood characteristics (Verburg et al., 2010). Regrowth of natural vegetation was simulated as a function of the local growing conditions, and pressures from human population density, grazing and management (Verburg et al., 2010). The model uses a 1-year time step, 1 km^2 spatial resolution and distinguishes 17 land-use types, based on a spatially and thematically aggregated version of the CLC2000 land-cover map (EEA, 2000; Overmars et al., 2014; Schulp et al., 2016). Figure 2.1 shows the procedure for land-use-change allocation.

There are four 'boxes' of information needed to model land-use changes:

- Spatial policies and restrictions on land-use change (e.g. Natura 2000);
- Land-use requirements in terms of area demand for agriculture, urban development or nature;
- Location characteristics and maps that define the suitable location for each land-use type based on empirical analysis. For example, the European soil map can be translated into functional properties, such as soil fertility and water retention capacity. In addition to the soil map, there is a set of 100 factors that range from accessibility to bio-physical properties; the factors can be dynamic in time (e.g. in case of population which is based on scaling down EUROSTAT NUTS level projections). A full list of the factors considered can be found in Verburg et al. (2006);
- A set of rules on possible conversions between land-use types (conversion elasticity, land-use transition sequences).

For each time step, land-use demand is allocated on the basis of location characteristics, land-use-specific conversion settings and spatial policies and restrictions. The allocation is done as follows:

- The suitability for each land-use type throughout Europe is calculated;
- A preliminary land-use allocation is made by allocating the land-use type with the highest suitability to each 1 km^2 grid cell;
- The preliminary allocation is then compared with the demand;
- If the preliminary allocation does not match the demand, the competitive advantage of the land-use types is adapted and a new preliminary allocation is made;
- The first four steps are repeated until the demand has been fulfilled;
- The allocation takes into account spatial policies and restrictions by excluding designated areas from land-use changes. Rules for possible conversions between land-use types are accounted for by excluding certain land-use conversions or by increasing the suitability of land-use types relative to each other, thus making the conversion from one type of land use into another more likely. This procedure is elaborated in Section 2.3.

2.2 Technical details of land-use-change modelling

2.2.1 Land-use classification

The CLUE land-use classification system used in the CLUE-scanner was also used for ecosystem services modelling. Table 2.1 describes the 16 CLUE land-use classes used in the Nature Outlook. The CLUE classes can be easily translated into the CORINE classes (Table A1 in Appendix 1).

Table 2.1. Detailed description of CLUE land-use types used in the Nature Outlook. Descriptions and pictures are taken from Tucker et al. (2013).

Land-use coding	Name of land-use type	Detailed description of land-use type
0	Built-up area 	This land cover class contains all built-up area (and other human fabric). It includes continuous urban fabric, discontinuous urban fabric, industrial areas, commercial areas, road and rail networks, (air)ports, mineral extraction sites, dump sites, construction sites, green urban areas, sports facilities, and leisure facilities.
1	Arable land (non-irrigated) 	This land cover class contains all agricultural land that is not pasture or permanent crops. In case biofuels are separately shown on the map they are excluded from this class. In addition, this class does not include irrigated agricultural land uses (i.e. irrigated arable land) and permanent crops.
2	Pasture 	This class contains all types of "pasture", including pastures used for the production of fodder. Included are also pastures with a lot of hedges (boscage). In principle it excludes grassland in rotation (< 5 years) which is part of arable land.
3*	(semi-) Natural vegetation 	This class includes all (semi-) Natural vegetation types that are non-forest with the exception of small forest patches as occurring in agricultural landscapes. This class includes Natural grasslands, scrublands and regenerating forest (below 2 meters). Inland wetlands and heather/moorland are not included in this class, as they are a separate class in the CLUE-map. It includes also rangeland.

4**	Inland wetlands 	This class covers all inland wetlands and peat bogs. Only standing waters are included in this land cover class. Flowing rivers and other water courses are included in a separate class.
5**	Glaciers and snow 	This class covers all glaciers and permanent snow.
6	Irrigated arable land 	This class contains all irrigated agriculture/arable land. It includes rice fields, but not greenhouses, and spray/rotary sprinklers.
7*	Recently abandoned arable land 	This class contains recently abandoned arable land that is no longer used in a crop rotation. It includes very extensive farmland not reported in agricultural statistics. It consists of herbaceous vegetation, grasses and shrubs below 30 cm. This class naturally transgresses into the class "(semi-) Natural vegetation". Most of this land cover type is still classified as arable land or permanent crops in the input data for the CLUE-map. Therefore, this class will only evolve during the simulations.

8	Permanent crops 	This class contains all land cover classes that are associated with permanent crops. It includes all kinds of agro-forestry classes, such as dehesas and montanas.
10	Forest 	The forest class contains production forest, protected forest, and forest not currently harvested for other reasons. It does not include other types of natural vegetation, nor does it contain agro-forestry land cover types.
11**	Sparsely vegetated areas 	This class contains all land cover types that are extremely sparsely vegetated. It includes bare rock and, badlands, etc.
12**	Beaches, dunes and sands 	This class includes land cover types such as beaches, dunes and sands in general.

13**	Salines 	This class contains salt pans, but excludes salt marshes.
14**	Water and coastal flats 	All water surfaces and coastal flats
15**	Heathland and moorlands 	Vegetation with low and closed cover, dominated by bushes, shrub and herbaceous plants (heather, briars, broom, gorse, laburnum). Most often succession into forest vegetation is constraint by climate or soil conditions.
16*	Recently abandoned pasture land 	This class contains recently abandoned pasture land. It includes very extensive pasture land not reported in agricultural statistics. It consists of herbaceous vegetation, grasses and shrubs below 30 cm. This land cover class contains vegetation that is no longer production grassland but cannot yet be considered Natural grassland. It may be under very extensive grazing regime not being respected in agricultural statistics. This may include horse keeping. This class Naturally transgresses into the land cover class "(semi-) Natural vegetation". Most of this land cover type is still classified as pasture land in the land use map of the year 2000. Therefore, this class will only evolve during the simulations.

* These classes are considered to be an intermediate stage in the natural succession from recently abandoned farmland to (semi-) natural vegetation. Under certain conditions, succession will be so slow that the vegetation will remain classified under the abandoned farmland class for a long period of time.

** These land-use types are assumed to be constant during simulations with CLUE. These areas are assumed to be unsuitable for agriculture or urban expansion. This assumption is based on the adverse environmental conditions at these locations. Natural succession is also assumed to be hampered by adverse environmental conditions.

2.2.2 Location-specific preference additions

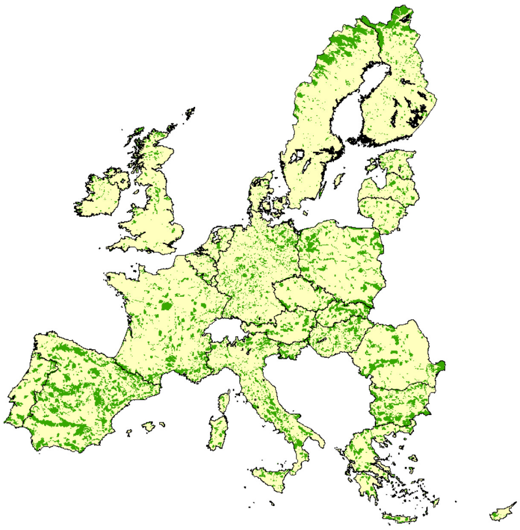
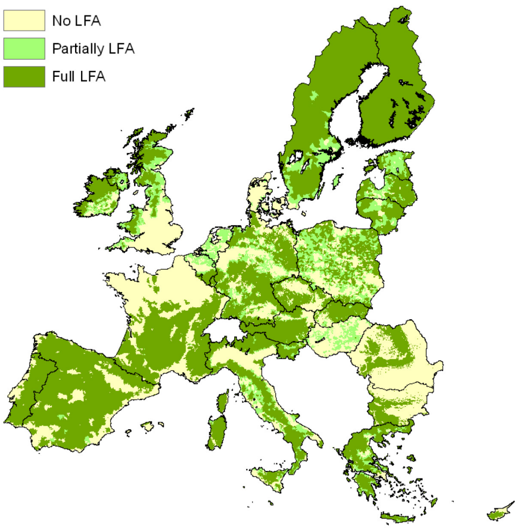
Spatial policies can change the suitability for a certain land use at a certain location. For example, farming can continue on areas less suitable for arable production based on soil and climatic due to Less-Favoured Area (LFA) subsidy. Such an effect of a policy is modelled by increasing the suitability of a location for a land-use type in areas to which the policy is targeted (Figure 2.1, top left box). Default values for the changes in suitability due to the location-specific preference additions representing the spatial policies, have been defined. . Table 2.2 lists the default settings for spatial zonings and Table 2.3 describes the maps. Table 2.4 describes the weight assigned to the location-specific preference addition maps in the modelling of land-use change.

Table 2.2. Default location-specific preference additions used in modelling land-use changes. 'X' indicates that a spatial zoning is included in the location-specific preference additions.

Spatial zoning	Default settings
Natura 2000 areas	X
LFA areas cropped in the year 2000	X
National protected areas	
Areas with a high provision of regulating and cultural ecosystem services	
Areas with a high erosion risk	X
Semi-natural areas in the year 2000	
Areas that are cropped in the year 2000*	X

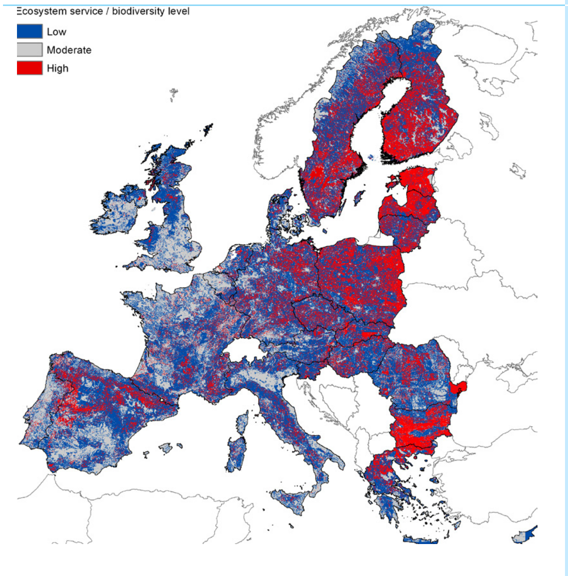
* *arable land, permanent grassland and permanent crops*

Table 2.3. Maps of location-specific preference additions. Descriptions and pictures are taken from Tucker et al. (2013).

Map	Description
	Natura 2000 areas A definite GIS map for Natura 2000 is not available to date, therefore a preliminary version was used for this project. The European Natura 2000 database holds information about sites designated by EU Member States under the Birds Directive (79/409/EEC) and the Habitats Directive (92/43/EEC). These are referred to as Specially Protected Areas (SPAs) for birds and adopted Sites of Community Importance (SCIs) for habitats and other species.
	LFA’s The LFA map is derived from the spatial dataset Less-Favoured Areas 2000-2006 based on GISCO Communes version 2.3. Areas that are fully eligible to one of the LFA articles are classified as 1. The non-LFA areas are classified as 0.

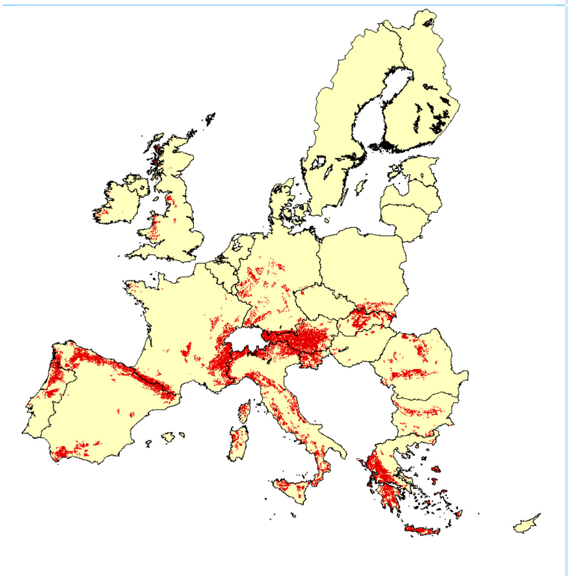
National protected areas

Map of WDPA areas up to IUCN category IV (IUCN and WDPA, 2013).



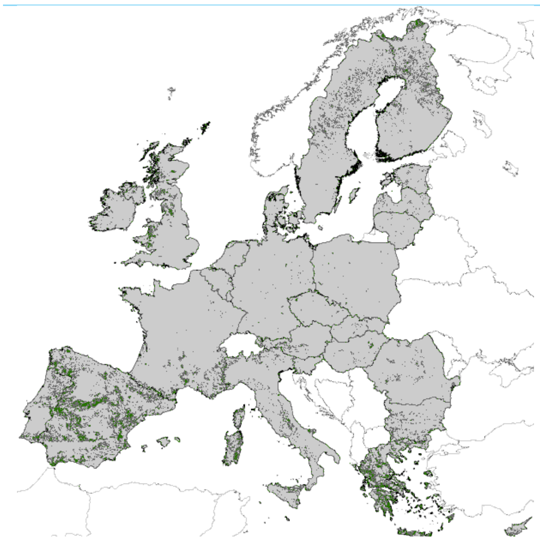
Ecosystem services and biodiversity areas

This map identifies areas with a low, moderate or high potential for ecosystem services supply or biodiversity. For this, a map of the bundle of regulating services was used. The ES bundle map is the sum of the normalised services. A map of bird species richness in 2000 was normalised and added. The map was reclassified to distinguish the hotspots (areas with values in the upper quartile of the values distribution) and cold spots (areas with values in the lower quartile of the values distribution).



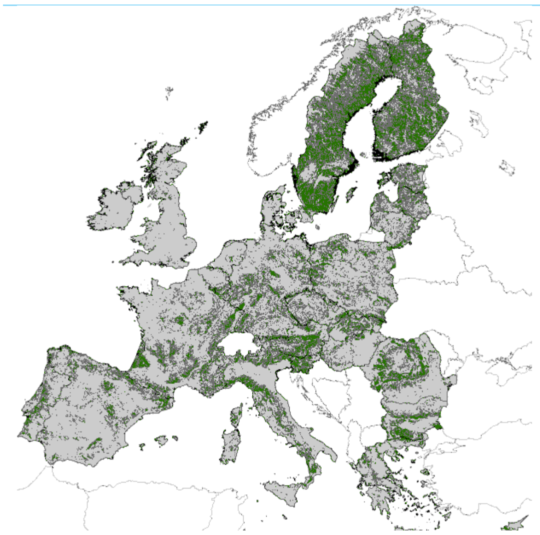
Erosion sensitive areas

Delineation of areas with a high potential for soil erosion. Derived from a potential soil erosion map that was computed as the product of slope, soil erodibility and rain erosivity. A threshold was identified by making an overlay with current arable land, whereby it was aimed that approximately 8% of current arable land would be eligible for receiving subsidies to prevent soil erosion.



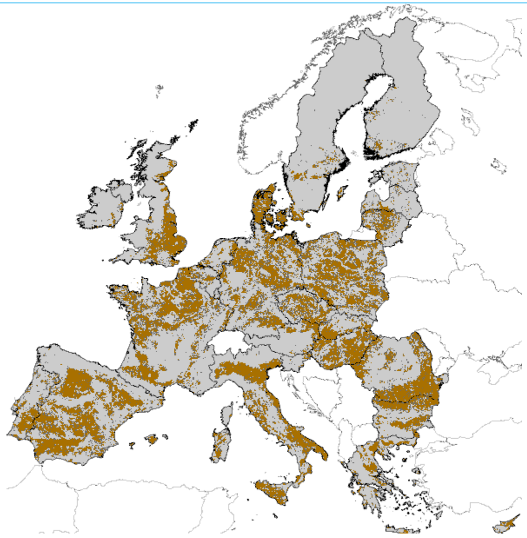
(Semi)natural areas

Delineation of natural and semi-natural vegetation in the year 2000.



Forest areas

Delineation of forested areas in the year 2000.



Cropped areas

Delineation of cropped areas in the year 2000.

Table 2.4. Description and weight of location-specific preference addition maps for the default settings.

Land-use code and name		Default settings
0	Urban	
1	Rain fed arable	0.2 in currently cropped LFA areas
2	Pasture	0.2 in currently cropped LFA areas
3	Semi-natural	
4	Irrigated arable	
5	Recently abandoned arable	
6	Permanent crops	0.2 in currently cropped LFA areas
7	Forest	
8	Recently abandoned pasture	
9	Static land use types	

2.2.3 Land-use conversions

'Allow drivers' are maps that define locations where certain land-use conversions are or are not allowed (e.g. protected areas), or where there are temporal constraints on certain conversions (e.g. succession time). These allow driver maps contain the spatially explicit settings as used in the conversion matrices. Table 2.5 gives a description of these drivers. The model codes indicated by 'X..' refer to the specific allow driver maps in the CLUE-scanner framework and the driver codes are used in the conversion matrices. Drivers specifying temporal constraints indicate the maximum or minimum years after which a conversion can or should take place.

Table 2.5. Description of spatial restrictions maps.

Model Code	Driver code	Driver description
X1	52	Natura2000 (0, outside 1)
X4	55	Succession semi-natural to forest in A1 and A2
X5	56	Succession abandoned arable to semi-natural in A2
X6	57	Succession abandoned pasture to semi-natural in A2
X7	60	Natura2000 + erosion sensitive (0; outside (1)

Table 2.6 presents the used conversion matrix for the Trend scenario. This table indicate which land-use conversions are allowed. Values of 1 indicate that the conversion is allowed, values of 0 indicate that the conversion is not allowed. Other numbers refer to the spatial restrictions maps listed in Table 2.5. For example, a conversion from semi-natural to arable land is allowed outside Natura 2000 sites. Inside Natura 2000 sites such change is not allowed (code 52).

Table 2.6. Conversion matrix for the Trend scenario. Values of 1 indicate that the conversion is allowed, values of 0 indicate that the conversion is not allowed. Other numbers refer to the spatial restrictions maps listed in Table 2.5.

Current land use	Conversion to: Built-up	Arable	Pasture	Semi-natural	Irrigated arable land	Abandoned arable	Permanent crops	Forest	Abandoned pasture	Other
Built-up	1	0	0	0	0	0	0	0	0	0
Arable	1	1	1	0	0	1	1	0	0	0
Pasture	1	1	1	0	0	0	1	0	1	0
Semi-natural	1	52	52	1	0	0	52	55	0	0
Irrigated arable land	0	0	0	0	1	0	0	0	0	0
Abandoned arable	1	52	52	56	0	1	52	0	0	0
Permanent crops	1	1	1	0	0	1	1	0	0	0
Forest	1	52	52	0	0	0	52	1	0	0
Abandoned pasture	1	52	52	57	0	0	52	0	1	0
Other	0	0	0	0	0	0	0	0	0	1

2.2.4 Conversion elasticities

The conversion elasticities (Table 2.7) determine how easily a certain land use can be converted into another and are therefore a proxy for the conversion costs (0 = very easy to convert and 1 is very difficult to convert). These values are based on expert knowledge and calibration of earlier applications of this modelling framework (Verburg and Overmars, 2009).

Table 2.7. Conversion elasticities. Values of 1 indicate the conversion is difficult, values of 0 indicate the conversion is easy.

Land-use type	Default settings
Built-up	1
Arable	0.4
Pasture	0.3
Semi-natural	0.7
Irrigated arable land	1
Abandoned arable	0.3
Permanent crops	0.8
Forest	0.7
Abandoned pasture	0.3
Other	1

2.2.5 Neighbourhood settings

The neighbourhood settings determine how the land-use allocation depends on the land use in the surrounding areas, and this is used to determine the fragmentation patterns. For each land-use type, a fraction of the suitability that is defined by neighbourhood settings is specified (Table 2.8). This varies between zero (no impact of land use in surrounding areas) to 1 (allocation fully based on land use in surrounding areas). Second, the size of the surrounding area is specified for each land-use type (Table 2.9). The values are chosen on the basis of the scenario specifications and calibrated on the basis of previous model applications (Verburg and Overmars, 2009).

Table 2.8. The fraction of the location suitability that is determined by land use in the surrounding areas. Value of '0' indicates there is no such influence, and '1' indicates that the land use in the surrounding area fully determines the allocated land use.

Land-use type	Default settings
Built-up	0.3
Arable	0
Pasture	0
Semi-natural	0
Irrigated arable land	0
Abandoned arable	0
Permanent crops	0
Forest	0
Abandoned pasture	0
Other	0

Table 2.9. Cells considered for calculating neighbourhood effects. The '0' value indicates the cell for which these effects were calculated. Values >0 represent the cells used for calculating neighbourhood effects, including their awarded weight, ranging from 0.001 to 1.

Land-use type	Default settings
Built-up	11111 11111 11011 11111 11111[2]

[2] Standard CLUE-simulation documentation. It indicates that 2 cells around each cell are included in calculating neighbourhood effects, in each direction.

3 Land management drivers

This chapter describes the characteristics of the land management drivers used in the ecosystem, modelling (Table 3.1). Maps for the drivers serving as input in the ecosystem service models were created for the Trend scenario (year 2000 and 2050).

Table 1.1. Land management drivers considered.

Land management drivers	Unit	Source
Agricultural intensity	5 classes	CAPRI-CLUE modelling (Temme and Verburg, 2011)
Forest management	5 classes	Forest Management Approaches (Duncker et al., 2012; Hengeveld et al., 2012) implemented in EFISCEN model (Schelhaas et al., 2007)
Green elements	Number of intersects	Tieskens et al. (submitted)

3.1 Agricultural intensity

We built on the methodology of Temme and Verburg (2011), who proposed to use a combination of European level databases to construct land-use intensity maps with separate methodologies for arable land and grassland.

Nitrogen application was used as an indicator for the intensity of arable land management. Data at the highest spatial resolution available are on NUTS2/3 level. For each administrative unit, nitrogen input levels are reported per crop type collected within the Farm Structure Survey (FSS) and the Land Use/Cover Area frame statistical Survey (LUCAS) (Gallego and Delincé, 2010). LUCAS provides point-based observations of crop types from 2006, for about 150,000 sample points across agricultural areas in the EU. Each point of the LUCAS data set was assigned the crop-specific nitrogen application rate reported in the FSS data set for the corresponding administrative unit, assuming that variation in nitrogen application within an administrative unit may be approximated by the cropping pattern. Nitrogen application rates were then classified into three classes: low (<50 kg/ha); medium (50–150 kg/ha) and high (>150kg/ha) (Overmars et al., 2014) (Table 3.2). Based on these observations of nitrogen application rates, the probability of occurrence of each intensity class at a specific location was explained by a set of environmental and socio-economic locational factors using multinomial regression. Locational factors included are topographic conditions, soil and climate conditions, population densities and accessibility. A list of all factors included is provided by Temme and Verburg (2011).

For grassland a different approach was taken as for arable land, also as described by Temme and Verburg (2011). For the LUCAS observations of grassland, the nitrogen input was estimated based on the local stocking densities with cattle. Stocking densities were derived from the livestock maps of Neumann et al. (2009). We assumed a uniform quantity of 100 kg N/ha per cow per year and reclassified the observations into two classes: intensive grassland with > 50 kg N/ha and extensive grassland with < 50 kg N/ha (Table 3.2). Similar to the procedure for arable land, country-specific logistic regression models are estimated and used within the administrative units for scaling down the areas of the different intensity classes to individual locations.

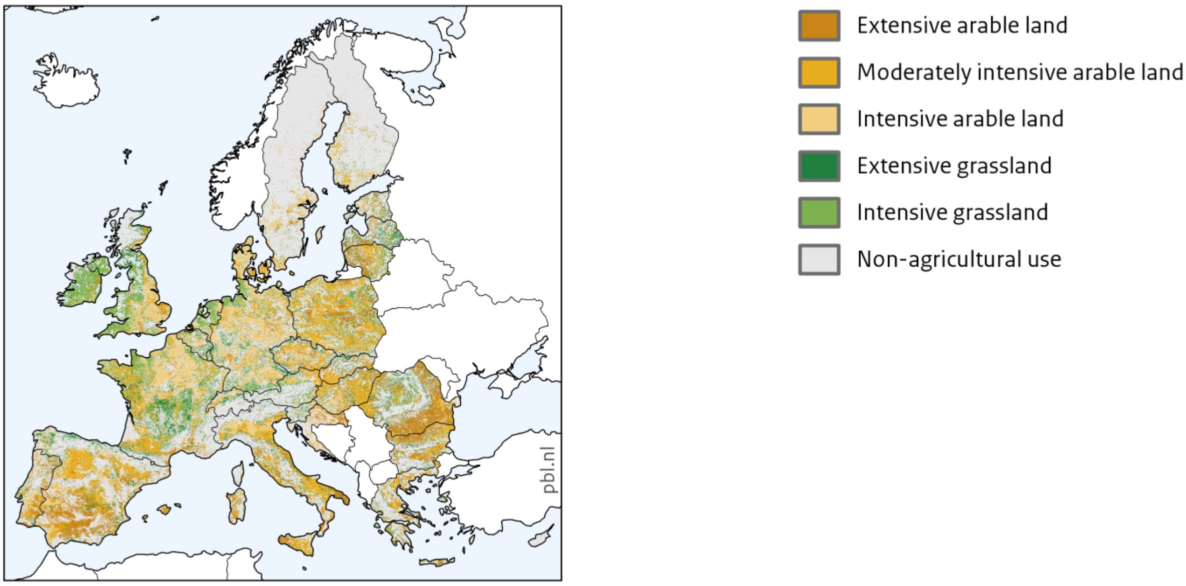
The estimated regression models were used to predict the intensity class on each location classified as arable land or pasture. This was done based on the areas required for each intensity class following CAPRI simulations for specific years. The regression models were estimated for all countries. For the countries without LUCAS data (Czech Republic, Slovakia, Hungary, Romania and Bulgaria), we used regressions estimated from neighbouring countries with comparable agricultural practices. For Croatia and Switzerland, intensity classes were derived from (Monfreda et al., 2008). Maps of fertiliser and manure input were added together, smoothed and expanded to the missing border cells by a 75 km circle focal mean, extracted for cropland and grassland in the year 2000 and reclassified following the three classes: low (<50 kg/ha); medium (50–150 kg/ha) and high (>150 kg/ha). Figure 3.1 shows the land-use intensity for 2000.

Table 3.2. Explanation of the agricultural intensity map.

Intensity class	Explanation	Ellenberg N range	Intensity class	Explanation	Ellenberg N range
1 Extensive	Arable land, <50 kg N/ha	3–6	4 Extensive	Pasture, <50 kg N/ha	3–7
2 Moderately intensive	Arable land, 50–150 kg N/ha	5–8	5 Intensive	Pasture, 50–150 kg N/ha	6–9
3 Intensive	Arable land, >150 kg N/ha	7–9			

Figure 3.1.

Land use intensity, 2000



Source: CAPRI-CLUE modelling

3.2 Forest management

We used the EFISCEN model (European Forest Information SCENario model) to simulate forest management (Schelhaas et al., 2007). EFISCEN is a large-scale forest resource model, used to provide projections under alternative scenarios. It was originally developed for Sweden (Sallnäs, 1990) and later applied to the whole of Europe to explore the future of forests, including growth rate, climate impacts and carbon budgets (Nabuurs et al., 2006; Schelhaas et al., 2007). The model was also used, among others, in the European Forest Sector Outlook Study (United Nations et al., 2011) and the VOLANTE EU project for exploring the future of the European forestry sector and modelling forest ecosystem services.

The EFISCEN model works at the aggregated level of provinces to national level, depending on the forest area and data availability. The initial state of the forest and the current growth are derived from detailed measurements, usually done by the respective National Forest Inventory (NFI). For use in the model, the data are aggregated to regions, tree species, site classes and/or ownership ('forest types'). Data needed are area, average growing stock and average growth per age class for each of these combinations, for each country under study. The state of the forest is described by a distribution of area over age and volume classes; the development over time is determined by natural processes (e.g. growth and mortality) and influenced by management regimes (i.e. thinning, final felling, choice of tree species in regeneration) and changes in forest area. Management can be optimised for different targets, such as biodiversity conservation and wood energy maximisation. The initialisation data used in Nature Outlook are the same as in VOLANTE. More details on the EFISCEN initialisation data can be found in the VOLANTE project documentation (Lotze-Campen et al., 2013). The Trend scenario in the Nature Outlook is based on the A2 scenario of the VOLANTE project. A description of the scenario implementation and the model framework can be found in the VOLANTE project documentation (Lotze-Campen et al., 2012).

To run the EFISCEN model, information about wood demand, afforestation/deforestation, changes in growth level as a consequence of climate change and (changes in) forest management are needed. Five forest management approaches (FMA) are distinguished (Duncker et al., 2012) (Table 3.3), explicitly mapped over Europe (Hengeveld et al. 2012). Suitability of a certain location for each FMA is based on 1) dominant tree species, 2) biogeographic region, 3) slope, 4) proximity to smaller cities, 5) proximity to larger cities, 6) percentage of forest cover, 7) stand area, and 8) Natura2000 coverage. The factors are weighted based on expert knowledge. The resulting map indicates the suitability of a location for a particular FMA. Separate maps for the individual FMAs are merged into a single map by attributing the FMA with the highest suitability to each location. Comparison of this map with forest inventory data from the Netherlands and Umbria showed that the FMA map consistently slightly underestimated the intensity of the management regime (Hengeveld et al., 2012). This was confirmed in a comparison with country-level statistics. The map is documented in more detail in Hengeveld et al. (2012). The forest map is static potential forest management map, i.e. only available for the year 2000 (Figure 3.2). Actual forest area was clipped for the year 2000 and 2050. Except for the area of forest, no changes were assumed for 2050.

Based on an overlay of the species map (Brus et al., 2012) and the potential FMA map (Hengeveld et al., 2012), we identified for each species how much area is managed according to a certain FMA, for the base land-use map of 2000. Each of these FMAs was run separately in the EFISCEN model. FMA3 is managed with limited interventions to balance economic and ecological objectives. FMA4 and FMA5 have intensive management with shortened rotations of 10 and 20 years, respectively. FMA2 has a prolonged rotation of 20 years to mimic natural processes, and FMA1 is unmanaged (Duncker et al., 2012; Hengeveld et al., 2012). The matching of the species represented in EFISCEN and those in the map by Brus et al. (2012) is similar to that in Schelhaas et al. (2015). First, FMA5 was deducted from the national wood demand, then FMA4 was deducted from the remaining demand, and so on.

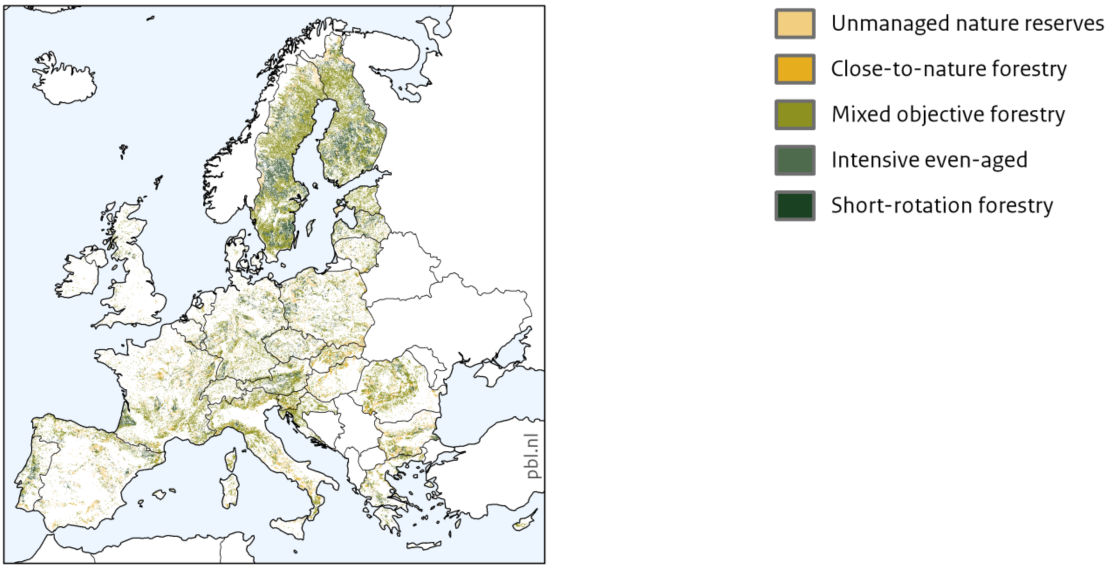
The model produces several outputs, such as increment, stem wood removal, extracted residues, deadwood, and carbon in biomass and soil, for the EU-27 countries on NUTS 2 level. Results from all FMA runs were aggregated to the country level and subsequently scaled down to a 1 km^2 gridded species map (Brus et al., 2012).

Table 3.3. Forest Management types.

FMA	Explanation
1	Unmanaged nature reserves
2	Close-to-nature forestry
3	Mixed objective forestry
4	Intensive even-aged
5	Short-rotation forestry

Figure 3.2.

Distribution of forest area over the Forest Management Approaches, 2000



Source: EFISCEN modelling

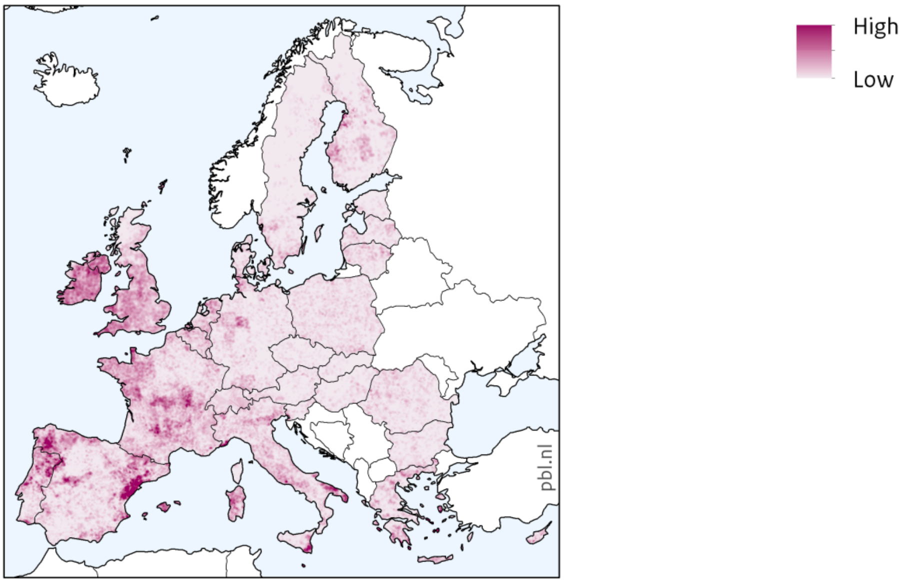
3.3 Green landscape elements

Green linear landscape elements (GLs) are hedgerows and tree lines across the landscape. The map of the presence of green lines from Tieskens et al. (submitted) was used for the year 2000 (Figure 3.3). Regarding the extrapolation for 2050, our assumption was that at places where agricultural field size is small (i.e. smaller than 10 ha) and agriculture becomes more intensive, green elements disappear by 2050. For agricultural field size, the map from Kuemmerle et al. (2013) was used. The map of Tieskens et al. (submitted) excludes Croatia. Therefore, for Croatia we assumed no GLs.
There is another map of green lines by Van der Zanden et al. (2013). The main difference between the two maps is that Van der Zanden et al. (2013) used the LUCAS 2009 database with different sampling methods for western and eastern Europe and made a scale up on the basis of region-

specific regression, whereas Tieskens et al. (submitted) used the LUCAS 2012 database and simple kriging. The map of Van der Zanden et al. (2013) excludes Croatia, Romania, Bulgaria and Switzerland, whereas as the map of Tieskens et al. (submitted) excludes only Croatia. We tested that using another GL map has little effect on the ecosystem services results.

Figure 3.3.

Presence of green landscape elements, 2000



Source: Tieskens et al. (submitted)

4 Ecosystem services modelling

This chapter describes the ecosystem services models used in the Nature Outlook and model settings for the Trend scenario. Furthermore, examples for output maps are presented and uncertainties are discussed. Because of their generic character, the ecosystem services models could be applied also beyond the Nature Outlook.

4.1 Indicators for ecosystem services

4.1.1 Overview

Seven GIS-based ecosystem services models are described that can assess scenario effects for wild food provision, carbon sequestration, flood regulation, erosion prevention, pollination, pest control and recreation. Six of the ecosystem services models (wild food provision, carbon sequestration, flood regulation, erosion prevention, pollination and recreation) were adopted from the VU University Amsterdam. Most models are developed within the CONNECT project. Most models have been applied for European scale policy support before (Schulp et al., 2016; Tucker et al., 2013). The pest control model was developed by PBL building on earlier works. The models can be classified as ‘intermediate complexity’ models, which are suitable for large-scale simulations but are closely based on scaled up results of more process-based models (Schulp et al., 2014b). Timber production was simulated with the EFISCEN model (Schelhaas et al., 2007) run by Wageningen Environmental Research. A full model documentation is provided by Schelhaas et al. (2007) and this model is not further described here. Table 4.1 provides an overview of the studied ecosystem services following the CICES classification (Maes et al., 2015) and their modelled indicator.

Table 4.1. Overview of the included ecosystem services.

CICES category	Modelled indicator description	Reference
PROVISIONING – Nutrition – Wild Food	Species richness of edible wild plants, mushrooms and game	Schulp et al. (2014a)
PROVISIONING – Materials – Timber production	Timber production	Schelhaas et al. (2007)
REGULATING – Regulation of physical environment – Carbon sequestration	Sequestration and emission of CO_2 in soil and vegetation	Schulp et al. (2008)
REGULATING – Flow regulation – flood regulation	Relative water retention in river catchment	Stürck et al. (2014) and (2015b)
REGULATING – Flow regulation – Erosion prevention	Erosion risk; protective vegetation cover	Pérez-Soba et al. (2010) and Tucker et al. (2013)

REGULATING – Regulation of biotic environment – Pollination	Percentage of cropland that can be accessed by pollinators from natural habitat	Serna-Chavez et al. (2014)
REGULATING – Regulation of biotic environment – Pest control	Pest predation rate (in %)	This report (Petz et al. 2016)
CULTURAL – Intellectual and Experiential– Recreation	Capacity of the landscape to support recreation	Van Berkel and Verburg (2011)

4.1.2 Technical issues

The coverage of the study is EU 29 (EU 28 + Switzerland). For wild food and recreation, the modelling was done without Switzerland and Croatia (EU-27). Land-use simulations and indicator simulations were done based on a WGS1972 Albers Conical Equal Area projection. A 1 km spatial resolution was used. All models, except those on flood regulation, are available as ArcInfo AML scripts and ArcInfo Model Builder version. The flood regulation model combines MatLAB calculations and ArcGIS Model Builder components. The pest control model is available only in ArcInfo Model Builder. For the carbon sequestration, erosion prevention and pollination r scripts are available.

4.2 Wild food provision

4.2.1 Methodology

Table 4.2. The main characteristics of the wild food availability model.

Indicator name	Wild food availability
Short description	Species richness of a set of vascular plant, mushroom, and game species that are collected and consumed throughout Europe
Units	Number of species
Spatial resolution	1 km^2
Temporal resolution	Start and end year of simulation
Output maps	Game species richness; Mushroom species richness; Vascular plant species richness; Total wild food species richness; Wild food sufficiency / variety index
Main reference	Schulp et al. (2014a)

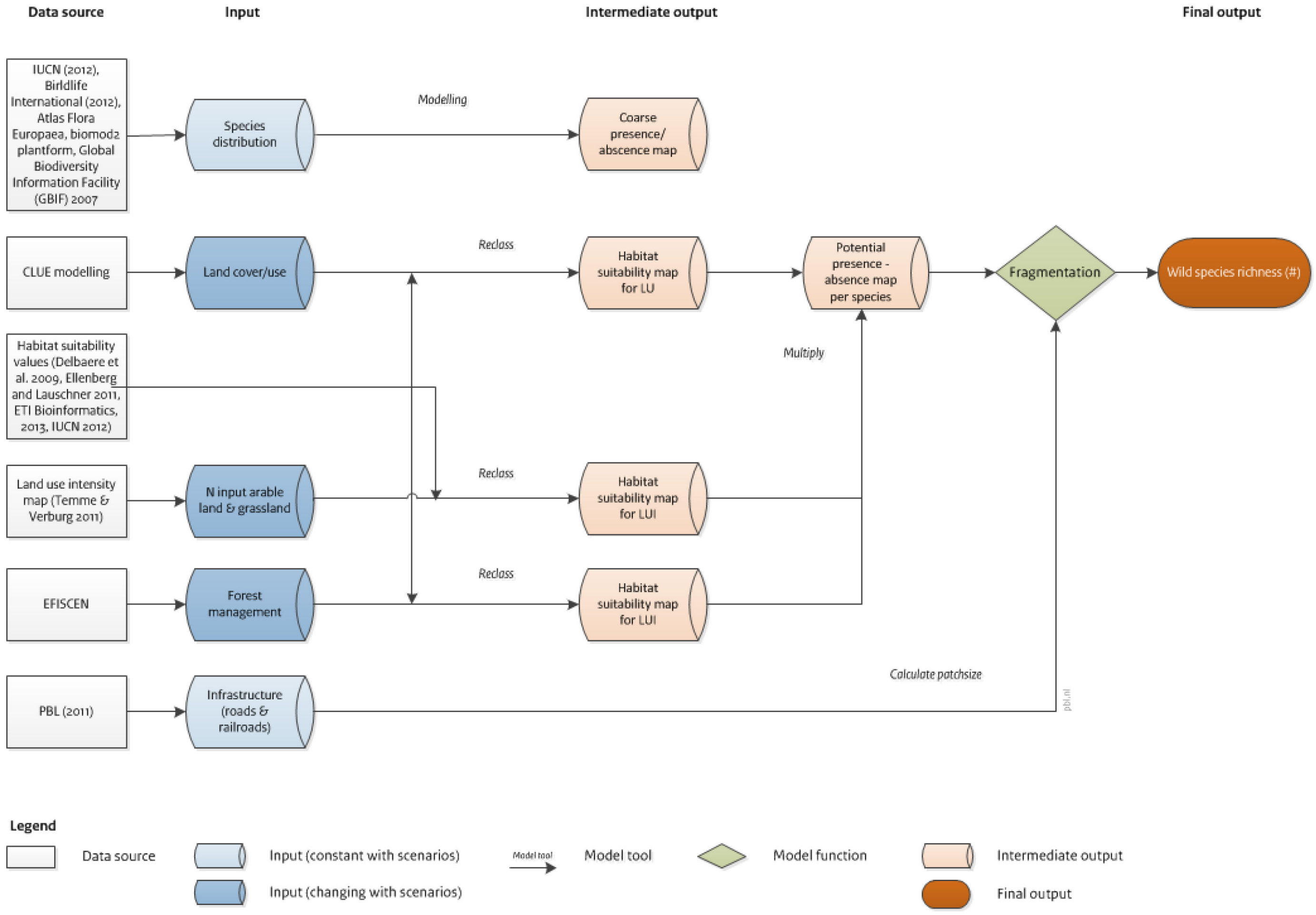
Table 4.2 gives an overview of the main characteristics to simulate wild food supply in Europe (Schulp et al, 2014a). Figure 4.1 gives a schematic overview of the model and the input and output data are described in Table 4.3. The AML model script is presented in Appendix 2. Because of the data availability, simulation is only applied to the EU-27 (without Switzerland and Croatia). The model from Schulp et al. (2014a) has also a component to simulate wild food demand in Europe.

Table 4.3. Input and output parameters of the wild food availability model.

Name	Unit	Source	Description
INPUT			
Land cover	CLUE classes (16)	CLUE modelling	CLUE land-cover map 1x1 km
Agricultural intensity	5 classes	CLUE modelling	Agricultural intensity measured by N input
Forest management	5 classes	EFISCEN modelling	Forest management map
Species distribution	Presence/absence (≥50 km resolution)	IUCN (IUCN, 2012), Birdlife International (2012) and the Atlas Flora Europaea (Lahti and Lampinen, 1999)	Broad-scale distribution maps of wild food species
	Probability of occurrence (≥50 km resolution)	Guisan and Thuiller (2005) and Thuiller et al. (2009)	Consensus map of probability of occurrence of species for which no distribution maps were available. Calculated with Biomod2 platform.
Habitat suitability values	Yes (1) / No (0)	Delbaere et al. (2009)	Habitat suitability values based on CORINE land cover
	Yes (1) / No (0)	Delbaere et al. (2009), Ellenberg and Lauschner (Ellenberg and Lauschner, 2010)	Habitat suitability values based on agricultural land-use intensity
	Yes (1) / No (0)	Delbaere et al. (2009), ETI Bioinformatics (2013), IUCN (2012), Bundesambt für Naturschutz (2001)	Habitat suitability values based on forest management
Infrastructure	Yes (1) / No (0)	PBL (2011)	Major roads and railroads
OUTPUT			
Game/mushroom/plant availability	Species number		Richness of wild plant, mushroom or game species (#)
Wild food availability	Species number		Total wild species richness (#)
Wild food sufficiency / variety index	Categorical variable (see description)		Indication if wild food species are absent, available in limited richness, or available in abundant richness

Figure 4.1.

Wild food model



Source: Schulp et al, (2014, a)

Wild food availability was measured as the species richness of a set of vascular plant, mushroom, and game species that are collected and consumed in a grid cell. In the wild food availability model (2014a), an indicator for species richness of main wild food species is used that was based on an extensive literature review about wild food consumption (Eggers et al., 2009; Louette et al., 2010; Overmars et al., 2014). The indicator was calculated from data on species occurrence and their sensitivity to environmental pressures (Delbaere et al., 2009), namely land-use and management changes. The impact of land-use and management change is expected to be an important driver for wild food species in the coming decades and is therefore chosen as the environmental pressure of interest.

In the literature review of Schulp et al. (2014a), wild food species collected and consumed in the EU were identified. This included 97 game species, 152 mushroom species and 592 vascular plant species. While the collection and consumption of most of these species is restricted to a specific EU region, a subset of species is commonly collected and consumed throughout Europe. This included 38 game species, 27 mushroom species and 89 vascular plant species. This subset is used to map the spatial variability of wild food availability. A few species were not included because of lack of spatial data. The final species selection is given in Table 4.4, Table 4.5 and Table 4.6.

Table 4.4. Mushroom species included in wild food supply model.

Latin name	Code	Latin name	Code
Agaricus arvensis	MR1	Lactarius sanguifluus	MR14
Agaricus campestris	MR2	Leccinum scabrum	MR15
Agaricus silvaticus	MR3	Lepista nuda	MR16
Armillaria mellea	MR4	Macrolepiota procera	MR17
Boletus edulis	MR5	Morchella esculenta	MR18
Cantharellus cibarius	MR6	Pleurotus ostreatus	MR19
Clitocybe odora	MR7	Russula cyanoxantha	MR20
Craterellus cornucopioides	MR8	Suillus grevillei	MR21
Fistulina hepatica	MR9	Suillus luteus	MR22
Hydnum repandum	MR10	Suillus variegatus	MR23
Hygrophorus eburneus	MR11	Tricholoma terreum	MR24
Laccaria amethystine	MR12	Tuber aestivum	MR25
Lactarius deliciosus	MR13	Xerocomus chrysenteron	MR26

Table 4.5. Vascular plant species included in the wild food supply model.

Latin name	Code	Latin name	Code	Latin name	Code
Achillea millefolium	VP1	Fragaria vesca	VP31	Ribes rubrum	VP61
Allium ampeloprasum	VP2	Hippophae rhamnoides	VP32	Ribes uva-crispa	VP62
Allium schoenoprasum	VP3	Humulus lupulus	VP33	Rosa canina	VP63

Allium ursinum	VP4	Juniperus communis	VP34	Rosa pouzinii	VP64
Amelanchier ovalis	VP5	Lathyrus tuberosus	VP35	Rosa tomentosa	VP65
Argentina anserina	VP6	Laurus nobilis	VP36	Rosmarinus officinalis	VP66
Arum italicum	VP7	Malus sylvestris	VP37	Rubus caesius	VP67
Asparagus acutifolius	VP8	Malva sylvestris	VP38	Rubus chamaemorus	VP68
Berberis vulgaris	VP9	Matricaria chamomilla	VP39	Rubus fruticosus	VP69
Bunium bulbocastanum	VP10	Mentha aquatica	VP40	Rubus idaeus	VP70
Calamintha nepeta	VP11	Mentha arvensis	VP41	Rubus loganobaccus	VP71
Capparis spinosa	VP12	Mentha longifolia	VP42	Rubus ulmifolius	VP72
Capsella bursa-pastoris	VP13	Mentha pulegium	VP43	Rumex acetosa	VP73
Carum carvi	VP14	Mentha spicata	VP44	Rumex acetosella	VP74
Castanea sativa	VP15	Mentha suaveolens	VP45	Salvia officinalis	VP75
Celtis australis	VP16	Myrtus communis	VP46	Sambucus nigra	VP76
Chenopodium album	VP17	Nasturtium officinale	VP47	Scolymus hispanicus	VP77
Chenopodium bonus-henricus	VP18	Origanum heracleoticum	VP48	Silene vulgaris	VP78
Cichorium intybus	VP19	Origanum vulgare	VP49	Sonchus oleraceus	VP79
Cirsium arvense	VP20	Oxalis acetosella	VP50	Sorbus aucuparia	VP80
Cornus mas	VP21	Papaver rhoeas	VP51	Taraxacum officinale	VP81
Corylus avellana	VP22	Petroselinum crispum	VP52	Thymus serpyllum	VP82
Crataegus monogyna	VP23	Plantago lanceolata	VP53	Tussilago farfara	VP83
Cynara cardunculus	VP24	Portulaca oleracea	VP54	Urtica dioica	VP84
Daucus carota	VP25	Prunus avium	VP55	Vaccinium myrtillus	VP85
Diplotaxis tenuifolia	VP26	Prunus spinosa	VP56	Vaccinium oxycoccos	VP86
Elymus repens	VP27	Prunus virginiana	VP57	Vaccinium uliginosum	VP87
Eruca sativa	VP28	Ranunculus ficaria	VP58	Vaccinium vitis-idaea	VP88
Ficus carica	VP29	Ribes alpinum	VP59	Viola odorata	VP89
Foeniculum vulgare	VP30	Ribes nigrum	VP60		

Table 4.6. Game species included in the wild food supply model. Effects of habitat fragmentation are considered for the species presented in *bold italic*.

Latin name	Code	Latin name	Code	Latin name	Code
Alces alces	GA1	Coturnix coturnix	GA12	Sus scrofa	GA23
Alectoris rufa	GA2	***Dama dama***	GA13	Tetrao tetrix	GA24
Anas clypeata	GA3	Gallinago gallinago	GA14	Turdus merula	GA25
Anas crecca	GA4	***Lepus europaeus***	GA15	Anser anser	GA26
Anas penelope	GA5	Lepus timidus	GA16	Anser fabalis	GA27
Anas platyrhynchos	GA6	***Oryctolagus cuniculus***	GA17	Lagopus lagopus	GA28
Anas querquedula	GA7	Perdix perdix	GA18	Phasisnus colchicus	GA29
Capra pyrenaica	GA8	Rangifer tarandus	GA19	Streptopelia decaocto	GA30
Capreolus capreolus	GA9	***Rupicapra rupicapra***	GA20	Tetrao urogallus	GA31
Cervus elaphus	GA10	***Scolopax rusticola***	GA21		
Columba palumbus	GA11	Streptopelia turtur	GA22		

The calculation rules are as follows (also see Figure 4.1):

1. For each species, coarse-scale presence/absence maps are created. These originate from IUCN (IUCN, 2012), Birdlife International (2012) and the Atlas Flora Europaea (Lahti and Lampinen, 1999). Where no coarse distribution patterns were available, the probability of occurrence was estimated using species distribution models (Guisan and Thuiller, 2005) within the biomod2 platform (Thuiller et al., 2009). Biomod2 uses an ensemble modelling approach that relates species' occurrences to selected influential environmental variables and enables examination of species–environment relations throughout a wide range of modelling techniques (Thuiller et al., 2009). The output is a consensus probability map ranging from 0 to 1. The probability of occurrence was here modelled based on occurrence data from the Global Biodiversity Information Facility (GBIF) (Yesson et al., 2007). Isothermality, temperature seasonality, temperature annual range, mean temperature of coldest quarter and annual precipitation from WorldClim (Hijmans et al., 2005) were used as dependent variables. Occurrence probability maps were then converted into binary presence/absence maps using a threshold maximising the predictive accuracy of the models.
2. These coarse-scale presence/absence maps are scaled down by using habitat suitability maps based on land cover and intensity. These maps are created as follows:
    a) For each species, a 1km resolution habitat map was made by reclassifying the land-use map from the CLUE-scanner. The habitat map indicates if the land-use type is suitable for the species (1) or not (0). This judgement of suitability was done based on habitat suitability values of each land-use type for each species (Delbaere et al., 2009). These habitat suitability values were based on CORINE land cover. For all land-use types, with the exception of built-up areas, we considered the maximum of the CORINE suitability levels given by Delbaere et al. (2009) representative for

the CLUE land-use class. For built-up areas, we used the median instead, given the underrepresentation of green elements suitable for wild flora and fauna.

b) For each species, a map of the agricultural land-use intensity (Potter et al., 2010; Temme and Verburg, 2011) was reclassified into a habitat suitability map indicating if the land-use intensity is suitable for the species (1) or not (0). Suitability ratings showing if a game or mushroom species occur in an agricultural intensity class were based on Delbaere et al. (2009), ETI Bioinformatics (2013) and IUCN (2012). Descriptions of species' response to agricultural intensity were translated into a suitability by expert judgement. For plant species, the suitability for occurrence of agricultural intensity classes were based on the Ellenberg ranges (Ellenberg and Lauschner, 2010) and Delbaere et al. (2009). Ellenberg values were translated into suitability under the assumption that if the Ellenberg N range under which a species can occur overlaps with the Ellenberg range of the agricultural intensity class (Table 3.2), then the species can occur in that intensity class (Overmars et al., 2014).

c) The impact of forest management was included based on the FMA map. The FMA map was reclassified into a habitat suitability map indicating if the forest management type is suitable for the species (1) or not (0). Information of species' response to forest intensity from Delbaere et al. (Delbaere et al., 2009), ETI Bioinformatics (ETI Bioinformatics, 2013) and IUCN (IUCN, 2012) was translated into a suitability based on expert judgement. For plants, we based the suitability on the hemerobic range as given by the Bundesambt für Naturschutz (2001). Hemeroby gives an indication for the human impact on the environment. We assumed that (1) species restricted to Hemeroby class A occur in unmanaged forests; (2) species with class O occur in close-to-nature forestry systems (3) species with Hemeroby classes M and B occur in mixed objective forestry, and species that can occur in Hemeroby classes C, P, and T can occur in intensive even-aged and short-rotation systems. Every habitat suitability is given in Appendix 4.

3. The habitat suitability maps based on land cover and intensity and the 50 * 50 km resolution presence (1) / absence (0) map are multiplied, resulting in a 1 km resolution map of potential presence / absence of each species.
4. A few species are sensitive to fragmentation of their habitat (Delbaere et al., 2009). For these species a map of the habitat patch size (obtained from the previous step) intersected with the roads and railroads was created. Following Alkemade et al. (2009), suitability of patches with a size <500 km2 was set to zero.
5. Species richness maps are calculated by adding together the maps of the previous steps.
6. The wild food variety / sufficiency index indicates if wild food species are absent, available in limited richness, or available in abundant richness. To calculate the indicator, firstly, the plant species richness and mushroom species richness maps were added together. Secondly, the plants and mushroom species richness as well as the game species richness were classified into the classes absent (0), species richness lower than median (1), and species richness equal to or higher than median (2) (Table 4.7). Static values from the simulation base year were used to ensure comparability of the index over years. Threshold values are 18 species for plants and mushrooms, and 7 species for game. Thirdly, the index is calculated as: WFSIndex = (10 * game classified map) + plants&mushrooms classified map. The indicator merges plants and mushrooms and assesses game separately. This is done under the assumption that there are multiple practical and administrative barriers for collecting game, while collecting plants and mushrooms is similarly easy.

Table 4.7. Interpretation of wild food variety/sufficiency index. Legend: 0 value = game species and plant and mushroom species are both absent. 22 value = both are abundant. 12 value = game species richness is low and plant and mushroom species richness is abundant.

Edible plants + mushroom species richness	Game species richness		
	Absent	Low species richness	Abundant species richness
Absent	0	10	20
Low species richness	1	11	21
Abundant species richness	2	12	22

4.2.2 Discussion

The wild food supply indicator was based on land-cover and land-use data, coarse-resolution species distribution data, and empirical relations between land use and land cover on the one hand, and species occurrence on the other. Furthermore, the indicator was based on a selection of 146 species of game, mushrooms, and vascular plants that are consumed throughout Europe. The species selection was based on a systematic review of all English literature on wild food gathering in the European Union since 1997, and a systematic review of bilingual national-level statistics on wild food gathering. Only querying in English introduces a risk of overlooking species. As the final indicator only uses species that are consumed in multiple countries, the risk that important generic species are overlooked is limited and, given the large set of species included, it is unlikely that spatial patterns would change considerably upon including or excluding a few species. The coarse-scale distribution data are presence data aggregated to a 50 km resolution. In each 50x50 km grid cell, consequently, a wide range of environments could be included, of which only part is actually suitable as a habitat for the species considered. Scaling down these data on land use and land cover largely overcomes this resolution issue. Empirical data describing the relation between land use and land cover on the one hand and species occurrence on the other, was taken from Delbaere et al. (Delbaere et al., 2009) and supplemented with specialised databases on species characteristics (ETI Bioinformatics, 2013; Schulp et al., 2014a). These databases utilise a more detailed land-cover classification than this study, meaning that in the indicator used here the occurrence in each land-use type might be overestimated.

The main uncertainty in model assumptions is that we use species richness as an indicator for wild food availability. Next to species richness, also abundance of specific species of interest is, however, important. Due to lack of abundance data and due to lack of data on quantities of wild food collected, an indicator based on species richness is the only feasible option for mapping wild food availability (ETI Bioinformatics, 2013; Schulp et al., 2014a). Furthermore, when combining the input data described above in the final indicator, spatial uncertainties emerging from the coarse resolution of distribution data and thematic uncertainties emerging from the classification of the land-use map are combined. This altogether results in an indicator that adequately reflects broad patterns of wild food availability, but should not be analysed for small extents or at pixel level. This indicator is the first map of wild food availability in the European Union. A cross check is, therefore, not feasible.

4.3 Carbon sequestration

4.3.1 Methodology

Table 4.8. The main characteristics of the carbon sequestration model.

Indicator name	Carbon sequestration
Short description	The CLUE-SINKS model is a bookkeeping model to calculate the amount of carbon that is sequestered in or emitted from soils and biomass
Units	Tonne C/km^2 per year
Spatial resolution	1 km^2
Temporal resolution	Start year and end year of simulation
Output maps	Biomass sinks in forest, nature, and permanent crops Soil sink / sources Total sinks / sources
Reference	Schulp et al. (2008)

The CLUE-SINKS (ETI Bioinformatics, 2013; Schulp et al., 2014a) is a bookkeeping model that calculates the amount of carbon that is sequestered in or emitted from soils and biomass (Table 4.8). The approach has been widely used in EU scale projects, including EURURALIS (Rienks, 2008) and VOLANTE (Mouchet and Lavorel, 2013), various consultancy missions for the European Commission (Pérez-Soba et al., 2010; Tucker et al., 2013) and scientific papers (Mouchet and Lavorel, 2013; Stürck et al., 2015b). Figure 4.2 gives a schematic overview of the model and the input and output data are described in Table 4.10. The AML model script is to be found in Appendix 5.

Land-use types differ in the amount of carbon they sequester or emit in soil and vegetation. Carbon is sequestered in soils of forests, pasture and natural vegetation, and emitted by croplands and parts of wetlands. Additionally, in forests large amounts of carbon are stored in vegetation. The amount of carbon sequestered is also dependent on the type of management. Changes in land use can thus result in changes in carbon emission / sequestration. In the model, emission / sequestration is defined by an emission factor; this is a region-specific, land-use-type-specific carbon sequestration / emission per km^2 per year. For each grid cell, the sequestration / emission is equal to the emission factor of that land-use type. When the land-use changes, the emission factor changes to the emission factor of the new land-use type. Deforestation causes loss of carbon from biomass. In the case of deforestation, 80% of the carbon in forest biomass is lost (Schulp et al., 2008). Forest biomass stocks are taken from EFISCEN simulations (Schelhaas et al., 2007). Other factors influencing carbon emission and sequestration are the amount of carbon already present in the soil (SOC) (Bellamy et al., 2005; Sleutel et al., 2003) and the age and management regime of forests (Schelhaas et al., 2007).

The calculation rules are as follows (also see Figure 4.2):

1. Calculate carbon sequestration / emission from biomass. We used emission factors from the EFISCEN model simulations for forest (Schelhaas et al., 2007) and from Janssens et al. (2005) for cropland, pasture, forest and peatland. Emission factors for other land-use types are derived from these as follows:
    - The emission factor for inland wetlands is the same as the emission factor of peatland.

- The emission factor of heath and moorlands is the same as the emission factor of grassland.
- The emission factor of natural vegetation other than forest is takes as 25% of the forest emission factor. This is independent of forest management, and is therefore derived from a baseline scenario with zero management.
- The emission factor of permanent crops is set at 60 tonnes carbon per km^2 in soil (Freibauer et al., 2004; Smith, 2004). Additionally, during the simulation period newly established areas of permanent crops sequester 223 tonnes per km^2 in biomass (average of value of two studies (Sofo et al., 2005; Villalobos et al., 2006)).
- For pastures on peat, peatland emission factor is used. For pastures on mineral soils there is a specific emission factor (derived from Janssens et al. (2005) and overlaid with SOC / peat map). Furthermore, the emission factor is modified as a function of the intensity: low * 0.67, high * 1.27.
- For arable lands, including non-irrigated and irrigated arable lands and biofuels, the emission factor is differentiated between soil organic carbon content following Table 4.9. Furthermore, the emission factor is modified as a function of the intensity: low * 1.67; moderate * 0.84; high * 0.80.
- Emission is zero for built-up area; glaciers and snow; sparsely vegetated areas; beaches, dunes and sands; salines; water and coastal flats.

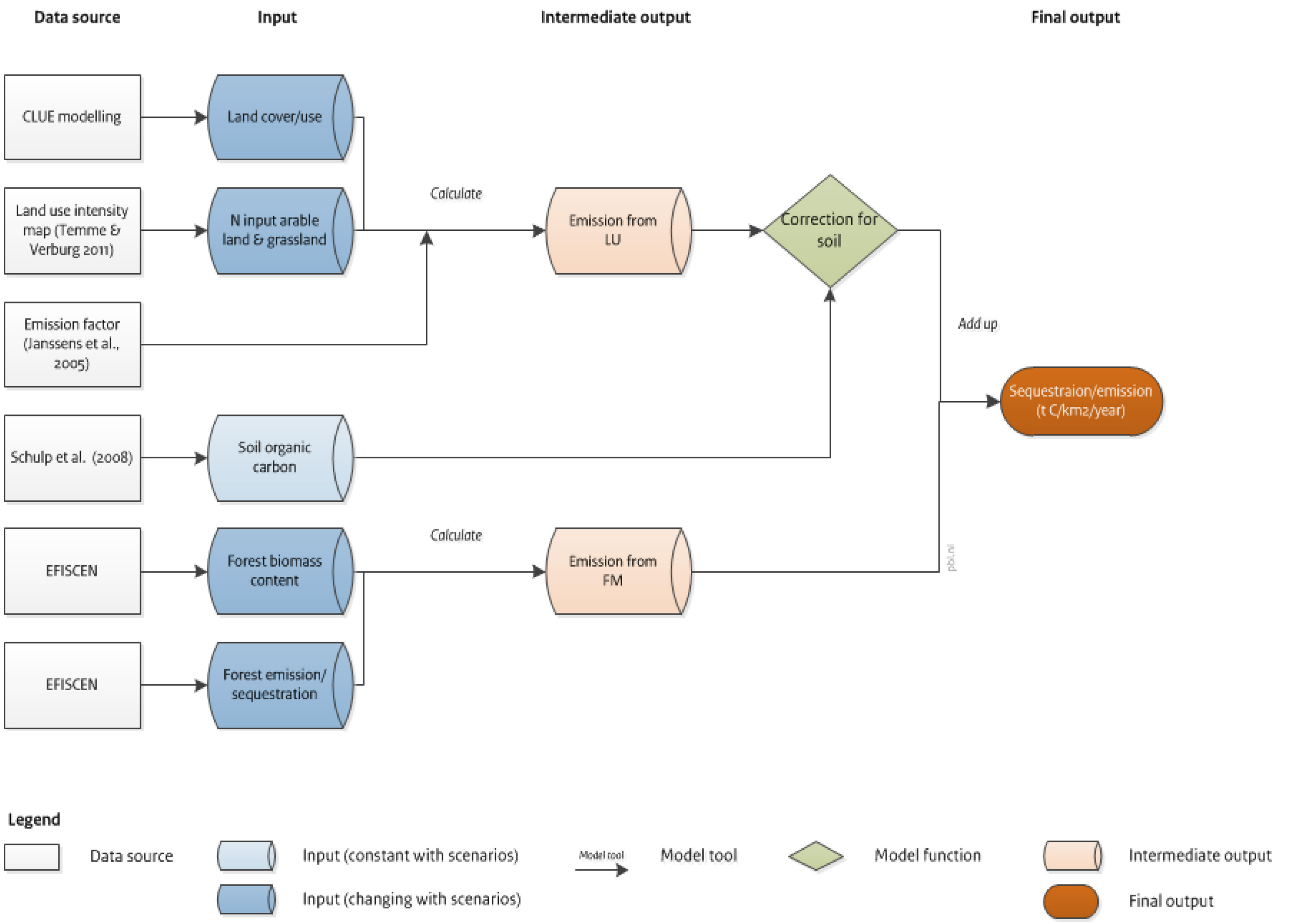
2. Correction of carbon sequestration / emission for soil. Data was obtained from Schulp et al. (2008).
3. Carbon stock changes in biomass are calculated separately from carbon stock changes in soil and are, as a final calculation step, added to or subtracted from emission / sequestration from soil.

Table 4.9. Modification of cropland emission factors as a function of soil organic carbon content (Schulp et al., 2008). (Diff. factor 0.2 means that, for a SOC stock of 1% to 2%, the final crop emission factor is the baseline crop emission factor multiplied by 0.2)

SOC, in %	Diff factor	SOC, in %	Diff. factor
0	No emission	12.5–25	2
0.01–1	0.1	25–35	2.5
1–2	0.2	>35	3.5
2–6	0.65	Peat (from European Soil Database)	Emission factor of peatland
6–12.5	1.6		

Figure 4.2.

Carbon sequestration model



Source: CLUE-SINKS (Schulp et al., 2008)

Table 4.10. Input and output parameters of the carbon sequestration model (see also Appendix 3).

Name	Unit	Source	Description
INPUT			
Land cover	CLUE classes (16)	CLUE modelling	CLUE land-cover map 1x1 km
Agricultural intensity	5 classes	CLUE modelling	Agricultural intensity measured by N input
Soil organic carbon	0–8 (SOC classes); 9 (peat)	Schulp et al. (2008)	Combination of JRC soil organic carbon map (Jones et al., 2004) and soil map (European Soil Bureau Network and the European Commission, 2004)
Emission factors	Tonne C/km^2 per year	Janssens et al. (2005)	Map with emission factor for each land-use type (see calculation rules)
		EFISCEN	Forest emission factors for soil and biomass from EFISCEN simulations
Forest biomass content	Tonne C/km^2	EFISCEN	Map of forest biomass carbon content per EFISCEN region
OUTPUT			
Carbon sequestration / emission	Tonne C/km^2 per year		Annual carbon sequestered or emitted by biomass and soil

4.3.2 Discussion

Input data uncertainties most importantly comprise the uncertainty in emission factors. Emission factors are country-specific and have a coefficient of variation (i.e. standard deviation as a percentage of the mean) of 90% for pasture, 75% for cropland, and 20% for wetlands for individual locations (Schulp et al., 2008). These emission factors average out emission / sequestration behaviour over all soils and management regimes. In the indicator, this averaging is disentangled by modifying the emission factor in areas with different soil characteristics or management regimes. Carbon sequestration and emission in 2000 were compared with numbers from other studies. All studies have large uncertainties and figures derived with the current models fall within the commonly found range (Schulp et al., 2008).

The ‘bookkeeping’ approach is a common approach at large scales. More complex process-based models have a much higher data requirement. While bookkeeping approaches strongly simplify or disregard processes, process-based models strongly simplify spatial variability of inputs over large areas, highly simplify land-use dynamics, and commonly assume equilibrium conditions at the start of the simulation. Among all factors, land-use change is the driving factor influencing most the carbon dynamics at EU scale over timeframes of a few decades.

Most importantly, the indicator cannot account for sink saturation. This is observed to happen from approximately 20 years after land-use conversion onwards. Given that the emission factors are averaged emission / sequestration observations over a whole country, saturated as well as unsaturated conditions are included. This approach therefore probably underestimates carbon dynamics directly after land-use conversion and overestimates carbon dynamics after a longer time.

The uncertainty in the emission factors does propagate into the outputs. In a sensitivity analysis, Schulp et al. (2008) simulated emission / sequestration in the EU over a 30-year time frame under four scenarios, using the lower and upper confidence limit of the emission factors. This resulted in a confidence interval of sequestration within one scenario at the end year of the simulation of 65 Tg C per year, considerably larger than the differences among the scenarios. Nevertheless, the temporal trends within the scenarios, and the differences among the scenarios were consistent among all compared studies. Outputs of future simulations done with this model were compared qualitatively with future carbon dynamics as simulated with other models. Land-use-type-specific trends in carbon dynamics were in the same order of magnitude as changes found in a range of different studies (Schulp et al., 2008). A quantitative comparison of model outputs in the year 2000 with three other ecosystem service models showed a relatively high agreement among the models. The simulated map of the year 2000 was most different from a carbon sequestration map based on land cover only, and most similar to a climate regulation map based on land cover and a set of additional environmental variables. Nevertheless, the four models that were compared agreed if a region sequestered or emitted carbon in almost 70% of the European territory. Disagreement mostly arises in Scandinavia, where including or excluding forest management practices result in differences among the models (Schulp et al., 2014b).

4.4 Flood regulation

4.4.1 Methodology

Table 4.11. The main characteristics of the flood regulation model.

Indicator name	**Flood regulation**
Short description	The landscape’s capacity to modify the river discharge after heavy precipitation events potentially causing flood events
Units	0–100
Spatial resolution	1 km^2
Temporal resolution	Start year and end year
Output maps	Relative water retention (normalised flood regulation supply index ranging from 0–100)
Reference	Stürck et al. (2014) and (2015b)

The model has a flood regulation supply and a flood regulation demand component (Stürck et al., 2014; Table 4.11). The current model set-up and parameterisation is described in detail in Stürck et al. (2015b), which slightly differs from the previous version of the model application (Stürck et al., 2014).

Natural landscape features as terrain, vegetation and soils can alter the runoff regime and ultimately the discharge in a river catchment, due to their changing water retention potentials. This water retention represents the landscape's capacity to modify the river discharge after heavy precipitation events potentially causing flood events. We measure water retention with a flood regulation supply index. The value of the index depends on environmental conditions, such as catchment type, precipitation type, water holding capacity and effect of land use and its intensity (i.e. crop factor) (Figure 4.3). The flood regulation supply index was derived from catchment experiments with the hydrological model STREAM (Aerts et al., 1999). For these experiments, a number of catchments were selected to cover the geomorphological variety of catchment forms within Europe. Each catchment was calibrated on the basis of observed river discharge data. Land-use and soil characteristics were iteratively changed within the selected catchments, based on predefined location characteristics of the catchment. The effects of these land-use and soil alterations within the specified zones during different types of heavy precipitation events were analysed. The resulting index itself was based on alterations in water retention within a distinct time frame at the outlet of a catchment (Stürck et al., 2015a). The water retention values retrieved from these operations done for a particular subset of the river catchments were entered into a look-up table, which distinguishes the catchment type, precipitation type, catchment zone, crop factor and water holding capacity classes. The look-up table was then applied to the current environmental inputs and the index is returned for all grid cells in the EU. Therefore, in the Nature Outlook, the STREAM model itself is not used, only the look-up table based on the STREAM model experiments (the effect of land-use type and intensity on the crop factor and water holding capacity is calculated in the ArcGIS Model Builder and the reclassification with the look-up table is covered in the Matlab script). Figure 4.3 gives a schematic overview of the model and the input and output data are described in Table 4.12. The Matlab model script is to be found in Appendix 6.

Background of the STREAM model and the calculation of water retention: the STREAM (Spatial Tools for River basins and Environment and Analysis of Management options) is a conceptual empirical hydrological model (Aerts et al., 1999). Its core compartment is formed by a GIS-based spatially distributed rainfall runoff model. The model is aimed to assess the processes that impact water availability within a river basin. It is optimised for the analysis of effects of land-use and climate changes on freshwater hydrology in large river basins. This makes STREAM a suitable instrument for scenario analysis in water resource management. The model is capable of processing input data of any spatial and temporal resolution. For further information, see Stürck et al. (2014). In this application, an extreme scenario of soil / land use was designed for each experiment catchment, representing the 'worst case' scenario in terms of water retention. The discharge outputs retrieved from the STREAM model runs are analysed for the quantities of retained water after a certain time step after a precipitation event occurred (Eq. 1). These values are compared for each run with a 'worst case' scenario, where soil and land-use parameters are set to least favourable conditions (Eq. 2). The relative difference of each run compared to the worst case scenario for the respective catchment and precipitation type is than normalised to the maximum (Eq. 3).

$$\textit{Relative water retention} = (\textit{total precipitation} - \textit{discharge}) / \textit{total precipitation} \quad \text{(eq. 1)}$$

$$R = \textit{relative water retention}_I - \textit{relative water retention}_{min} \quad \text{(eq. 2)}$$

Where R = increased water retention of model run *i* compared to worst case scenario

$$I = (R_i - R_{min}) / (R_{max} - R_{min}) \quad \text{(eq. 3)}$$

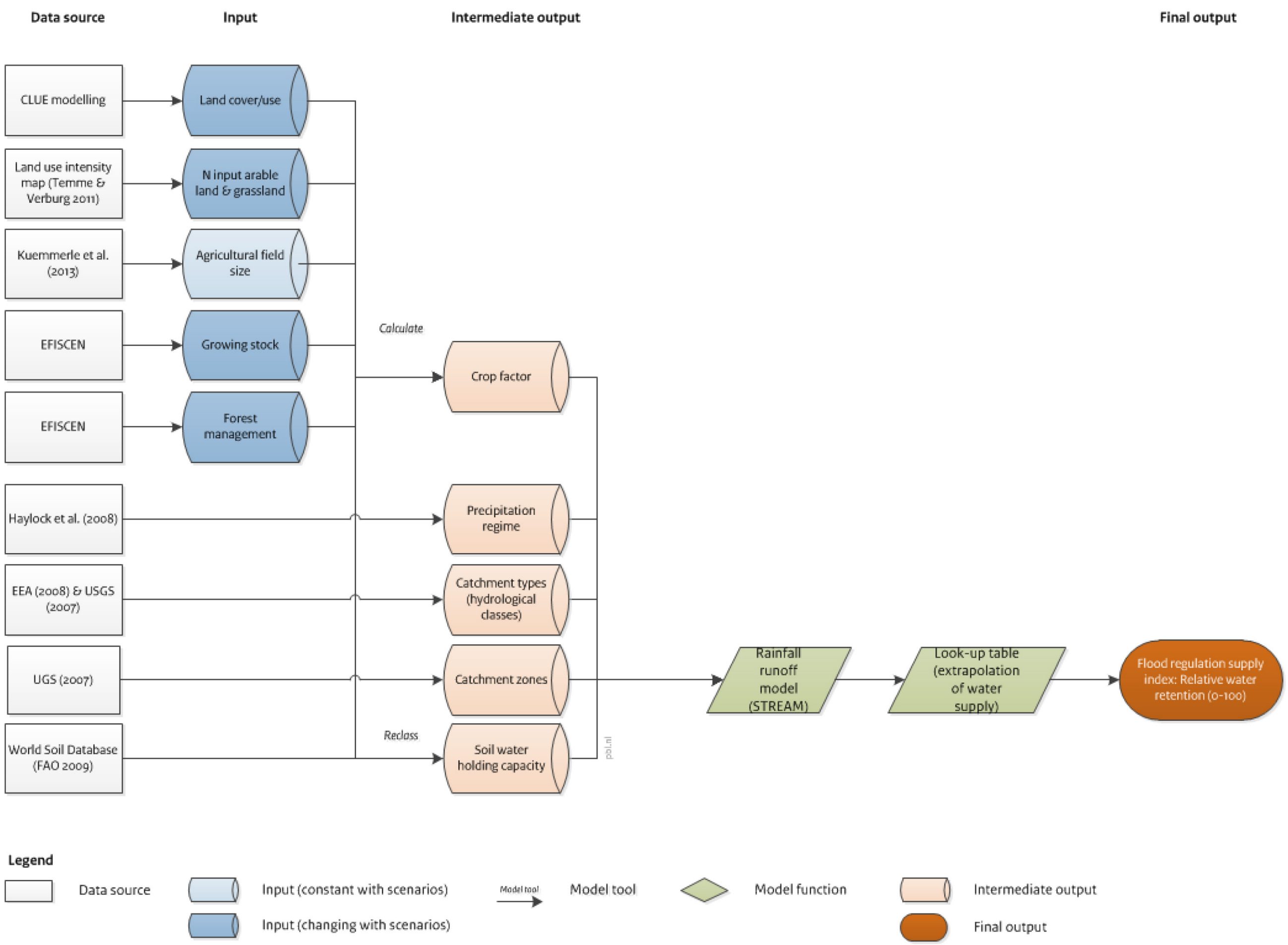
Where I = normalised increased water retention of model run *i* compared to minimum and maximum increased water retention values.

Table 4.12. Input and output parameters of the flood regulation model (see also Appendix 3).

Name	Unit	Source	Description
INPUT			
Land cover	CLUE classes (16)	CLUE modelling	CLUE land-cover map 1x1 km
Agricultural intensity	5 classes	CLUE modelling	Agricultural intensity measured by N input
Forest management	5 classes	EFISCEN modelling	Forest management map
Growing stock	m3/ha	EFISCEN modelling	Average forest growing stock volume reclassified to three classes according to Stürck et al. (2015b)
Agricultural field size	ha	Kuemmerle et al. (2013)	The relative frequency of field sizes across the EU was analysed and crop factors were calculated using a weighed mean of field sizes' influence on the factor
Catchment types	5 classes	EEA (2008) and USGS (2007)	Classification of EU river catchments into hydrology classes
Catchment zones	3 classes	USGS (2007)	Map indicating the relative position within river catchment
Precipitation regime	4 classes	Haylock et al. (2008)	Classification of daily precipitation 1990–2000 into precipitation distribution regimes
Water holding capacity	7 classes	FAO (2009)	Water holding capacity (WHC) describes the maximum water quantity soil can potentially contain before it is saturated; varies with soil texture, particle density, soil depth and fraction of organic matter. Values were adopted from the Harmonized World Soil Database and were reduced at sites that have nearly impervious soils, such as for areas covered by built-up areas, rocks, and glaciers.
OUTPUT			
Relative water retention	0–100		Normalised flood regulation supply index

Figure 4.3.

Flood regulation model



Source: Stürck et al., 2014 & 2015

4.4.2 Discussion

Water retention was mapped as the percentage of precipitation in a precipitation event that is captured by vegetation within a catchment. The calculation method was developed for the VOLANTE FP7 project and has subsequently been applied by Tucker et al. (2013).

As a vegetation input map, CORINE land cover was used. For individual land-cover classes better proxy maps are available (e.g. MODIS cover fractions for nature, individual crop types for agricultural land) but CORINE provides a consistent and reliable map that combines all land-cover types into a single map and is, therefore, considered the best alternative. Catchment topography was quantified using a 1 km resolution digital elevation model (United States Geological Survey, 2007), and a well established EU scale catchment map. The 1 km resolution causes loosing some precision in classifying pixels into catchments, but is considered a good level of precision for European scale applications. Water holding capacity was taken from FAO's Harmonized World Soil Database (FAO, 2009). This database combines and harmonises soil maps made by various world regions, including the European Soil Database (European Soil Bureau Network and the European Commission, 2004). Water holding capacity is commonly derived from mapped soil properties, most importantly texture, using an expert-based set of rules that derives additional soil characteristics from observed soil properties. In the European Soil Database, the confidence level of this water holding capacity is ranked low, meaning that a considerable variation is to be expected around the values represented in the maps (European Soil Bureau Network and the European Commission, 2004). Nevertheless, this is the only European-wide European map available of water holding capacity.

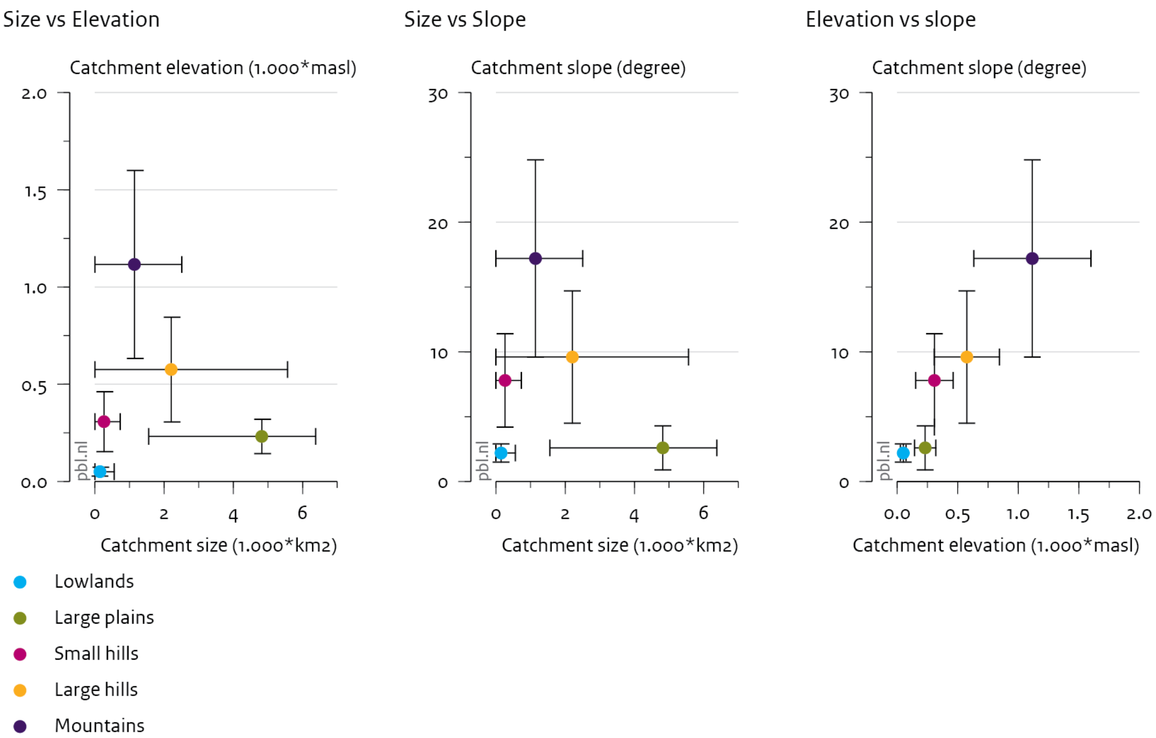
A few uncertainties arise from the model assumptions. In mapping water retention, Europe's catchment areas were classified into five categories based on their topography (size, elevation, slope). Although this analysis ensured a maximum cluster differentiation using a sensitivity analysis, there is some overlap between different categories of clusters with respect to size, elevation, and slope (Figure 4.4). In particular, differences between small and large hills catchments and between large hills and mountain catchments are small and slightly different clustering parameters might cause some shifts in the classification.

A second uncertainty is introduced by the land cover's capacity for water retention. A 'crop factor' that describes this retention has been attached to each type of land cover. The crop factors have a typical uncertainty range of around 20% of their mean value (Stürck et al., 2014) and several of the land-cover types consequently do not exhibit a significant difference of their crop factor. Third, as indicated before, the water holding capacity has a high but not further quantified uncertainty. Next, water retention was simulated for a restricted number of precipitation events. These are based on extremes as observed in the applied climate data. Although not covering a complete range, they do correctly represent water retention in a situation of realistic, yet extreme, events. Finally, results of a set of simulation experiments (Stürck et al., 2014) are scaled up to the entire extent of Europe. Multiple linear regressions were then applied to quantify the impact of individual variables on the water retention (Stürck et al., 2014). This also provides a quantification of the total percentages explained variation in water retention by the variables included in the current model. Only for large plains under five-day rain events or one-day rain events in wet regions, R2 values below 0.75 were found, while all R2 values were higher than 0.70.

In a systematic comparison of flood regulation maps, Schulp et al. (2014b) found that maps resulting from the model presented here reasonably agreed with three other maps of the same ecosystem service. Scattered areas of strong disagreement of the service were found throughout Europe and in approximately 80% of the area of Europe the models agreed if a location was a hotspot or a cold spot. Agreement was best upon assessing if a location supplied little of the service. A comparison with independent data that reflect the ecosystem service indicated that the model performed better than random.

Figure 4.4.

Range of clustering variables in clustering of river catchments



Source: Based on Stürck et al. (2014)

4.5 Erosion prevention

4.5.1 Methodology

Table 4.13. The main characteristics of the erosion prevention model.

Indicator name	Erosion risk
Short description	Soil loss through sheet and rill erosion as a function of topography, soil, precipitation intensity and land use
Units	Tonne/ha
Spatial resolution	1 km^2
Temporal resolution	Start year and end year
Output maps	Erosion risk (tonne/ha) Protective vegetation cover
Main reference	Pérez-Soba et al. (2010) and Tucker et al. (2013)

The erosion prevention model uses soil erosion risk as an indicator of soil erosion regulation (Table 4.13). Figure 4.5 gives a schematic overview of the model and the input and output data are described in Table 4.15. The model was built in ArcGIS model builder following the methodological steps described below.

The model was built on the work of Pérez-Soba et al. (2010), which uses the Universal Soil Loss Equation (USLE) (Wischmeyer and Smith, 1978). The USLE gives a quantitative estimate of erosion risk in tonne ha^{-1} at a 1 km^2 resolution:

$A = R * K * L * S *C$
in which:
A = mean (annual) soil loss (tonne ha^{-1} yr^{-1}),
R = rainfall erosivity factor (MJ mm ha^{-1} h^{-1} yr^{-1}),
K = soil erodibility factor (tonne h MJ^{-1} mm^{-1}),
L = slope length factor (-),
S = slope steepness factor (-),
C = protective vegetation cover factor (-).

First, a potential for soil erosion was derived from rainfall regime (R), soil erodibility (K) and topography (L & S), whereby rainfall regime is considered to be variable in time. The R-map was developed in Perez-Soba et al. (2010) using fine resolution (1 km^2) monthly rainfall data from WorldClim for the year 2000, which are incremented with 50 km resolution annual rainfall projections (A2 scenario of the EURURALIS project) from IMAGE/HADCM (Hijmans et al., 2005). The R-factor is calculated using the formula of Renard and Freimund (1994):

$R = 0.739F^{1.847}$ (if $F < 55$)
$R = 95.77 – 6.081F + 0.477F^2$ (if $F > 55$)
In which F is a fine-resolution map of the precipitation intensity in 2000, calculated as:
$\Sigma(\text{monthly precipitation})^2$ / annual precipitation.

A KLS map was also developed in Perez-Soba et al. (2010). The K was calculated from soil properties (soil texture, organic matter content), and the L and S were calculated from a Digital Elevation Model (DEM).

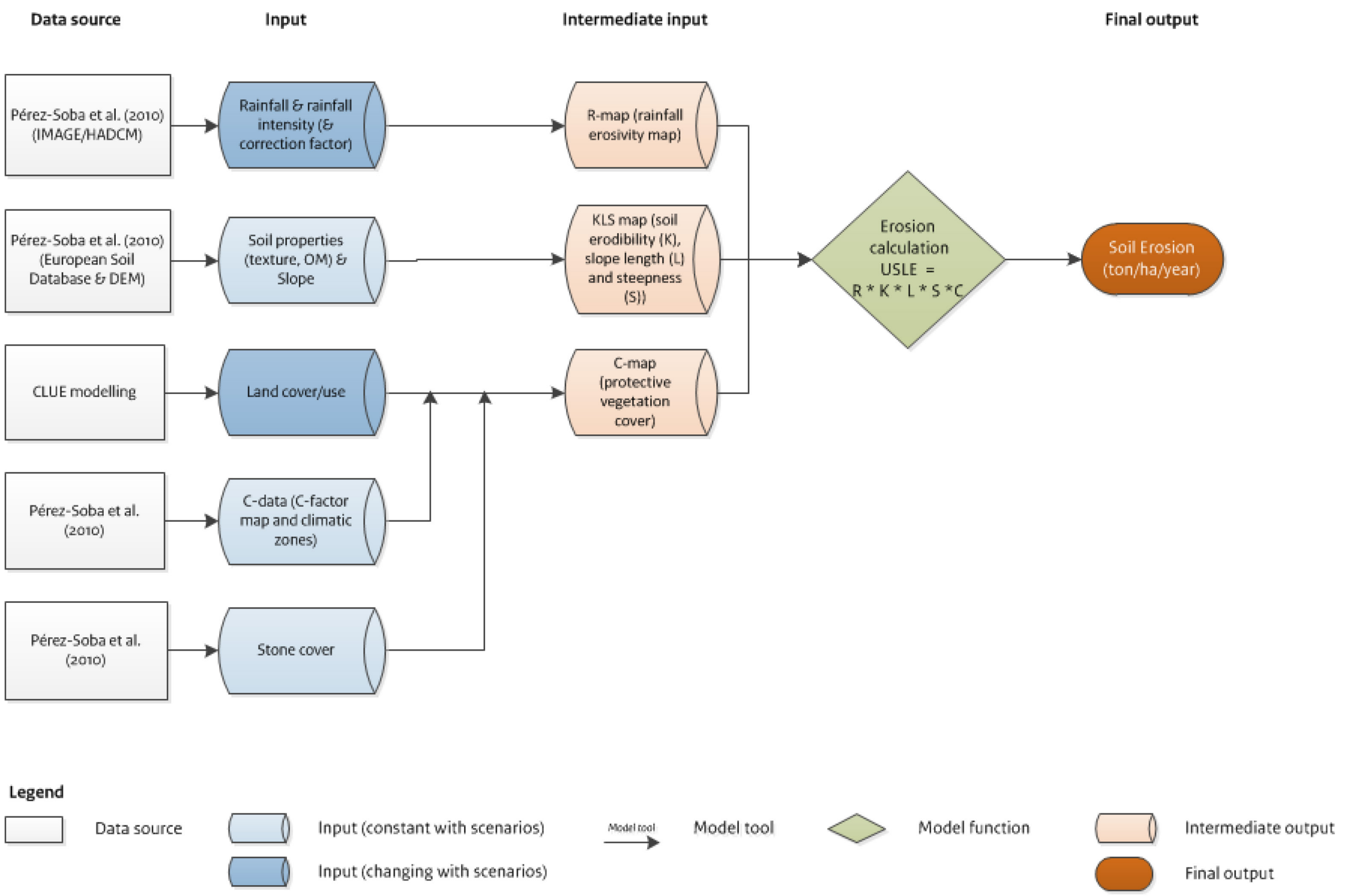
Second, the land-use map was used to derive a measure for the protective vegetation cover (C), needed to obtain an actual soil erosion map (Pérez-Soba et al., 2010). A C-map was calculated by reclassifying the CLUE land-use maps according to Table 4.14, based on the EU scale MESALES model (Le Bissonnais et al., 2002). The C-factor is defined as the ratio of soil loss from land with a specific vegetation to the corresponding soil loss form continuous fallow. Its value depends on vegetation cover and management practices. Classification was applied to three climatic zones: boreal, temperate and Mediterranean. The C-values per land-cover type were obtained by an overlay of land-use map in 2000 with the C-factor map made by Knijf et al. (2000). Furthermore, stone cover was considered to protect sediment from being washed away, which was implemented by multiplying the reclassification by the stone protection map (Pérez-Soba et al., 2010).

Table 4.14. C-values for CLUE land-use categories, based on the MESALES model (Le Bissonnais et al., 2002).

CLUE Code	CLUE Land-use type	Protective vegetation cover factor		
		Mediterranean	Boreal	Temperate
0	Built-up areas	0	0	0
1	Arable land (non-irrigated)	0.32	0.32	0.24
2	Pasture	0.1	0.05	0.03
3	Semi-natural vegetation	0.1	0.03	0.03
4	Inland wetlands	0	0	0
5	Glaciers and snow	0	0	0
6	Irrigated arable land	0.32	0.32	0.24
7	Recently abandoned arable land	0.2	0.2	0.15
8	Permanent crops	0.25	0.15	0.15
10	Forest	0.32	0.32	0.24
11	Sparsely vegetated areas	0.005	0.001	0.001
12	Beaches, dunes and sands	0.25	0.15	0.15
13	Salines	0	0	0
14	Water and coastal flats	0	0	0
15	Heather and moorlands	0	0	0
16	Recently abandoned pasture land	0.005	0.001	0.001

Figure 4.5.

Soil erosion model



Source: Perez-Soba et al. (2010)

Table 4.15. Input and output parameters of the soil erosion model (see also Appendix 3).

Name	Unit	Source	Description
INPUT			
Land cover	CLUE classes (16)	CLUE modelling	CLUE land-cover map 1x1 km
Climatic zones	3 classes	Pérez-Soba et al. (2010)	Climatic zones (boreal, temperate and Mediterranean) used to map protection that land cover provides against erosion
Rainfall	mm	Pérez-Soba et al. (2010)	Rainfall data to calculate rainfall intensity, with the correcting F (below) using year-specific precipitation
F	-	Pérez-Soba et al. (2010) and Hijmans et al. (2005)	Correction Factor: Sum of ((monthly precipitation)^2/annual precipitation) in 2000, calculated based on WorldClim data
KLS map	-	Pérez-Soba et al. (2010)	Product of soil erodibility (K), slope length (L) and slope steepness (S) factors
C data	0–1	Pérez-Soba et al. (2010)	Map of the MESALES C-factor. It is used to reclassify the CLUE land-cover map into protection that the land cover provides against erosion
Stones	0.5, 1	Pérez-Soba et al. (2010)	0.5 for very stony areas, i.e. soil mapping units with an agricultural limitation due to stones and gravel according to European Soil Database;1 for areas with few or no stones.
OUTPUT			
Protective vegetation cover	-		Potential soil erosion, the protection that land cover provides against erosion
Erosion risk	Tonne/ha/yr		Actual soil erosion

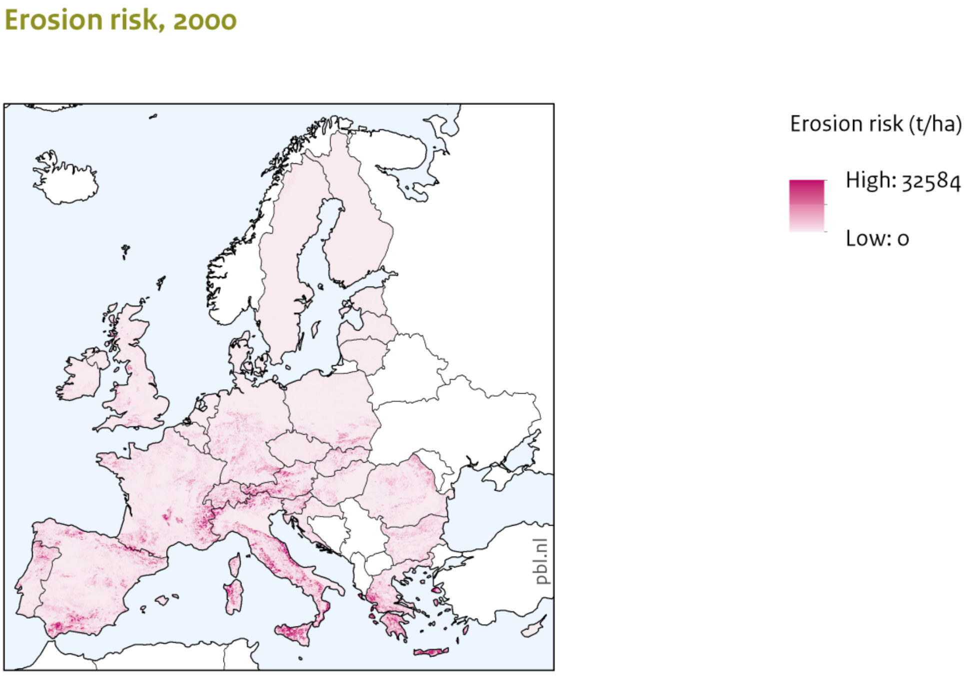
4.5.2 Discussion

The model has been applied before in various studies, including Pérez-Soba et al. (2010) and Tucker et al. (2013). A main uncertainty in the input data is related to the resolution of the model. Calculation of erosion risk is strongly scale-dependent and at a 1 km resolution, many details in the landscape disappear that strongly influence the erosion quantities. This most importantly applies for the representation of slopes, which are most likely underestimated. A systematic comparison of erosion rates simulated with two erosion models operating at a 1 km and a 10 km resolution showed that, if the underlying elevation data were correctly aggregated, spatial patterns of erosion risk at European scale remained largely intact, while overall erosion rates were lower. Differences are higher when erosion rates are higher than 100 tonnes/ha (Mantel et al., 2014), while at lower rates correlations between erosion rates modelled with the two different models are high. The C-factors were derived by comparing a region-specific land-use map with an normalised difference vegetation index (NDVI) map that represents cover fractions throughout Europe (Pérez-Soba et al., 2010). This scaling of the NDVI includes some arbitrary choices. A major problem is that NDVI is only sensitive to healthy vegetation that is photosynthetically active, while this condition is less relevant for explaining the protection against erosion (Van der Knijf et al., 2000). To compensate for this, maximum C-values were assigned to forest and grassland, and C-values of heath and moors were increased to mimic the dense vegetation cover that remains upon a low vegetation vitality as observed through the NDVI measurements (Pérez-Soba et al., 2010). C-factors are, altogether, crude estimates. Quantification of the uncertainty is not available. An improvement of the C-factor of the approach used in this report is the inclusion of a stone cover fraction. This has been identified as an important factor for explaining the protection against erosion and had not been included before (Pérez-Soba et al., 2010).

This model is based on the USLE, which is the most commonly applied model for soil erosion at multiple scales because of its simplicity and robustness (Pérez-Soba et al., 2010). A limitation of the model is that it only includes sheet / rill erosion and disregards other types of erosion, including gully erosion, which can lead to considerable soil loss. Secondly, the model does not describe the impact of the interaction between soil and climatic conditions on the infiltration process correctly (Mantel et al., 2014).

Figure 4.6 shows the output of the erosion prevention model for 2000. A comparison of model results of the current approach with three other models for erosion protection indicated that outputs of erosion protection models vary widely. In more than half of the European territory, different models for the erosion prevention ecosystem service resulted in contrasting estimates throughout Europe (Schulp et al., 2014b). Comparing with the C-factor map, Panagos et al. (2015) showed patterns that were broadly similar. Both maps show very low erosion protection in Spain, southern Hungary, and eastern Greece, very low to low erosion protection in southern Romania, and Bulgaria, low erosion protection in Poland and France, and high to very high erosion protection in northern Europe and mountainous areas. Deviations are most importantly seen in England, where the current study shows a very low erosion protection, while Panagos et al. (2015) indicate a moderate level of protection. This difference is due to the different scales of analysis, and the inclusion of crop types by Panagos et al. (2015). The 100m resolution deployed by Panagos et al. (2015) estimates slightly more landscape variation in England than the current study. Furthermore, Panagos et al. (2015) estimate a higher cover fraction for the cereal crops that are important in England. Given that these do not provide cover during the time that rainfall is most intensive, it is uncertain how realistic this assumption is.

Figure 4.6.



Source: Output of the erosion prevention model

4.6 Pollination

4.6.1 Methodology

Table 4.16. The main characteristics of the pollination model.

Indicator name	Pollination
Short description	Area of cropland (in %) within 2 km of pollinator habitat
Units	Area %
Spatial resolution	1 km^2
Temporal resolution	Start year and end year
Output maps	Cropland accessible by wild pollinators (Values ≥ 50%)
Main References	Serna-Chavez et al. (2014)

The pollination model uses the method of Serna-Chavez et al. (2014) to simulate pollination (Table 4.16). Figure 4.7 gives a schematic overview of the model and the input and output data are described in Table 4.18. The model was built in ArcGIS model builder following the methodological steps described below.

The natural and semi-natural land cover was used as potential habitat for unmanaged pollinators. Serna-Chavez et al. (2014) established an empirical relation between the percentage of natural habitat and the percentage of cropland that is accessible for pollinators, taking 2 km as an effective distance. First, the percentage of potential habitat and cropland, and the portion of croplands within 2 km of the potential habitat were estimated from differently sized windows in aerial photographs. Then, a regression was fit on the percentage of potential habitat and the portion of croplands within 2 km of this potential habitat. The relation applies in areas with land cover consisting of a mix of croplands and natural habitats, as these are the areas where there is an actual flow of pollination. After applying this relation, the accessible cropland area can be identified. Areas benefiting from pollination services were defined as areas where crops depending or profiting from biotic pollination are produced. Serna-Chavez et al. (2014) developed and tested this approach for a variety of window sizes. Best fit was achieved with a 10x10 km window size (i.e. around a 5 km radius), but given the match with specific global-scale data sets as required in the paper by Serna-Chavez et al. (2014), this regression equation specific for the 10x10 window size was not reported. We do, however, apply the regression equation specific for the 10x10 window size (Serna-Chavez et al., pers. comm.). To map the flow of pollen using this indicator, we classified the land-use map resulting from the CLUE-scanner simulations into natural and semi-natural habitat and other land cover (Table 4.17). Next, the area percentage of GLs was calculated after Schulp et al. (2014c). Then the percentage of natural and semi-natural land cover and GLs was added together, and the average percentage, in a 5 km radius, was calculated using focal statistics. With the equation given by Serna-Chavez et al. (pers. comm.), the percentage of cropland that can be accessed by pollinators from this natural habitat was calculated. This was mapped at 1 km^2 resolution for croplands.

The calculation rules are as follows (see also Figure 4.7):

1. The CLUE land-cover map was reclassified, resulting in a map showing the habitat percentage for wild pollinators. These are the natural and semi-natural land-use types and agricultural land-use types with a low level of disturbance (Table 4.17):
    a) Land-use types 3, 4, 7, 10, 11, 15, 16 were reclassified to 100 (i.e. 100% of this land cover provides habitat).
    b) Land-use types 2 and 8 were reclassified to 50 (i.e. these land-cover types can provide habitat. As a rough estimate, we assume that half of it indeed provides habitat, while in the other half the disturbances due to cattle, management and pesticides are too frequent to enable wild pollinators nesting).
    c) Other land-use types are reclassified to zero (i.e. no habitat for wild pollinators).
2. The area percentage of habitat in GLs was calculated using:

    $$GL_{area} = 100 * (GL_{density} * GL_{width}) / \text{transect length}$$

    In which GL_{area} is the area percentage of GLs (%); $GL_{density}$ is the average number of intersects with GLs on a 250m transect (#), GL_{width} is the width of GLs (m). In this analysis, we used an average width of 2m.
3. Habitat density from linear elements and other land cover was added together.
4. The average habitat percentage for each grid cell was calculated as the focal mean in a 5 km radius.
5. For each cell, the percentage of cropland accessible from the pollinator habitat was calculated as:

    % accessible cropland = (3E-4 * HabPerc3) – (0.0332 * HabPerc2) + (4.1044 * HabPerc) – 19.5

6. Cut off at 0 and 100.
7. This equation only applies in areas with a mix of croplands and nature. To identify these areas, the land-use maps were reclassified into agricultural areas (Table 4.17), and the

agricultural areas with a percentage of cropland accessible from the pollinator habitat were selected.

8. This map was reclassified into:
    a) No cropland;
    b) Cropland accessible by wild pollinators: 1 (Values ≥ 50%);
    c) Cropland inaccessible by wild pollinators: 0 (Values<50%).

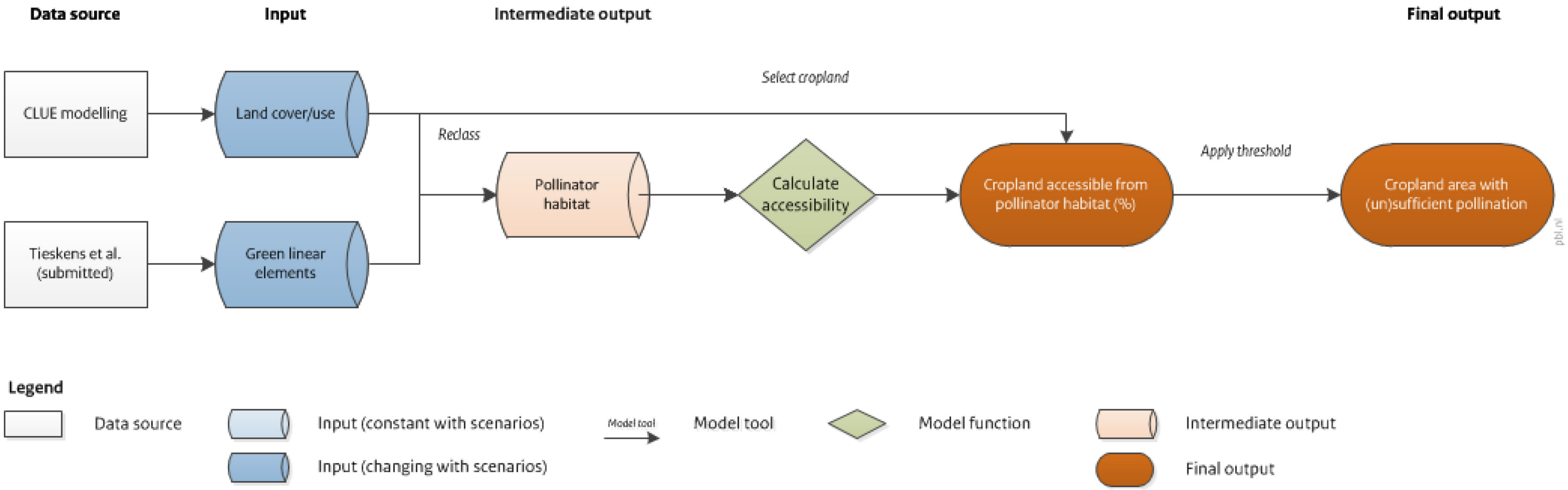
The output maps are from step 7 and 8.

Table 4.17. Percentage of habitat for wild pollinators and natural predator and croplands benefitting from natural pollination and pest control, per CLUE land-cover class. References: for wild pollinator habitat: Schulp et al. (2014c) and Tucker et. al (2013); for natural predator habitat: Boccaccio et al. (2009), Bianchi et al. (2006), Elliott et al. (2002a), Elliott et al. (2002b), Rusch et al. (2013a), Rusch et al. (2013b).

CLUE Code	CLUE Land-use type	Habitat percentage for wild pollinators	Habitat percentage for natural predators	Cropland benefitting from pollination and pest predation
0	Built-up areas	0	0	
1	Arable land (non-irrigated)	0	0	yes
2	Pasture	50	50	
3	Semi-natural vegetation	100	100	
4	Inland wetlands	100	100	
5	Glaciers and snow	0	0	
6	Irrigated arable land	0	0	yes
7	Recently abandoned arable land	100	100	
8	Permanent crops	50	0	yes
10	Forest	100	100	
11	Sparsely vegetated areas	100	100	
12	Beaches, dunes and sands	0	0	
13	Salines	0	0	
14	Water and coastal flats	0	0	
15	Heather and moorlands	100	100	
16	Recently abandoned pasture land	100	100	

Figure 4.7.

Pollination model



Source: Serna-Chavez et al. (2014)

Table 4.18. Input and output parameters of the pollination model (Appendix 3).

Name	Unit	Source	Description
INPUT			
Land cover	CLUE classes (16)	CLUE modelling	CLUE land-cover map 1x1 km
Green linear elements	Number of intersections	Tieskens et al. (submitted)	The probability of encountering a GL at a 250m transect
OUTPUT			
Pollination service	0–100		% cropland accessible from the pollinator habitat
	Yes (1) / No (0)		Cropland area with (in)sufficient pollination

4.6.2 Discussion

A common indicator to map the regulation of pollen flow is visitation probability (Ricketts et al., 2008), which describes the probability that a crop is visited by a pollinator as a function of the distance to pollinator habitat. The pollination flow is best indicated by mapping the visitation probability using high-resolution land-cover data (Maes et al., 2012). However, future land-use-change projections at a resolution higher than 1 km^2 are not available at the European scale. Therefore, we used the alternative approach of Serna-Chavez et al. (2014).

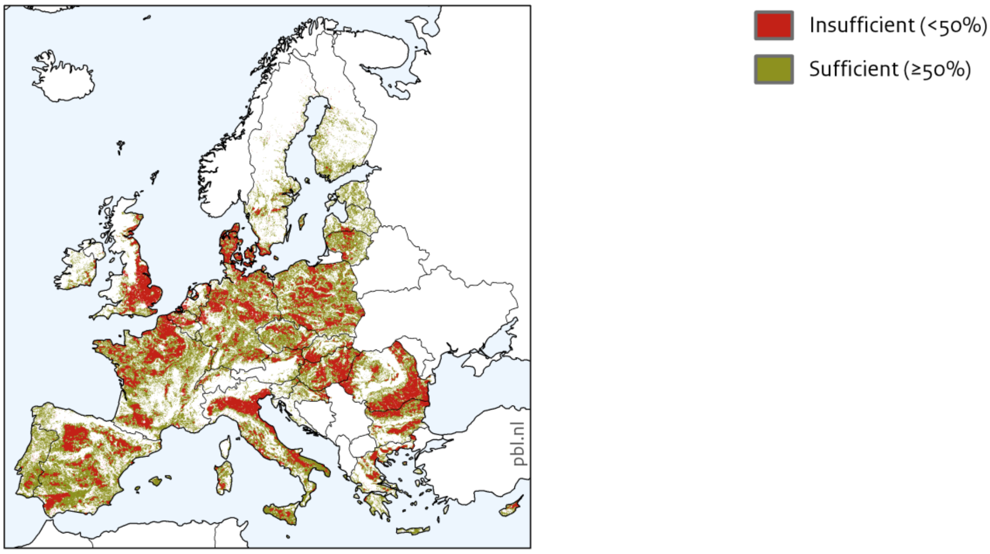
This indicator we used is based solely on the land-cover map. A main uncertainty related to the input data is the classification of the land-cover classes into 'habitat' and 'not habitat' for pollinators. We assumed that croplands do not provide pollinator habitat, while 50% of each pasture grid cell provides pollinator habitat and natural land-cover types are suitable as habitat for pollinators. The suitability of cropland as a habitat for pollinators strongly depends on management, which is not captured in the land-use map applied here. Within grid cell variability can result in distances between habitat and cropland of <1 km, strongly increasing the visitation probability and meaning that the percentage of accessible cropland in this study might be underestimated. Another study (Schulp et al., 2014c) that mapped pollination supply analysed the impact of habitat classification on pollination supply. That study showed that sensitivity to the habitat classification was very large in Hungary, northern Italy, parts of Spain, small, scattered, areas in Poland. Irrespective of the habitat classification, habitat percentages were lowest for croplands that are a hotspot for pollinator dependency and highest for croplands without pollinator dependent crops (Schulp et al., 2014c). For the uncertainty of the GLs map, see Section 4.7.2.

The indicator quantifies the percentage of cropland accessible to pollinators based on an empirical relation between pollinator habitat cover and the accessible cropland cover, based on an inventory of Google Earth snapshots. The empirical analysis is built on 30 observations that stretch between 8% and 70% pollinator habitat cover, has an R^2 of 94%, and a parameter uncertainty range of max. 10% for the different parameters. Outputs, thus, are robust, and little changes in spatial patterns due to this empirical relation is to be expected.

Pollination ecosystem service can be very different in certain parts of Europe (e.g. Scandinavia, Central Germany, Ireland, large parts of the UK, and scattered parts in southern, central, and eastern Europe) if different mapping approaches are applied (Schulp et al., 2014b). Pollination supply strongly depends on the landscape configuration, and existing indicators strongly differ if and how they account for this (Schulp et al., 2014b). Not accounting for landscape configuration for example results in very high pollination supply throughout forested areas while indicators that do account for landscape configuration either only include forest edges (because crop pollinators tend to be open-land species that do not nest in deep forests) or nature areas close to croplands (Schulp et al., 2014c). Both Zulian et al. (2013) and Schulp et al. (2014c) mapped visitation probability applying different distance decay functions, which led to different results. Zulian et al. (2013) obtained a map with generally high values for southern Europe and low values for northern Europe, whereas Schulp et al. (2014c) received a more diverse map with high values mainly in parts of France, Spain, Italy and parts of eastern Europe. These differences are mainly due to combining supply and demand in a single indicator by Zulian et al. (2013), while Schulp et al. (2014c) mapped supply and demand separately. Serna-Chavez et al. (2014) used the indicator pollinator habitat percentage and mapped pollinator habitat percentage within a 2 km range of croplands, at global scale (Serna-Chavez et al., 2014). Their map shows less areas as suitable for potential pollinator habitat, than our map (Figure 4.8). This is also due to the different land-cover maps used as input (MODIS vegetation map versus CORINE land-cover map).

Figure 4.8.

Pollination, 2000



Source: Output of the pollination model

4.7 Pest control

4.7.1 Methodology

Table 4.19. The main characteristics of the pest control model.

Indicator name	**Pest control**
Short description	Average pest predation rate (in %) within 2 km of the agricultural area
Units	%
Spatial resolution	1 km^2
Temporal resolution	Start year and end year
Output maps	Agricultural land with sufficient pest control (Predation rate > 25.83%)
Main References	This report

The main characteristics of the pest control model are described in Table 4.19. Figure 4.9 gives a schematic overview of the model and the input and output data are described in Table 4.20. The model was built in ArcGIS model builder following the methodological steps described below.

Pest predation rate, meaning the percentage of pests killed by natural enemies, was used as an indicator for natural pest control. Natural vegetation, such as the percentage of forest, woodland, tree lines and pasture in the surroundings, provide habitat for natural enemies of agricultural pests (Bianchi et al., 2006; Veres et al., 2013). There is a clear relation between the efficiency of predation and the amount of natural and semi-natural vegetation (Veres et al., 2013). If there is more natural and semi-natural vegetation, agricultural pests (e.g. aphids, Lepidoptera species) are less abundant (Letourneau and Goldstein, 2001; Roschewitz et al., 2005; Veres et al., 2006) or predators are more abundant and more active (Bianchi et al., 2008; Bianchi et al., 2005; Rusch et al., 2013a; Rusch et al., 2011; Thies et al., 2003).

We applied a generic function between the percentage of natural and semi-natural vegetation and the pest predation rate, building on empirical studies carried out in Europe by Lai (2015). The model is a result of an extensive literature review by Lai (2015). It was estimated with weighted average approach using data from seven empirical studies carried out in Europe. These studies estimated parasitism or predation rates by spins and insects on wheat (Thies et al. (2005) and Schmidt et al. (2005)) and oil crop pests (oilseed rape (Rusch et al., 2013b; Thies et al., 2003; Thies and Tscharntke, 1999; Zaller et al., 2009) and olive (Boccaccio and Petacchi, 2009)) in relation to the percentage of arable land / non-crop area / grassy fallow / woodland in the surrounding areas.

First, the potential habitats of natural predators were mapped. We classified the land-use map resulting from the CLUE-scanner simulations into natural and semi-natural habitat and other land cover (Table 4.17). We focused only on small predators (e.g. spins and insect). All of the selected classes were considered to provide equally habitat for predators, hence, are equally efficient in providing the ecosystem service. Green linear landscape elements (e.g. hedgerows and tree lines; GL) are also important in providing habitat for natural predators (Bianchi et al., 2006). The area percentage of GLs was calculated after Schulp et al. (2014c). Then, the area percentages of natural and semi-natural land cover and GLs were added together, and the average percentage within a 2 km radius was calculated using focal statistics. The 2 km indicates the effective distance of natural pest control (Boccaccio and

Petacchi, 2009; Rusch et al., 2013b; Thies et al., 2003). After this, the regression model for the percentage of semi-natural vegetation and predation rate was applied. The service is provided on agricultural areas (Table 4.17) with at least 20% non-crop area (i.e. natural and semi-natural vegetation) within the effective distance (Bianchi et al., 2013). This corresponds with about 26% of predation rate.

The calculation rules are as follows (see also Figure 4.10):

1. The CLUE land-cover map was reclassified, resulting in a map showing the habitat percentage for natural pest predators. These are the natural and semi-natural land-use types and agricultural land-use types with a low level of disturbance (Table 4.17):
    a) Land-use types 3, 4, 7, 10, 11, 15, 16 are reclassified to 100 (i.e. 100% of this land cover provides habitat).
    b) Land-use type 2 was reclassified to 50 (i.e. this land-cover type can provide habitat. As a rough estimate, we assume that half of it indeed provides habitat for natural predators, while in the other half the disturbances due to cattle, management and pesticides are too frequent to provide habitat for natural pest predators).
    c) Other land-use types are reclassified to zero (i.e. no habitat for natural pest predators).
1. The area percentage of habitat in GLs was calculated using:

    $GL_{area} = 100 * (GL_{density} * GL_{width}) / transect\ length$

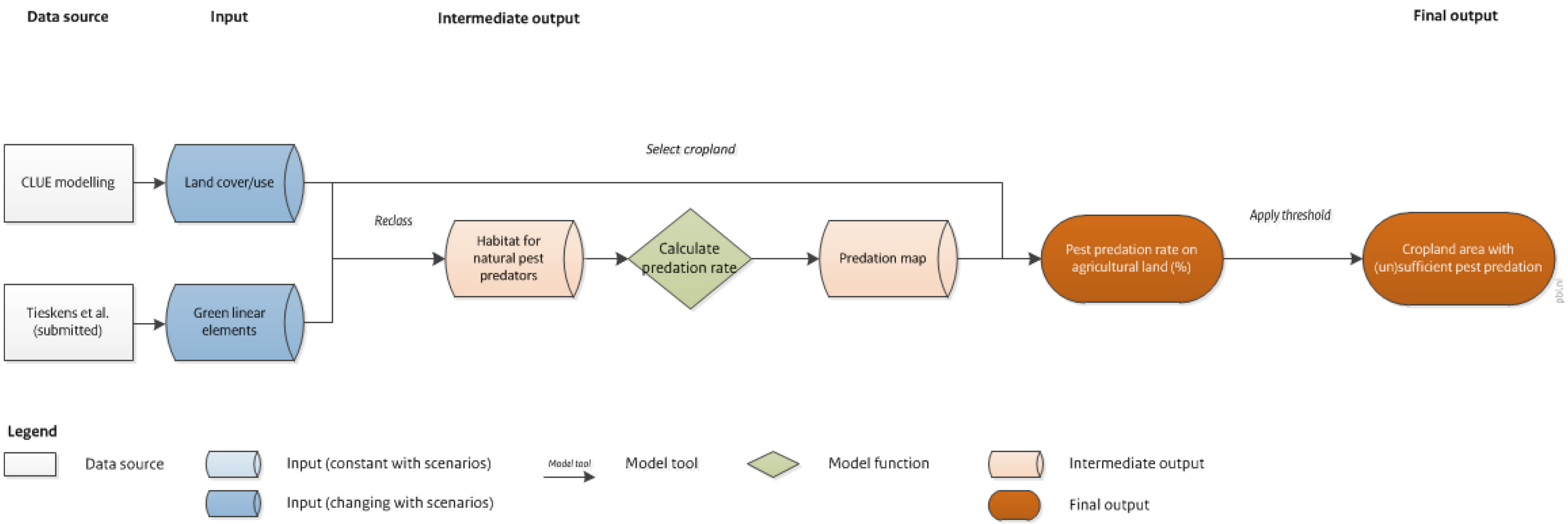
    In which GL_{area} is the area percentage of GLs (%); $GL_{density}$ is the average number of intersects with GLs on a 250m transect (#), GL_{width} is the width of GLs (m). In this analysis, we used an average width of 2m.
2. Habitat density from linear elements and other land cover was added together.
3. Cut off at 100.
4. The average habitat percentage for each grid cell is calculated as the focal mean in a 2 km radius.
5. From step 4, the predation rate (in %) was calculated as:

    *Predation rate = 19.65 + (0.309*average habitat for natural predators)*

6. The CLUE land-cover map was reclassified into agricultural areas depending on pest control (for selected land-cover classes see Table 4.17). Other areas were excluded.
7. Selection of agricultural areas with a sufficient rate of predation (min. 26%).

Figure 4.9.

Pest control model



Source: This report

Table 4.20. Input and output parameters of the pest control model (see also Appendix 3).

Name	Unit	Source	Description
INPUT			
Land cover	CLUE classes (16)	CLUE modelling	CLUE land-cover map 1x1 km
Green linear elements	Number of intersections	Tieskens et al. (submitted)	The probability of encountering a GL at a 250m transect
OUTPUT			
Pest control service	0–100		Average pest predation rate (in %) within 2 km of the agricultural area
	Yes (1) / No (0)		Agricultural area with sufficient/insufficient pest control

4.7.2 Discussion

Pest control was calculated based on the land cover and the GL maps. One of the main uncertainty related to the input data is the classification of the land-cover classes into 'Land-cover types that provide habitat for natural pest predators'. The suitability of natural and semi-natural vegetation as a habitat for natural predations strongly depends on management, which is not captured in the rough classes of the land-use map we used. Our reclassified map is similar to the map of 'semi-natural areas in agricultural land' provided by García-Feced et al. (2015), except for that of northern Europe, where not much agriculture takes place. For the map of GLs' uncertainty occurs in three stages: 1) the estimation of GL as described by Tieskens et al. (submitted), 2) the conversion of the number of intersections to area of GLs as described by Schulp et al. (2014c), and 3) our extrapolation of the area of green lines for 2050 (as described in Section 3.3). The land-use data set has a bigger influence on the results than the GL data set, because the contribution of land use to semi-natural vegetation reaches 100%, whereas the one of GL is max. 8.4%.

Combing information about different agricultural pests is a source of uncertainty. The few empirical studies we found about the presence of nature (i.e. non-crop habitat) and pest predation rate show big data variance, even when the studies target the same crop and related pest. We used the weighted average approach to aggregate the regression lines of the individual studies. The most important benefit of this approach is that it considers the quality of each study based on variances (numbers of data points and standard errors) of each study. Uncertainty emerges from the data preparation and the regression modelling. Empirical data from Rusch et al. (2013b) and Schmidt et al. (2005) needed to be transformed from densities of natural enemies or pests to predation rate. Uncertainties arose from two steps when empirical data needed to be transformed: 1) relations between percentage of natural land cover and species densities; and 2) relations between species densities and predation rate. When no data transformation is needed, uncertainties arise only from estimating the regression model between percentage of natural land cover and predation rate (Tin-Yu Lai, 2015). We found that adding an additional study to improve the function has small effect on the results. These suggest that besides the presence of nature there are other important, but unknown factors influence pest predation rate.

We used an aggregated indicator of multiple agricultural pests. Studies were selected where the indicator of pest control was the predation rate or a similar indicator that could be transformed into the predation rate (i.e. Boccaccio et al. (2009), who used the emergence of parasitoids). We related the pest predation rate to the particular area of nature, because of data availability, even if the area of the edge of nature patches may be more important (Bianchi et al., 2008). Pest control could be measured with other indicators, such as the richness of species providing natural pest control (Mouchet and Lavorel, 2012). Mouchet and Lavorel (2012) used the assumption that higher number of species leads to greater natural control of pests and calculated the number of species naturally controlling invertebrate pests by overlaying species distribution.

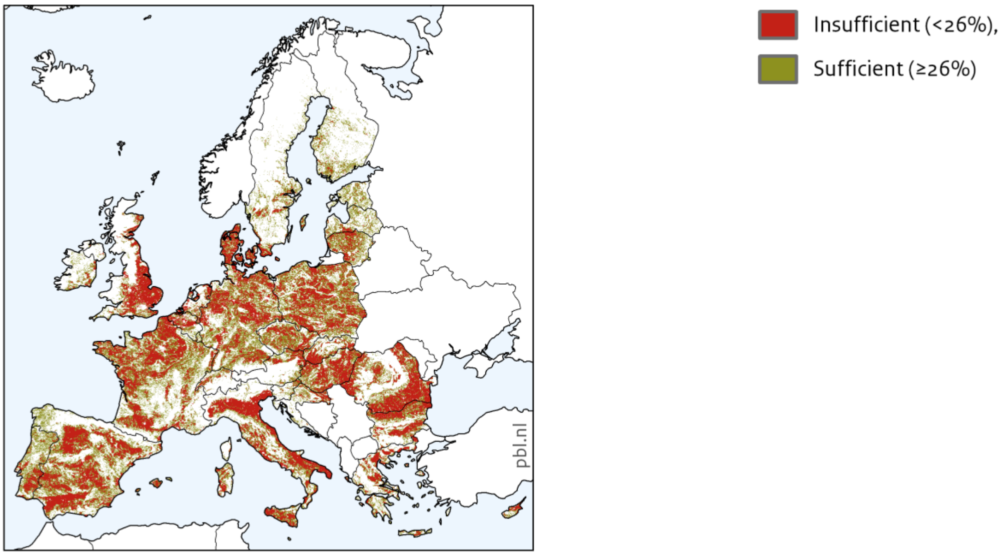
There is an upper-bound (around 50%) and a lower-bound (around 20%) limitation of predation rate in corresponding to 100% and 0% of natural areas in the model. The upper-bound limitation can be explained as a balance arising from the pest–predator dynamics as confirmed by fieldwork studies (Ulber et al., 2010). However, the bottom-bound limitation of predation rate can be zero in the reality as Letourneau el at. (2012) shows that if percentage of cropland area is above a certain level, the predation rate drops to zero and cannot recover. This is not represented in the model.

The choice of threshold has remarkable consequences for the results. A level of 20–30% non-crop habitat has been suggested as a threshold for effective predation according to one of the latest studies (Bianchi et al., 2013), which we followed. Applying our model, this corresponds to about min. 26% predation rate (see Section 4.7.1). However, Hawkins and Cornell (Hawkins and Cornell, 1994) indicated, for example, that the biological control is no longer successful when the parasitism rate is below 32% to 36%. Furthermore, there is also a variation in the effective distance among studies or predators.

The variation in the input data and, hence, the model function influences the results. The difference in the mean values by taking only the two wheat studies or the five oil crop studies is bigger than the difference between the results for the 2000 and 2050, which is only decimal. Nevertheless, the pattern of the pest control service does not change by modifying the function, as it is mainly dependent on the land-use-input data set.

The pest control map strongly depends on the indicator used. Using species richness as an indicator leads to a rather different pest control map than our method. It results in a smooth map and gives high values for southern and central Europe and low values for the United Kingdom and northern Europe (Mouchet and Lavorel, 2013). Our map is patchier and gives low values in areas with large-scale agriculture (e.g. Po River Plain) and high values in areas with small-scale agriculture (e.g. parts of France, Germany and Scandinavia) across the whole of Europe (Figure 4.10). The different pattern can be explained by the fact that in our method not only species habitat / presence of nature, but its distance to agriculture has been also considered. Mouchet and Lavorel (2012) measure biodiversity more accurately ('species richness' vs 'presence of nature'), but neglect its location to agricultural fields that benefit from it. The maps have also a different coverage, because Mouchet and Lavorel's map (2013) also covers also non-cultivated areas.

Pest control, 2000



Source: Output of the pest control model

Figure 4.10.

4.8 Recreation

4.8.1 Methodology

Table 4.21. The main characteristics of the recreation model.

Indicator name	**Nature based tourism**
Short description	Capacity of the ecosystem/landscape to provide recreational services
Units	Dimensionless (0–100)
Spatial resolution	1 km^2
Temporal resolution	Start year, end year
Output maps	Recreation capacity map
Reference	Van Berkel and Verburg (2011)

The model is based on the work of Van Berkel and Verburg (2011) and it simulates the capacity of the ecosystem/landscape to provide recreational services (Table 4.21). Figure 4.11 gives a schematic overview of the model and the input and output data are described in Table 4.22. The AML model script is provided in Appendix 7. Because of the data availability, simulation could be done only for EU-27 (without Switzerland and Croatia).

Landscapes' capacity for nature-based tourism and recreation was modelled with a dimensionless index. Certain landscape features attract tourist more than others. Literature and empirical studies confirm that especially forest areas, water bodies, variation in the landscape, protected areas and attractions sites, such as UNESCO sites and natural monuments, are suitable assists related to nature tourism (Goossen and Langers, 2000; Van Berkel and Verburg, 2011). The capacity of the ecosystem to support recreation and tourism is therefore mapped based on the degree of landscape variation (where the presence of forest has the highest recreation capacity); the presence of coasts, lakes and rivers, and the topography. The presence of protected areas, High Nature Value farmlands and natural monuments are landscape features supporting attractiveness of the landscape and are included in the model as tourist attraction sites.

The calculation rules are as follows (see also Figure 4.11):

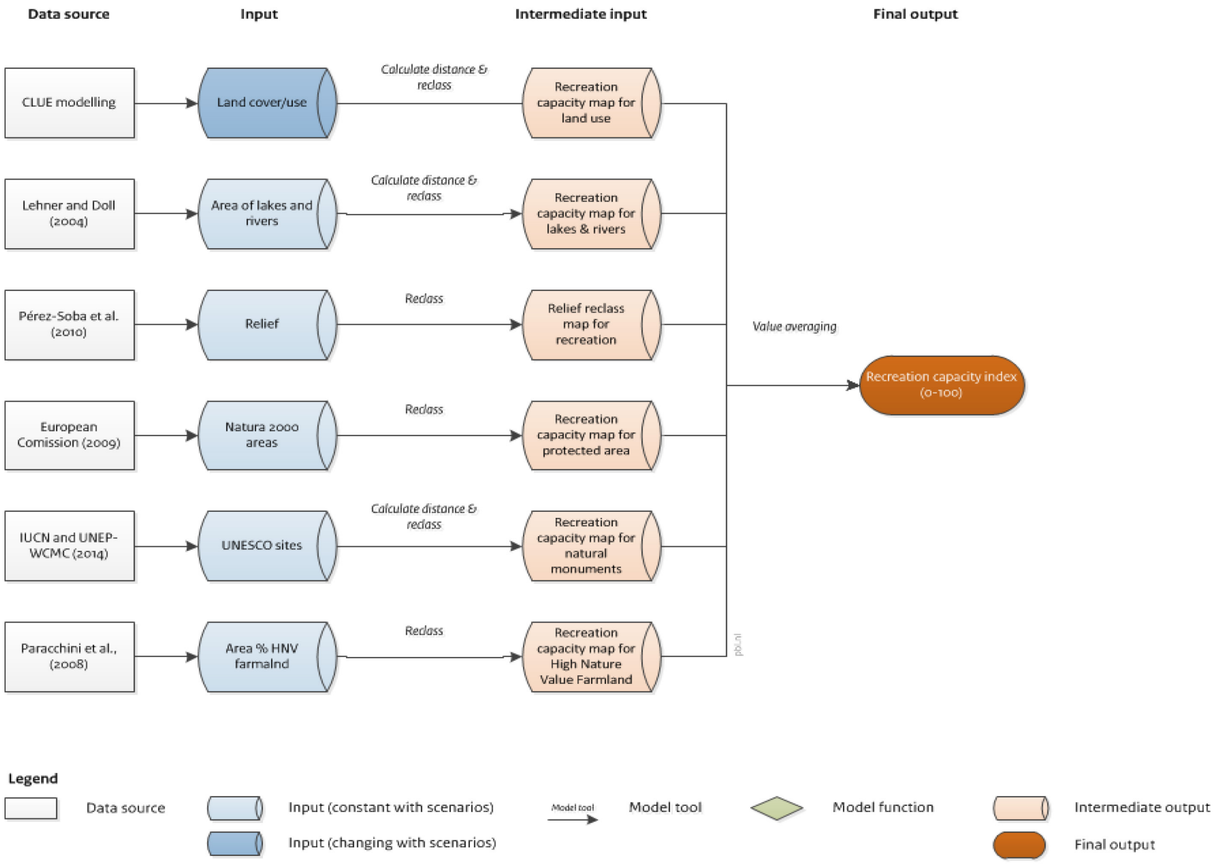
1. Landscape variation: The land-use map resulting from CLUE simulations is subdivided into four landscape types. These are assigned a capacity to provide recreational services based on the landscape type:
   a) Forest: More than two thirds of the land use in a 5 km radius is forest (land-use type 10) – Capacity 100;
   b) Peri-urban: more than one quarter of the land use in a 5 km radius is built-up (land-use type 0) – Capacity zero;
   c) Open or agriculture: more than 80% of the land use in a 5km radius is agriculture (land-use types 1, 2, 6, 8, 9, 18) – Capacity 30;
   d) Mosaic landscapes: more than 80% of natural land-use types (Land-use types 3, 4, 5, 7, 11, 12, 13, 14, 16, 17) in a 5 km radius – Capacity 70.
   e) The capacity of the landscape types is merged, giving priority in the order peri-urban, open, forest, and mosaic.
2. Water attractive areas: selection of lakes and rivers from global database of lakes, reservoirs and wetlands (Lehner and Döll, 2004); Areas within 5 km of lakes or 2 km of rivers receive a capacity of 100.
3. Relief: the relief classes are assigned capacities to provide recreational services. Flat landscapes: 30; Rolling landscapes: 50; Hilly landscapes: 70; mountainous landscapes: 100; very mountainous landscapes: zero (because of low accessibility). For the description of these classes see Table 4.21.
4. Protected areas: Natura 2000 sites are assigned a capacity to provide recreational services of 100.
5. Tourist attractions: Areas within 5 km of Natural and UN designated regions of special natural significance are assigned a capacity of 100.
6. HNV farmlands: farmlands with 0% HNV coverage were assigned a capacity of zero, farmlands with ≤ 50% HNV coverage were assigned a capacity of 50, and farmlands with >50% HNV coverage were assigned a capacity of 100.

Steps (1–6) each result in a capacity map ranging from zero to 100.

7. An average value of maps resulting from step 1–6 was calculated representing the recreation capacity for Europe.

Figure 4.11.

Nature Based Tourism model



Source: Van Berkel and Verburg (2011)

Table 4.22. Input and output parameters of the recreation model (see also Appendix 3).

Name	Unit	Source	Description
INPUT			
Land cover	CLUE classes (16)	CLUE modelling	CLUE Grid 1x1 km.
Lakes and rivers	Yes (1) / No (0)	Lehner and Döll (2004)	From the global lakes and wetland database, lake and river class are selected; areas within 5 km of lakes or 2 km of rivers in Europe highlighted as water attractive areas.
Relief	Classes: Flat – rolling – hilly – mountainous – very mountainous	Perez-Soba et al. (2010)	Classification of the relief within a 10 km radius: Flat: 0–20m elevation difference; Rolling: 20–80m elevation difference; Hilly: 80–200m elevation difference; Mountainous: 200–500m elevation difference; Very mountainous: >500m elevation difference.
Protected areas	Yes (1) / No (0)	European Commission (2009)	Natura 2000 areas
Natural monuments	Presence (1) / absence (0)	IUCN and UNEP-WCMC (2014)	Protected areas of Europe including UNESCO sites and national protection areas
HNV farmlands	%	Paracchini et al. (2008)	Area of 1 km^2 grid cell (in %) that is of High Natural Value (HNV)
OUTPUT			
Recreation capacity index	0–100		Dimensionless index for landscapes' capacity for nature-based tourism and recreation

4.8.2 Discussion

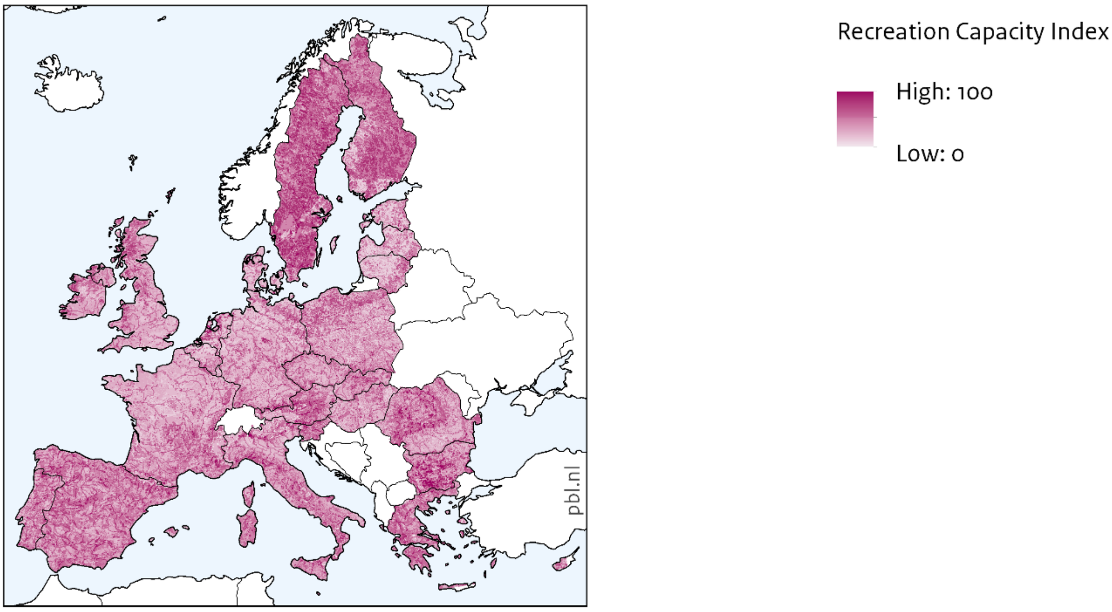
The recreation indicator is based on land-cover data, extent of lakes and rivers, elevation, presence of protected areas and natural monuments, and HNV farmlands. A main drawback of the land-cover map used here is the inaccurate representation of mosaic landscapes. Due to accounting for a neighbouring region in classifying the land-use map, this is overcome in the model. There is no definitive estimate of the uncertainty of the lakes and river data set (Lehner and Doll, 2004). The applied data set compiles a wide range of underlying sources and considered the most comprehensive spatial data set on lakes, rivers, and wetlands. The combination of different datasets as well as the underlying digitation has, however, introduced errors. Comparisons with remote sensing data show a reasonable agreement (Lehner and Doll, 2004). A 1 km resolution elevation map was used. This is a low resolution for representing elevation differences (Mantel et al., 2014), but as only the elevation range in a 10 km radius was considered, these inaccuracies are mostly averaged out. The presence of protected areas was based on the official EU map of protected areas. The presence of natural monuments was based on the World Database of Protected Areas. This is a comprehensive database, but it does contain inaccuracies in spatial representation (IUCN and UNEP-WCMC, 2014). The HNV farmland map used here was a simple classification of a 100 m resolution CORINE map into areas (in %) covered by natural grasslands and mosaic land-cover types (Cooper et al., 2007). Although this largely simplifies nature's value, the areas identified in the map do correlate well with richness of generalist bird species across e.g. Germany (Aue et al., 2014).

A main uncertainty related to the input data is assigning a recreation potential value to each input. The parameterisation was done by a panel of experts that identified inputs used as well as importance of each individual input (Van Berkel and Verburg, 2011). A validation against camping site density resulted in an R^2 of 0.752 (Van Berkel and Verburg, 2011), but also demonstrated contradictions, most importantly a low campsite density near Natura 2000 areas. Overall, the high R2, however, provides a good confidence in the map.

There are also other methods for mapping recreation. Paracchini et al. (2014) similar, but partly different indicators and assumptions. They used the degree of naturalness (based on CORINE land-cover map and agricultural and forest management), Natura 2000 protected areas and water aspect (i.e. distance to lake and coast and bathing water quality) to create a recreation potential map. This was combined with an accessibility map (i.e. distance from urban area and road) to include also the demand for recreation. Our approach neglects accessibility, hence, also the demand for recreation.

Our recreation capacity map gives generally higher values for Scandinavia and Mediterranean and lower values for western and central Europe. The pattern of water flows and waterbodies is also visible on the map, as areas nearby water have higher recreational value (Figure 4.13). Paracchini et al. (2014) gives a similar, but partly different recreation potential map. They provide high values for Scandinavia in general and there are patches with high recreational values also in other parts of Europe. Patches with low recreational value can be found across the whole of Europe, except for in Scandinavia. Nevertheless, the general patterns are the same between the two maps, as (natural) forests, diverse landscapes, protected areas and areas close to water have high value and intensively managed (agricultural) areas have low value. These differences and similarities in the output maps can be explained by the similar, but slightly different indicators and assumptions applied in our study and by Paracchini et al. (2014).

Recreation, 2000



Source: Output of the recreation model

Figure 4.12. Recreation index in 2000

5 Potential improvements

The ecosystem services models with intermediate complexity described in this document are suitable for large-scale simulations and are closely based on scaled up results of more process-based models (Schulp et al., 2014b). Most models have previously been applied for European-scale policy support (Schulp et al., 2016; Tucker et al., 2013). In the Nature Outlook these ecosystem services models were applied parallel with the BioScore biodiversity model (Hendriks et al., 2016). The interaction between the ecosystem services and biodiversity models could be improved in the future.

The ecosystem services models are directly driven by land-cover change. Therefore, the quality and accuracy of the land-cover input and the assumptions it implies are determinative for the ecosystem services results. The models could be further improved by including aspects of ecosystem conditions, such as degradation (due to overuse and pollination, among others) and carrying capacity, in addition to the currently included land cover and aspects of land management (i.e. agriculture and forestry). Carrying capacity closely relates to sustainable production. This is particularly important for provisioning services, which are underpinned by regulating services. An example for this is sustainable crop production, which relies on natural pollination, pest control and carrying capacity of the soil.

The models described in this report simulate mainly the theoretical supply of an ecosystem services. Demand modules exists for certain services, such as the wild food demand (Schulp et al., 2014a) and the flood regulation (Stürck et al., 2014). For pollination and pest control demand has been taken into account by selecting agricultural areas, which benefit from the natural pollination and pest control. Nevertheless, while ecosystem services supply is derived from land cover and other biophysical factors, there is no consistent general method for simulating demand. Future developments could include a more systematic definition, indicator choice, simulation and analysis of ecosystem services supply, demand and the match between the two (Wolff et al., 2015).

The EU Biodiversity Strategy formulates general policy targets for the restoration of ecosystem services and sustainable production (European Commission, 2011). Unless the issues regarding accuracy and inclusion of ecosystem management described above, the ecosystem services models described in the report are suitable for analysing the current state of ecosystem services and project future changes in the light of these policy targets given that land use changes are considered a dominant impact. These quantitative models have also the potential for helping to formulate more concrete and quantitative policy targets, which are currently lacking.

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Appendix

Appendix 1

Table A1. Link between CORINE and CLUE land-use classifications.

CORINE Code	CORINE Explanation	CLUE Land-use code (Table 2.1)*
111	Continuous urban fabric	0
112	Discontinuous urban fabric	0
121	Industrial or commercial units	0
122	Road and rail networks and associated land	0
123	Port areas	0
124	Airports	0
131	Mineral extraction sites	0
132	Dump sites	0
133	Construction sites	0
141	Green urban areas	0
142	Sport and leisure facilities	0
211	Non-irrigated arable land	1
212	Permanently irrigated land	6
213	Rice fields	6
221	Vineyards	8
222	Fruit trees and berry plantations	8
223	Olive groves	8
231	Pastures	2
241	Annual crops associated with permanent crops	8
242	Complex cultivation patterns	1 or 2**

*: No CORINE equivalent exists for the classes 7 and 16 (recently abandoned farmland). These can be best compared to pastures, natural grasslands, or sclerophyllous vegetation.

**: This CORINE class is equally split between CLUE classes 1 and 2.

***: This CORINE class is divided over CLUE classes 1 (25% of the area), 2 (30%), and 3 (45%).

243	Land principally occupied by agriculture, with significant areas of natural vegetation	1 or 2 or 3***
244	Agro-forestry areas	8
311	Broad-leaved forest	10
312	Coniferous forest	10
313	Mixed forest	10
321	Natural grasslands	3
322	Moors and heathland	15
323	Sclerophyllous vegetation	3
324	Transitional woodland-shrub	3
331	Beaches, dunes, sands	12
332	Bare rocks	11
333	Sparsely vegetated areas	11
334	Burnt areas	11
335	Glaciers and perpetual snow	5
411	Inland marshes	4
412	Peat bogs	4
421	Salt marshes	14
422	Salines	13
423	Intertidal flats	14
511	Water courses	14
512	Water bodies	14
521	Coastal lagoons	14
522	Estuaries	14
523	Sea and ocean	14

Appendix 2

File names and names beginning with 'Y:\Project\...' refer to places where the files can be found by PBL staff.

Figure A2. AML script for wild food supply and demand (file name: WildFoodSupply_edit).

```
/*  WILD FOOD SUPPLY AND DEMAND
/*  Based on BIOSCORE tool
/*  Calculates species distribution of gathered and hunted plants, mammals and birds
/*  This version: VU, Nynke Schulp
/*  2015 June 5
/*
/*************************************************************************
/*
/* MAIN
/*
/*************************************************************************

&sv today := [date -TAG]
&watch
Y:\Project\M500067_EcologischeModellenEnGraadmeters\Data\ES_model\Data\BAU_run\_sc
ripts\NOL_WFSupply_%today%.txt &commands

  &type
  &type [date -full]
  &type

   grid
   verify off

  &sv indir =
Y:\Project\M500067_EcologischeModellenEnGraadmeters\Data\ES_model\Data\BAU_run\WF
Supply_In
  &sv basedir =
Y:\Project\M500067_EcologischeModellenEnGraadmeters\Data\ES_model\Data\BAU_run\Bas
eData
  &sv ludir =
Y:\Project\M500067_EcologischeModellenEnGraadmeters\Data\ES_model\Data\BAU_run\Lan
dUse_BAU
  &sv outdir =
Y:\Project\M500067_EcologischeModellenEnGraadmeters\Data\ES_model\Data\BAU_run\Out
puts
  &sv draftdir =
Y:\Project\M500067_EcologischeModellenEnGraadmeters\Data\ES_model\Data\BAU_run\_zo
oi

  &sv ys = 00
  &sv ye = 50

  &do sc &list re
```

```
        &type %sc% scenario

  &do y &list %ys% %ye%
  &type year %y%

/*  &sv sc = b2
/*  &do y &list 40

setwindow %basedir%\mask
setmask %basedir%\mask
setcell %basedir%\mask

&workspace %draftdir%

  &call Prepare
  &call game
  &call mushrooms
  &call plants
  &call Outputs

&type [date -full]

&end

&workspace
Y:\Project\M500067_EcologischeModellenEnGraadmeters\Data\ES_model\Data\BAU_run\_sc
ripts

quit
&return
quit

/*************************************************************************
/* Link tables
&type
&type linking suitability tables to land use map of %sc% scenario year 20%y%
&type

/*************************************************************************

&routine Prepare

  tmp0 = con(%ludir%\lu_%sc%%y% == 1, 110, con(%ludir%\lu_%sc%%y% == 2, 120,
con(%ludir%\lu_%sc%%y% == 10, 130, con(%ludir%\lu_%sc%%y% == 6, 160,
%ludir%\lu_%sc%%y%))))
  tmp1 = con(tmp0 == 110, (tmp0 + %ludir%\int_%sc%%y%), tmp0) /* Arable land
rainfed intensity
  tmp2 = con(tmp1 == 114, 111, con(tmp1 == 115, 113, con(tmp1 == 110, 111, tmp1)))
/* Remove accidental errors in rainfed arable land intensity
  tmp3 = con(tmp2 == 160, (tmp0 + %ludir%\int_%sc%%y%), tmp2) /* Arable land
irrigated intensity
  tmp4 = con(tmp3 == 164, 111, con(tmp3 == 165, 113, con(tmp3 == 160, 161, tmp3)))
/* Remove accidental errors in irrigated arable land intensity
```

```
  tmp5 = con(tmp4 == 120, (tmp4 + %ludir%\int_%sc%%y%), tmp4) /*Pasture intensity
  tmp6 = con(tmp5 == 121, 124, con(tmp5 == 122, 125, con(tmp5 == 123, 125, con(tmp5
== 120, 124, tmp5)))) /* Remove accidental errors in pasture intensity
  tmp7 = con(tmp6 == 130, (tmp6 + %ludir%\fm_%sc%%y%), tmp6)
  %indir%\LU = con(tmp7 == 130, 131, tmp7) /* Final land use / management map,
remove accidental errors in forest management

&workspace %indir%

  quit /*grid
  kill suittab info
  dbaseinfo suitsens.dbf suittab.tbl

  indexitem suittab.tbl LUM /* Make this the link field in the suitability table

tables

  select LU.vat
  alter value,value,,,LUM

quit /*tabs

  joinitem LU.vat suittab.tbl LU.vat LUM # ordered

grid
verify off
&return

/***********************************************************************
/* Downscale distribution maps to 1km resolution based on land use and management
/***********************************************************************

&routine plants
&workspace %draftdir%

&do sp &list VP1 VP2 VP3 VP4 VP5 VP6 VP7 VP8 VP9 VP10 VP11 VP12 VP13 VP14 VP15 VP16
VP17 VP18 VP19 VP20 VP21 VP22 VP23 VP24 VP25 VP26 VP27 VP28 VP29 VP30 VP31 VP32
VP33 VP34 VP35 VP36 VP37 VP38 VP39 VP40 VP41 VP42 VP43 VP44 VP45 VP46 VP47 VP48
VP49 VP50 VP51 VP52 VP53 VP54 VP55 VP56 VP58 VP59 VP60 VP61 VP62 VP63 VP64 VP65
VP66 VP67 VP68 VP69 VP70 VP71 VP72 VP73 VP74 VP75 VP76 VP77 VP78 VP79 VP80 VP81
VP82 VP83 VP84 VP85 VP86 VP87 VP88 VP89
          tmp32 = reclass(%indir%\LU.%sp%, %indir%\suit.txt, data)
          d_%sp% = (tmp32 * %indir%\utm_%sp%)
&end /* plant species loop

&return

&routine game
&workspace %draftdir%

&do sp &list GA1 GA2 GA3 GA4 GA5 GA6 GA7 GA8 GA9 GA10 GA11 GA12 GA13 GA14 GA15
GA16 GA17 GA18 GA19 GA20 GA21 GA22 GA23 GA24 GA25 GA26 GA27 GA28 GA29 GA30
GA31
```

```
        tmp32 = reclass(%indir%\LU.%sp%, %indir%\suit.txt, data)
        d_%sp% = (tmp32 * %indir%\utm_%sp%)
&end /* animal species loop

&do sp &list GA8 GA10 GA20 GA13 GA15 GA17 GA21

 tmp10 = con(d_%sp% == 1 and %basedir%\roadrail == 1, 1, 0)
 tmp11 = setnull(tmp10 == 0, 1)
 tmp12 = regiongroup(tmp11, #, eight, cross, 0)
 tmp13 = (int(zonalarea(tmp12)) / 1000000)
 tmp14 = con(isnull(tmp13), 1000, tmp13)
 tmp15 = tmp14 * d_%sp%
 d_%sp% = con(tmp15 > 500, 1, 0)

&end /* animal species loop - fragmentation

&return

&routine mushrooms
&workspace %draftdir%

&do sp &list MR1 MR2 MR3 MR4 MR5 MR6 MR7 MR8 MR9 MR10 MR11 MR12 MR13 MR14
MR15 MR16 MR17 MR18 MR19 MR20 MR21 MR22 MR23 MR24 MR26
        tmp32 = reclass(%indir%\LU.%sp%, %indir%\suit.txt, data)
        d_%sp% = (tmp32 * %indir%\utm_%sp%)
&end /* mushroom species loop

&return

/************************************************************************
/* Summarize outputs
/************************************************************************

&routine Outputs
 &workspace %draftdir%

  tmp20 = sum(d_VP1, d_VP2, d_VP3, d_VP4, d_VP5, d_VP6, d_VP7, d_VP8, d_VP9,
d_VP10, d_VP11, d_VP12, d_VP13, d_VP14, d_VP15, d_VP16, d_VP17, d_VP18, d_VP19,
d_VP20)
  tmp21 = sum(d_VP21, d_VP22, d_VP23, d_VP24, d_VP25, d_VP26, d_VP27, d_VP28,
d_VP29, d_VP30, d_VP31, d_VP32, d_VP33, d_VP34, d_VP35, d_VP36, d_VP37, d_VP38,
d_VP39, d_VP40)
  tmp22 = sum(d_VP41, d_VP42, d_VP43, d_VP44, d_VP45, d_VP46, d_VP47, d_VP48,
d_VP49, d_VP50, d_VP51, d_VP52, d_VP53, d_VP54, d_VP55, d_VP56, d_VP58, d_VP59,
d_VP60)
  tmp23 = sum(d_VP61, d_VP62, d_VP63, d_VP64, d_VP65, d_VP66, d_VP67, d_VP68,
d_VP69, d_VP70, d_VP71, d_VP72, d_VP73, d_VP74, d_VP75, d_VP76, d_VP77, d_VP78,
d_VP79, d_VP80)
  tmp24 = sum(d_VP81, d_VP82, d_VP83, d_VP84, d_VP85, d_VP86, d_VP87, d_VP88,
d_VP89)
```

```
  tmp25 = sum(d_GA1, d_GA2, d_GA3, d_GA4, d_GA5, d_GA6, d_GA7, d_GA8, d_GA9,
d_GA10, d_GA11, d_GA12, d_GA13, d_GA14, d_GA15, d_GA16, d_GA17, d_GA18, d_GA19,
d_GA20)
  tmp26 = sum(d_GA21, d_GA22, d_GA23, d_GA24, d_GA25, d_GA26, d_GA27, d_GA28,
d_GA29, d_GA30, d_GA31)

  tmp27 = sum(d_MR1, d_MR2, d_MR3, d_MR4, d_MR5, d_MR6, d_MR7, d_MR8, d_MR9,
d_MR10, d_MR11, d_MR12, d_MR13, d_MR14, d_MR15, d_MR16)
  tmp28 = sum(d_MR17, d_MR18, d_MR19, d_MR20, d_MR21, d_MR22, d_MR23, d_MR24,
d_MR26)

  tmp29 = sum(tmp20, tmp21, tmp22, tmp23, tmp24)
  tmp30 = sum(tmp25, tmp26)
  tmp31 = sum(tmp27, tmp28)

  %outdir%\PlantSR%sc%%y% = tmp29
  %outdir%\GameSR%sc%%y% = tmp30
  %outdir%\MushSR%sc%%y% = tmp31
  %outdir%\WFSR%sc%%Y% = sum(tmp20, tmp21, tmp22, tmp23, tmp24, tmp25, tmp26,
tmp27, tmp28)

  tmp32 = %outdir%\PlantSR%sc%%y% + %outdir%\MushSR%sc%%y%
  tmp33 = con(tmp32 == 0, 0, con(tmp32 < 19, 1, 2))
  tmp34 = con(%outdir%\GameSR%sc%%y% == 0, 0, con(%outdir%\GameSR%sc%%y%
< 8, 10, 20))

  %outdir%\WFvar%sc%%y% = tmp33 + tmp34

&type
&type finished calculating at [date -full].
&type

&return
```

Appendix 3

File names and names beginning with 'Y:\Project\...' refer to places where the files can be found by PBL staff.

Table A3. Input and output data files for all ecosystem models.

Variable	Source	Description	Unit	Path if not other stated: ***Y:\Project\M500067_EcologischeModellenEnGraadmeters\Data\ES_model\Data\BAU_run***	Name of data file	In which ecosystem services model is used?
INPUT						
Land cover/use	CLUE modelling	land cover/use modelled by CLUE	17 classes	LandUse_BAU BAU_run	2000: lu_re00copy1 2050: bau_2050_copy BAU_CLUE_151214_EU29_1km	All
Land-use intensity	CAPRI-CLUE modelling	Land-use intensity based on nitrogen application in arable land and pasture	0–5 classes	LandUse_BAU	2000: Int_re00 2050: Int_re50	Wild food provision, Carbon sequestration, Flood regulation
Green elements	Tieskens et al. (submitted)	Tree lines selected from the European Green elements density map	Nb of intersection	BaseData\Green_Infrastructure_GIS	GreeLines	Pollination, Pest control

Area of green elements	Derived from Tieskens et al. (submitted)	Area of green element calculated from the nb of intersections	area % GL/ km^2	LandUse_BAU\Green_Elements.gdb[3]	2000: ge00_EU28 (excluding Croatia) 2050: GE50_EU28_1km (excluding Croatia)	
Forest management	EFISCEN modelling	Potential forest management types	0–5 classes	LandUse_BAU	2000: Fm_re00 2050: Fm_re50	Wild food provision, Carbon sequestration, Flood regulation
Precipitation	Pérez-Soba et al. (2010)	Monthly total rainfall	mm	BaseData	2000: Pre12_00 2050: Pre12_50	Erosion prevention
Climatic zones	Pérez-Soba et al. (2010)	Climatic zones (boreal, temperate and Mediterranean) used to map protection that land cover provides against erosion		BaseData	zones	Erosion prevention
KLS map	Pérez-Soba et al. (2010)	Product of soil erodibility (K), slope length (L) and slope steepness (S) factors	-	BaseData	kls	Erosion prevention
Protective vegetation cover values	Pérez-Soba et al. (2010)	Vegetation cover protection against erosion from climate-zone-specific parameter values; reclassified for CLUE land-use map	0–1 values	BaseData	ErosionCoverZone1.txt ErosionCoverZone2.txt ErosionCoverZone3.txt	Erosion prevention
Stones	Pérez-Soba et al. (2010)	Mapping of very stony areas and areas with few or no	0 (very stony) –	BaseData	stoneprot	Erosion prevention

[3] Methodology: Y:\Project\M500067_EcologischeModellenEnGraadmeters\Data\Ecosysteem_diensten\Green_infrastructure_GIS\Green_elements_methodology

		stones, according to the European Soil Database	1 (few/no stones)			
Rainfall correction factor	Pérez-Soba et al. (2010) and Hijmans et al. (2005)	Correction factor for rainfall intensity for the year 2000 based on WorldClim monthly precipitation data	-	BaseData	F_2000	Erosion prevention
Soil organic carbon	Schulp et al. (2008)	Combination of JRC soil organic carbon map (Jones et al., 2004) and soil map (European Soil Bureau Network and the European Commission, 2004)	0–8 (SOC classes); 9 (peat)	BaseData	socpeat	Carbon sequestration
Emission factors	Janssens et al. (2005)	Map with emission factor for each land-use type (see calculation rules)	Tonne C/km^2 per year	BaseData	efpeat; efnat; efgrass, efcrop	Carbon sequestration
	EFISCEN modelling[4]	Forest emission factors for soil and biomass from EFISCEN simulations	Tonne C/km^2 per year	Y:\Project\M500067_EcologischeModellenEnGraadmeters\Data\ES_modelData\EFISCEN\BAU run\	2000: SoilC_2015 2050: SoilC_2015	Carbon sequestration
				Y:\Project\M500067_EcologischeModellenEnGraadmeters\Data\ES_modelData\EFISCEN\NVK maps forest final	2000: GS_ha_2015_baseline_all Harv_ha_2015_baseline_all.tif 2050: GS_ha_2015_baseline_all Harv_ha_2050_baseline_all.tif	Carbon sequestration
Forest biomass content	EFISCEN modelling	Map of forest biomass carbon content per EFISCEN region	Tonne C/km^2	Y:\Project\M500067_EcologischeModellenEnGraadmeters\Data\ES_model	2000: TreeC_ha_2015_baseline_all	Carbon sequestration

[4] These are carbon stock data provided by EFISCEN. Emission factors need to be calculated from them.

				Data\EFISCEN\NVK maps forest final	2050: TreeC_ha_2015_baseline_all	
Catchment types	EEA (2008) and USGS (2007)	Classification of EU river catchments into hydrology classes	-		-	Flood regulation
Catchment zones	USGS (2007)	Map indicating the relative position within river catchment	-		-	Flood regulation
Precipitation regime	Haylock et al. (2008)	Classification of daily precipitation 1990–2000 into precipitation distribution regimes	-		-	Flood regulation
Water holding capacity	FAO (2009)	Soil water holding capacity classification	-	Y:\Project\M500067_EcologischeModellenEnGraadmeters\Data\ES_model\Ecosysteem_modellen_UA\PBL_flood\flood_inputs\inputs	Waterh	Flood regulation
Lakes and rivers / Water attractive areas	Adapted from Lehner and Doll (2004)	From the global lakes and wetland database, lake and river class are selected; areas within 5km of lakes or 2km of rivers highlighted as water attractive areas	Yes (100) / No (0)	BaseData	ntwater	Recreation
Natural monuments	IUCN and UNEP-WCMC (2014)	Protected areas of Europe including UNESCO sites and national protection areas	Presence (1) / absence (0)	BaseData	Ntattr (EU-27) (EU29: Y:\data\natuur\NV2016\CN\nvk_cn_geodata.gdb\whs_2014)	Recreation

Protected areas	European Commission (2009)	Natura 2000 sites	Yes (1) / No (0)	Y:\Project\M500067_EcologischeModellenEnGraadmeters\Data\ES_model\Data\NATURA2000\N00_EU29_WGS.gdb	N00_EU29	Recreation
High Nature Value Farmland Index	Paracchini et al. (2008)	Area of 1km^2 grid cell (in %) that is of High Natural Value (HNV) reclassified in 0, 50, 100 (= HNV farmlands further than 1 hour but within 3 hours of large urban centres are assigned a capacity of 100)	0, 50, 100	BaseData	Nthnv (EU-27)	Recreation
Relief	Perez-Soba et al. (2010)	Classification of the relief within a 10km radius: Flat: 0–20m elevation difference; Rolling: 20–80m elevation difference; Hilly: 80–200m elevation difference; Mountainous: 200–500m elevation difference; Very mountainous: >500m elevation difference.	0 (Flat) – 30 (rolling) – 50 (hilly) – 70 (mountainous – 100 (very mountainous)	BaseData	Ntgeo (EU-27) (EU 29: Y:\Project\M500067_EcologischeModellenEnGraadmeters\Data\ES_model\Data\other data\DEM.gdb\ELV_EU29)	Recreation
OUTPUT						
Wild food provision		Game species richness	Richness of wild game species	Outputs	PlantSRre00, PlantSRre50	Wild food provision

	Mushroom species richness	Richness of wild mushroom species	Outputs	GameSRre00 GameSRre50	Wild food provision
	Vascular plant species richness	Richness of wild plant species	Outputs	MushSRre00 MushSRre50,	Wild food provision
	Total wild food species richness	Total wild species richness	Outputs	WFSR_re00 WFSR_re50	
	Wild food sufficiency / variety index	Indication if wild food species are absent, available in limited richness, or available in abundant richness	Outputs	WFvarre00 WFvarre50	Wild food provision
Carbon sequestration					Carbon sequestration
Flood regulation	Relative water retention	Indication if wild food species are absent, available in limited richness, or available in abundant richness	Outputs	Flood_lu_re50	Flood regulation
	Soil erosion risk	Tonne/ha/yr	Outputs	2000: Re1ker00	Erosion prevention

Erosion prevention					2050: Re1ker50	
		Protective vegetation cover based on land-use map	0–0.32	Outputs	2000: Re1kec00 2050: Re1ker 50	Erosion prevention
Pollination		% cropland accessible from the pollinator habitat	0–100 index	Y:\Project\M500067_EcologischeModellenEnGraadmeters\Data\ES_model\Pest_control_output.gdb	2000: PH_access100_agr_2000 2050: PH_access100_agr_2050	Pollination
		Cropland area with (in)sufficient pollination	0/1	Y:\Project\M500067_EcologischeModellenEnGraadmeters\Data\ES_model\Pest_control_output.gdb	2000: PH_agr_YN_2000 2050: PH_agr_YN_2050	Pollination
Pest control		Average rate of pest predation (%)	0–100 index	Y:\Project\M500067_EcologischeModellenEnGraadmeters\Data\ES_model\Pest_control_output.gdb	2000: Pred_rate_AGR_2000 2050: Pred_rate_AGR_2050	Pest control
		Agricultural area with (in)sufficient pest control	0/1	Y:\Project\M500067_EcologischeModellenEnGraadmeters\Data\ES_model\Pest_control_output.gdb	2000: Pred_rate_AGR_26_2000 2050: Pred_rate_AGR_26_2050	Pest control
Recreation		Recreation capacity index	0–100	Outputs	2000: Re1knt00 (EU-27) 2050: Re1knt50 (EU-27)	Recreation

Appendix 4

Table A4-1. Land-use suitability of CLUE land-use types for vascular plants in the wild food supply model. 0 = not suitable, 1= suitable. For the description of species codes see Table 4.5.

Species Code	CLUE Land-use type															
	0	1	2	3	4	5	6	7	8	10	11	12	13	14	15	16
VP1	0	1	1	1	0	0	0	1	1	1	0	0	0	0	0	1
VP2	0	1	0	0	0	0	0	1	1	0	1	1	0	0	0	1
VP3	0	0	0	1	0	0	0	1	0	0	1	0	0	0	0	1
VP4	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
VP5	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0
VP6	0	1	1	1	1	0	0	1	1	0	0	0	1	1	0	1
VP7	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0
VP8	0	1	1	1	0	0	0	1	1	0	0	0	0	0	0	1
VP9	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0
VP10	0	1	1	1	0	0	0	1	0	0	0	1	0	0	0	1
VP11	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0
VP12	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0

Species Code	CLUE Land-use type															
	0	1	2	3	4	5	6	7	8	10	11	12	13	14	15	16
VP46	0	1	1	1	0	0	0	1	1	1	0	0	0	0	0	1
VP47	0	0	1	1	1	0	0	1	0	0	0	1	0	1	0	1
VP48	0	0	1	1	0	0	0	1	1	1	0	1	0	0	0	1
VP49	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0
VP50	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0
VP51	1	1	1	1	0	0	0	1	1	0	0	0	0	0	0	1
VP52	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
VP53	1	1	1	1	0	0	0	1	1	0	0	1	0	0	0	1
VP54	1	1	1	1	0	0	0	1	1	0	0	0	0	0	0	1
VP55	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0
VP56	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0
VP57	0	1	1	1	0	0	0	1	0	1	0	1	0	0	0	1

VP13	0	1	1	1	0	0	0	1	1	0	0	0	0	0	0	1	VP58	0	0	1	1	0	0	0	1	0	1	0	0	0	0	1	1
VP14	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	1	VP59	0	0	0	1	0	0	0	0	1	1	1	1	0	1	0	0
VP15	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	VP60	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
VP16	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	VP61	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0
VP17	1	1	1	1	0	0	0	1	1	0	0	0	0	1	0	1	VP62	0	0	0	1	0	0	0	0	0	1	1	1	0	1	0	0
VP18	1	1	1	1	0	0	0	1	1	0	0	0	0	0	0	1	VP63	0	0	0	1	0	0	0	1	0	1	0	1	0	1	0	1
VP19	0	1	1	1	0	0	0	1	0	0	0	0	0	0	0	1	VP64	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0
VP20	0	1	1	1	0	0	0	1	0	1	0	1	1	1	1	1	VP65	0	0	0	1	0	0	0	0	0	1	0	1	0	0	0	0
VP21	0	0	0	1	0	0	0	0	0	1	1	0	0	0	0	0	VP66	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0
VP22	0	0	1	1	0	0	0	1	0	1	0	0	0	0	1	1	VP67	1	1	1	1	0	0	0	1	1	1	0	1	0	0	1	1
VP23	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0	VP68	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0
VP24	0	0	0	1	0	0	0	1	0	0	1	0	0	0	0	1	VP69	0	0	0	1	1	0	0	0	0	1	1	1	0	0	1	0
VP25	1	1	1	1	0	0	0	1	1	0	1	0	0	0	0	1	VP70	0	0	1	1	0	0	0	1	0	1	0	0	0	1	1	1
VP26	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	VP71	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0
VP27	1	1	1	1	0	0	0	1	1	0	0	1	1	1	1	1	VP72	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0
VP28	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	1	VP73	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	1
VP29	1	1	1	1	0	0	0	1	1	0	0	0	0	0	0	1	VP74	1	1	1	1	0	0	0	1	1	1	1	1	0	0	1	1
VP30	1	1	1	1	1	0	0	1	1	1	1	1	0	1	0	1	VP75	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0

VP31	0	0	1	1	0	0	0	1	0	1	0	0	0	0	1	1
VP32	0	0	0	0	0	0	0	0	0	1	0	1	0	1	1	0
VP33	0	0	1	1	0	0	0	1	0	1	0	0	0	0	1	1
VP34	0	0	1	1	0	0	0	1	0	1	0	1	1	1	1	1
VP35	0	1	1	1	0	0	0	1	1	1	1	1	0	1	0	1
VP36	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
VP37	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
VP38	1	1	0	0	0	0	1	1	0	0	0	1	0	1	0	1
VP39	0	1	0	0	0	0	1	1	0	0	1	1	1	1	0	1
VP40	0	0	1	1	1	0	0	1	0	1	1	1	0	1	0	1
VP41	0	0	1	1	0	0	0	1	0	1	1	0	0	1	1	1
VP42	0	0	1	1	0	0	0	1	0	1	0	0	0	1	0	1
VP43	0	0	1	1	0	0	0	1	0	0	0	0	0	1	0	1
VP44	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
VP45	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0

VP76	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0
VP77	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0
VP78	1	1	1	1	0	0	0	1	1	1	0	0	0	0	0	1
VP79	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0
VP80	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0
VP81	0	1	1	1	0	0	0	1	1	1	0	1	0	1	0	1
VP82	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
VP83	0	1	1	1	0	0	1	1	1	1	0	0	0	1	0	1
VP84	1	1	1	1	0	0	0	1	1	1	0	0	0	1	1	1
VP85	0	0	1	1	0	0	0	1	0	1	0	0	0	0	1	1
VP86	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0
VP87	0	0	1	1	1	0	0	1	0	1	0	0	0	0	1	1
VP88	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0
VP89	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0

Table A4-2. Suitability of CLUE land-use types for game and mushroom species plants in the wild food supply model. 0 = not suitable, 1= suitable. For the description of species codes see Table 4.4 and Table 4.6.

Game																
Species Code	CLUE Land-use type															
	0	1	2	3	4	5	6	7	8	10	11	12	13	14	15	16
GA1	0	0	0	1	1	0	0	0	0	1	0	0	0	0	1	0
GA2	0	1	1	1	0	0	0	1	1	0	1	0	0	0	0	1
GA3	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0
GA4	0	0	0	0	1	0	0	0	0	0	0	0	1	1	0	0
GA5	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
GA6	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0
GA7	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
GA8	0	0	0	1	0	0	0	1	0	1	1	0	0	0	1	1
GA9	0	1	1	1	0	0	0	1	1	1	1	0	0	0	1	1
GA10	0	0	0	1	0	0	0	1	0	1	1	0	0	0	1	1
GA11	0	1	1	1	0	0	1	1	1	1	0	0	0	0	0	1
GA12	0	1	1	1	0	0	0	1	1	0	1	0	0	0	0	1
GA13	0	0	0	1	1	0	0	1	0	1	0	0	0	0	0	1

Mushrooms																
Species Code	CLUE Land-use type															
	0	1	2	3	4	5	6	7	8	10	11	12	13	14	15	16
MR1	1	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0
MR2	1	0	1	1	0	0	0	1	0	1	0	0	0	0	0	1
MR3	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
MR4	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
MR5	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
MR6	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
MR7	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
MR8	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
MR9	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
MR10	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
MR11	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
MR12	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
MR13	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0

GA14	0	0	0	1	1	0	0	1	0	0	0	0	0	1	0	1	MR14	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0
GA15	0	1	1	1	0	0	1	1	1	0	0	0	0	0	0	1	MR15	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0
GA16	0	0	0	1	0	0	0	1	0	0	1	0	0	0	1	1	MR16	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
GA17	0	1	1	1	0	0	0	1	0	1	0	1	0	0	1	1	MR17	0	0	1	1	0	0	0	1	0	1	0	0	0	0	0	1
GA18	0	1	1	1	0	0	0	1	1	0	0	0	0	0	0	1	MR18	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
GA19	0	0	0	1	0	0	0	1	0	0	1	0	0	0	1	1	MR19	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0
GA20	0	0	0	1	0	0	0	1	0	1	1	0	0	0	1	1	MR20	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
GA21	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	MR21	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
GA22	0	1	1	1	0	0	0	1	1	1	0	0	0	0	0	1	MR22	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
GA23	0	1	1	1	0	0	0	1	1	1	0	0	0	0	0	1	MR23	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0
GA24	0	0	1	0	1	0	0	1	0	1	0	0	0	0	1	1	MR24	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
GA25	0	1	1	1	0	0	0	1	1	1	0	0	0	0	0	1	MR25	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
GA26	0	1	1	1	1	0	1	1	1	0	0	0	0	1	1	1	MR26	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
GA27	0	1	0	1	1	0	1	1	0	1	0	0	1	1	1	1																	
GA28	0	1	0	1	1	0	0	1	0	1	1	0	0	0	1	1																	
GA29	0	1	1	1	1	0	1	1	1	1	0	0	0	0	0	1																	
GA30	0	1	1	1	0	0	0	1	0	1	0	0	0	0	0	1																	
GA31	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0																	

Table A4-3. Land management suitability for vascular wild plants in the wild food supply model. 0 = not suitable, 1= suitable. For the description of species codes see Table 4.5.

Species code	Land Management (Coding see below)													Species code	Land Management (Coding see below)												
	Rainfed Arable			Irrigated Arable			Pasture				Forest				Rainfed Arable			Irrigated Arable			Pasture				Forest		
	E	M	I	E	M	I	E	I	U	C	M	I	S		E	M	I	E	M	I	E	I	U	C	M	I	S
VP1	1	1	1	0	0	0	1	1	1	1	1	0	0	VP46	1	1	1	0	0	0	1	1	1	1	1	1	1
VP2	1	1	0	0	0	0	0	0	0	0	0	0	0	VP47	0	0	0	0	0	0	1	1	0	0	0	0	0
VP3	0	0	0	0	0	0	0	0	0	0	0	0	0	VP48	0	0	0	0	0	0	1	0	1	1	1	1	1
VP4	0	0	0	0	0	0	0	0	1	1	1	0	0	VP49	0	0	0	0	0	0	0	0	1	1	1	0	0
VP5	0	0	0	0	0	0	0	0	1	1	1	0	0	VP50	0	0	0	0	0	0	0	0	1	1	1	0	0
VP6	1	1	1	0	0	0	1	1	0	0	0	0	0	VP51	1	1	0	0	0	0	1	1	0	0	0	0	0
VP7	0	0	0	0	0	0	0	0	1	1	1	1	1	VP52	0	0	0	0	0	0	0	0	0	0	0	0	0
VP8	1	1	0	0	0	0	1	1	0	0	0	0	0	VP53	1	1	0	0	0	0	1	0	0	0	0	0	0
VP9	0	0	0	0	0	0	0	0	1	1	1	0	0	VP54	1	1	0	0	0	0	1	0	0	0	0	0	0
VP10	1	0	0	0	0	0	1	0	0	0	0	0	0	VP55	0	0	0	0	0	0	0	0	1	1	1	0	0
VP11	0	0	0	0	0	0	0	0	1	1	0	0	0	VP56	0	0	0	0	0	0	0	0	1	1	1	0	0
VP12	0	0	0	0	0	0	0	0	0	0	0	0	0	VP57	1	1	0	0	0	0	1	1	1	1	1	1	1
VP13	1	1	1	0	0	0	1	1	0	0	0	0	0	VP58	0	0	0	0	0	0	1	1	1	1	1	0	0
VP14	0	0	0	0	0	0	1	1	0	0	0	0	0	VP59	0	0	0	0	0	0	0	0	1	1	1	0	0

VP15	0	0	0	0	0	0	0	0	1	1	1	0	0	VP60	0	0	0	0	0	0	0	0	0	0	0	0	0
VP16	0	0	0	0	0	0	0	0	1	1	1	1	1	VP61	0	0	0	0	0	0	0	0	1	1	1	0	0
VP17	1	1	1	0	0	0	1	1	0	0	0	0	0	VP62	0	0	0	0	0	0	0	0	1	1	1	0	0
VP18	0	1	1	0	0	0	0	1	0	0	0	0	0	VP63	0	0	0	0	0	0	0	0	1	1	1	0	0
VP19	1	1	0	0	0	0	1	0	0	0	0	0	0	VP64	0	0	0	0	0	0	0	0	0	0	0	0	0
VP20	1	1	1	0	0	0	1	1	1	1	1	1	1	VP65	0	0	0	0	0	0	0	0	1	1	1	0	0
VP21	0	0	0	0	0	0	0	0	1	1	1	0	0	VP66	0	0	0	0	0	0	0	0	1	1	1	1	1
VP22	0	0	0	0	0	0	1	1	1	1	1	0	0	VP67	1	1	1	0	0	0	1	1	1	1	1	1	1
VP23	0	0	0	0	0	0	0	0	1	1	1	0	0	VP68	0	0	0	0	0	0	0	0	1	1	0	0	0
VP24	0	0	0	0	0	0	0	0	0	0	0	0	0	VP69	0	0	0	0	0	0	0	0	1	1	1	0	0
VP25	1	0	0	0	0	0	1	0	0	0	0	0	0	VP70	0	0	0	0	0	0	1	1	1	1	1	0	0
VP26	0	0	0	0	0	0	0	0	0	0	0	0	0	VP71	0	0	0	0	0	0	0	0	1	1	1	1	1
VP27	0	1	1	0	0	0	1	1	0	0	0	0	0	VP72	0	0	0	0	0	0	0	0	1	1	1	0	0
VP28	1	1	0	0	0	0	0	0	0	0	0	0	0	VP73	0	0	0	0	0	0	1	1	0	0	0	0	0
VP29	1	1	1	0	0	0	1	1	0	0	0	0	0	VP74	0	0	0	0	0	0	1	0	1	1	1	1	1
VP30	1	1	1	0	0	0	1	1	0	1	1	1	1	VP75	0	0	0	0	0	0	0	0	0	0	0	0	0
VP31	0	0	0	0	0	0	1	1	1	1	1	0	0	VP76	0	0	0	0	0	0	0	0	1	1	1	1	1
VP32	0	0	0	0	0	0	0	0	1	1	1	0	0	VP77	0	0	0	0	0	0	0	0	0	0	0	0	0

VP33	0	0	0	0	0	0	0	1	1	1	1	0	0	VP78	1	1	0	0	0	0	1	1	1	1	1	0	0
VP34	0	0	0	0	0	0	1	0	1	1	1	0	0	VP79	0	0	0	0	0	0	0	0	0	0	1	1	1
VP35	1	1	1	0	0	0	1	1	1	1	1	1	1	VP80	0	0	0	0	0	0	0	0	1	1	1	0	0
VP36	0	0	0	0	0	0	0	0	0	0	0	0	0	VP81	0	1	1	0	0	0	0	1	1	1	1	1	1
VP37	0	0	0	0	0	0	0	0	1	1	1	0	0	VP82	0	0	0	0	0	0	0	0	1	1	1	0	0
VP38	1	1	1	1	1	1	0	0	0	0	0	0	0	VP83	1	1	1	1	1	1	1	1	1	1	1	1	1
VP39	1	1	0	1	1	0	0	0	0	0	0	0	0	VP84	0	1	1	0	0	0	0	1	1	1	1	1	1
VP40	0	0	0	0	0	0	1	0	1	1	1	0	0	VP85	0	0	0	0	0	0	1	0	1	1	1	0	0
VP41	0	0	0	0	0	0	1	1	1	1	1	1	1	VP86	0	0	0	0	0	0	0	0	1	1	1	0	0
VP42	0	0	0	0	0	0	1	1	1	1	1	0	0	VP87	0	0	0	0	0	0	1	0	1	1	1	0	0
VP43	0	0	0	0	0	0	1	1	0	0	0	0	0	VP88	0	0	0	0	0	0	0	0	1	1	1	0	0
VP44	0	0	0	0	0	0	0	0	0	1	1	1	1	VP89	0	0	0	0	0	0	0	0	1	1	1	0	0

*Coding of land management classes: Agriculture: **E**xtensive, **M**oderate, and **I**ntensive (see Table 3.2); Forest: **U**nmanaged nature reserves, **C**lose-to-nature forestry, **M**ixed objective forestry, **I**ntensive even-aged, and **S**hort-rotation forestry (see Table 3.3).*

Table A4-4. Land management suitability for game and mushrooms plants in the wild food supply model. 0 = not suitable, 1= suitable. For the description of species codes see Table 4.4 and Table 4.6.

Specie s code	Land Management (Coding see below)													Species code	Land Management (Coding see below)												
	Rainfed Arable			Irrigated Arable			Pasture		Forest						Rainfed Arable			Irrigated Arable			Pasture				Forest		
	E	M	I	E	M	I	E	I	U	C	M	I	S		E	M	I	E	M	I	E	I	U	C	M	I	S
GA1	0	0	0	0	0	0	0	0	1	1	1	1	1	MR1	0	0	0	0	0	0	1	1	0	1	1	1	1
GA2	1	1	1	0	0	0	1	1	0	0	0	0	0	MR2	0	0	0	0	0	0	1	1	0	1	1	1	1
GA3	0	0	0	0	0	0	0	0	0	0	0	0	0	MR3	0	0	0	0	0	0	0	0	1	1	1	1	1
GA4	0	0	0	0	0	0	0	0	0	0	0	0	0	MR4	0	0	0	0	0	0	0	0	1	1	1	1	1
GA5	0	0	0	0	0	0	0	0	0	0	0	0	0	MR5	0	0	0	0	0	0	0	0	1	1	1	1	1
GA6	0	0	0	0	0	0	0	0	0	0	0	0	0	MR6	0	0	0	0	0	0	0	0	1	1	1	1	1
GA7	0	0	0	0	0	0	0	0	0	0	0	0	0	MR7	0	0	0	0	0	0	0	0	1	1	1	1	1
GA8	0	0	0	0	0	0	0	0	1	1	1	1	1	MR8	0	0	0	0	0	0	0	0	1	1	1	1	1
GA9	1	1	0	0	0	0	1	1	1	1	1	0	0	MR9	0	0	0	0	0	0	0	0	1	1	1	0	0
GA10	0	0	0	0	0	0	0	0	1	1	1	1	0	MR10	0	0	0	0	0	0	0	0	1	1	1	1	1
GA11	1	1	1	0	0	0	1	1	1	1	1	1	0	MR11	0	0	0	0	0	0	0	0	1	1	1	0	0
GA12	1	0	0	0	0	0	1	0	0	0	0	0	0	MR12	0	0	0	0	0	0	0	0	1	1	1	1	1
GA13	0	0	0	0	0	0	0	0	1	1	1	1	1	MR13	0	0	0	0	0	0	0	0	1	1	1	1	1
GA14	0	0	0	0	0	0	0	0	0	0	0	0	0	MR14	0	0	0	0	0	0	0	0	1	1	1	1	1

GA15	1	1	0	0	0	0	1	0	1	1	1	1	1	MR15	0	0	0	0	0	0	0	0	1	1	1	1	1
GA16	0	0	0	0	0	0	0	0	0	0	0	0	0	MR16	0	0	0	0	0	0	1	1	1	1	1	1	1
GA17	1	0	0	0	0	0	1	0	1	1	1	1	1	MR17	0	0	0	0	0	0	1	0	1	1	1	1	1
GA18	1	0	0	0	0	0	1	0	0	0	0	0	0	MR18	0	0	0	0	0	0	0	0	0	1	1	1	1
GA19	0	0	0	0	0	0	0	0	0	0	0	0	0	MR19	0	0	0	0	0	0	0	0	1	1	1	0	0
GA20	0	0	0	0	0	0	0	0	1	1	1	0	0	MR20	0	0	0	0	0	0	0	0	1	1	1	1	1
GA21	0	0	0	0	0	0	0	0	1	1	1	1	1	MR21	0	0	0	0	0	0	0	0	1	1	1	1	1
GA22	1	1	0	0	0	0	1	1	1	1	1	1	1	MR22	0	0	0	0	0	0	0	0	0	0	1	1	1
GA23	1	1	0	0	0	0	1	0	1	1	1	0	0	MR23	0	0	0	0	0	0	0	0	1	1	1	1	1
GA24	0	0	0	0	0	0	1	0	1	1	1	0	0	MR24	0	0	0	0	0	0	0	0	1	1	1	1	1
GA25	1	0	0	1	0	0	1	0	1	1	0	0	0	MR25	0	0	0	0	0	0	0	0	1	1	1	1	1
GA26	1	1	1	1	1	1	1	1	0	0	0	0	0	MR26	0	0	0	0	0	0	0	0	1	1	1	0	0
GA27	1	1	1	0	0	0	0	0	1	1	1	1	1														
GA28	1	1	1	1	1	1	0	0	1	1	1	1	1														
GA29	1	0	0	0	0	0	1	0	1	1	1	0	1														
GA30	1	0	0	0	0	0	1	0	1	1	1	0	1														
GA31	0	0	0	0	0	0	1	1	1	1	1	1	1														

*Coding of land management classes: Agriculture: **E**xtensive, **M**oderate, and **I**ntensive (see Table 3.2); Forest: **U**nmanaged nature reserves, **C**lose-to-nature forestry, **M**ixed objective forestry, **I**ntensive even-aged, and **S**hort-rotation forestry (see Table 3.3).*

Appendix 5

File names and names beginning with 'Y:\Project\...' refer to places where the files can be found by PBL staff.

Figure A5. AML script for carbon sequestration (file name: NOL_Sink1year_new_edit).

```
/*  CARBON SEQUESTRATION IN ONE SINGLE YEAR
/*  This version: VU-IVM, Nynke Schulp
/*  2015 February 26

/***********************************************************************
/* MAIN
/***********************************************************************

&sv today := [date -TAG]
&watch
Y:\Project\M500067_EcologischeModellenEnGraadmeters\Data\ES_model\Data\BAU_run\_sc
ripts\NOL_Carbon_%today%.txt &commands

  &type
  &type [date -full]
  &type

   grid
   verify off

&sv basedir =
Y:\Project\M500067_EcologischeModellenEnGraadmeters\Data\ES_model\Data\BAU_run\Bas
eData_BAU
&sv ludir =
Y:\Project\M500067_EcologischeModellenEnGraadmeters\Data\ES_model\Data\BAU_run\Lan
dUse
&sv outdir =
Y:\Project\M500067_EcologischeModellenEnGraadmeters\Data\ES_model\Data\BAU_run\Out
puts
&sv draftdir =
Y:\Project\M500067_EcologischeModellenEnGraadmeters\Data\ES_model\Data\BAU_run\_zo
oi

&workspace %draftdir%
setwindow %basedir%\mask
setmask %basedir%\mask
setcell %basedir%\mask

  &do sc &list re /* fn bn etc
  &sv yz = 2000
  &sv ye = 2050
  &do y &list 15 30 50

 &call preparegrids
```

```
/* &call abandonedage
 &call natureef
 &call sinks

&end /* years loop
&end /* scenario loop
&watch &off

quit
&return
quit

/**********************************************************************
&routine preparegrids
/**********************************************************************

&type
&type make input land use and forest age map %sc% scenario year %y%...
&type

  tmp1 = con((%ludir%\lu_%sc%%y% == 3 and %basedir%\forestcorrect == 1), 10,
%ludir%\lu_%sc%%y%)
  tmp2 = con(%ludir%\lu_%sc%%y% == 1 or %ludir%\lu_%sc%%y% == 6, 110,
con(%ludir%\lu_%sc%%y% == 2, 120, con(%ludir%\lu_%sc%%y% == 3, 130,
con(%ludir%\lu_%sc%%y% == 6, 160, tmp1))))
  tmp3 = con(tmp2 == 110, (tmp2 + %ludir%\int_%sc%%y%), tmp2) /* Arable land
rainfed intensity
  tmp4 = con(tmp3 == 114, 111, con(tmp3 == 115, 113, con(tmp3 == 110, 111, tmp3)))
/* Remove accidental errors in rainfed arable land intensity
  tmp5 = con(tmp4 == 120, (tmp4 + %ludir%\int_%sc%%y%), tmp4) /*Pasture intensity
  tmp6 = con(tmp5 == 121, 124, con(tmp5 == 122, 125, con(tmp5 == 123, 125, con(tmp5
== 120, 124, tmp5)))) /* Remove accidental errors in pasture intensity

  cslutmp%y% = con(%ludir%\lu_%sc%%y% == 0 OR %ludir%\lu_%sc%y% == 5 OR
%ludir%\lu_%sc%%y% == 11 OR %ludir%\lu_%sc%%y% == 12 OR
%ludir%\lu_%sc%%y% == 13 OR %ludir%\lu_%sc%%y% == 14, 0, tmp6) /* reclassify
alles wat geen c opneemt / uitstoot naar nul.
  cslu%y% = con(age%y%_%sc% > 0, 7, cslutmp%y%)
&type [date -full]

&return

/**********************************************************************
&routine AbandonedAge

/**********************************************************************

&type Calculate the age of abandoned farmland for %sc% scenario, add land use type
"succession" to carbon seq land use map.

        temp0 = con((%ludir%\lu_re00 == 3 or %ludir%\lu_re00 == 7 or %ludir%\lu_re00
== 16), 1, 0)
```

```
&do yr = 1 &to 50
&sv j = [calc %yr% - 1]

	temp%yr% = con((%ludir%\lu_%sc%%yr% == 3 or %ludir%\lu_%sc%%yr% == 7
or %ludir%\lu_%sc%%yr% == 16) and temp%j% == 0, 1, con(temp%j% > 0, (temp%j%
+ 1), 0))

&end

	age%y% = con(temp0 == 1, 50, temp%y%)
/*	cslu%y% = con(age%y%_%sc% > 0, 7, cslutmp%y%)

&return

/***********************************************************************
&routine natureEF
&type calculate scenario specific emission factors for forest and nature for output years,
%sc% scenario
	temp0 = int(%basedir%\efiscenoutput_%sc%%y%) /* Ensure that EFISCEN output
is in same units as emission factors!!!
	temp1 = setnull((temp0 == 0), temp0)
	temp2 = eucallocation(temp1, #, #, 25, #)
	effor_%sc% = con(isnull(temp2), 0, temp2)

	temp8 = zonalmax(%basedir%\nuts2grid, temp1, DATA)
	temp9 = temp8 / 4
	efnat_%sc% = int(temp9)

&return

/***********************************************************************
&routine sinks
&type
&type calculate sinks
&type
/***********************************************************************

  tmp1 = con(cslu%y% == 4, %basedir%\efpeat, 0)
  tmp2 = con(cslu%y% == 8, 60, tmp1)
  tmp3 = con(cslu%y% == 15, %basedir%\efgrass, tmp2)
  tmp4 = con(cslu%y% == 3, efsnat_%sc%, tmp3)
  tmp5 = con(cslu%y% == 124, (%basedir%\efgrass * 0.67), tmp4)
  tmp6 = con(cslu%y% == 125, (%basedir%\efgrass * 1.27), tmp5)
  tmp7 = con(cslu%y% == 111, (%basedir%\efcrop * 1.67), tmp6)
  tmp8 = con(cslu%y% == 112, (%basedir%\efcrop * 0.84), tmp7)
  tmp9 = con(cslu%y% == 113, (%basedir%\efcrop * 0.80), tmp8)
  tmp10 = con(cslu%y% == 10, effor_%sc%, tmp9) /* ensure that this is the EFISCEN
emission factor in the right format.

  temp11 = con(cslu%y% == 7 and age%y% < 6, 0, temp10)
  temp12 = con(cslu%y% == 7 and age%y% > 5 and age%y% < 22, ((0.0525 * age%y%)
- 0.085) * %basedir%\efnat_%sc%, temp11)
```

```
  %outdir%\sink%sc%%yr% = con(cslu%y% == 7 and age%y% > 21 and age%y% < 44,
(1.05 * %basedir%\efnat_%sc%), temp12)

&return
```

Appendix 6

Figure A6. Matlab script for flood regulation. It contains the reclassification with the look-up table.

```
 %% Import stuff
[cropf] = rasterread('G:\PBL_flood\flood_calculation\cropf_re50.asc');
[precipitation] = rasterread('G:\PBL_flood\flood_calculation\precipitation.asc');
[locations] = rasterread('G:\PBL_flood\flood_calculation\locations.asc');
[watersheds] = rasterread('G:\PBL_flood\flood_calculation\watershed.asc');
[soil] = rasterread('G:\PBL_flood\flood_calculation\waterh_re50.asc');
save InputMaps
clc
clear

load InputMaps
cropf = cropf./10;
lookuptable = xlsread('G:\PBL_flood\flood_calculation\look-up.xlsx','Sheet1');

%% Create empty Index map
INDEX = NaN(size(soil));
[r, c] = size(INDEX);

%% Fill index map
thezeros = cropf < 4;
INDEX(thezeros) = 0;
ToFill = cropf >= 4;
watersheds2 = watersheds(ToFill);
precipitation2 = precipitation(ToFill);
locations2 = locations(ToFill);
soil2 = soil(ToFill);
cropf2 = cropf(ToFill);
clear('watersheds', 'soil', 'cropf', 'locations', 'precipitation');
INDEX2 = INDEX(ToFill);

for i = 1:length(INDEX2)
    A = lookuptable(:,1) == watersheds2(i,1);
    B = lookuptable(:,2) == precipitation2(i,1);
    C = lookuptable(:,3) == locations2(i,1);
    D = lookuptable(:,4) == soil2(i,1);
    E = A+B+C+D;
    F = E==4;
    G = lookuptable(F,:);
    cropf_low = floor(cropf2(i,1));
    cropf_high = ceil(cropf2(i,1));
    if cropf_low == cropf_high
        Z = G(:,5) == cropf2(i,1);
        INDEX2(i,1) = G(Z,6);
    else
        G1 = G(:,5) == cropf_low;
        G2 = G(:,5) == cropf_high;
```

```
         value_low = G(G1,6);
         value_high = G(G2,6);
         value = interp1([cropf_low cropf_high],[value_low value_high],cropf2(i,1));
         INDEX2(i,1) = value;
      end
   end

   INDEX(ToFill) = INDEX2;

      [cropf, X, Y] = rasterread('G:\PBL_flood\flood_calculation\watershed.asc');
   rasterwrite('G:\PBL_flood\flood_re50.asc',X,Y,INDEX);

   clc
   clear

&sv indir = D:\GISAnalysis\Natuurverkenning\LandUse
&sv outdir = D:\GISAnalysis\Natuurverkenning\Out
&sv basedir = D:\GISAnalysis\Natuurverkenning\BaseData
&workspace D:\GISAnalysis\_zooi

grid
verify off

&sv today := [date -TAG]

&watch D:\GISAnalysis\_scripts\watch\watch_NOLNatureTourism_%today%.txt &commands
&type [date -full]

 setwindow %basedir%\mask
 setmask %basedir%\mask
 setcell %basedir%\mask

 &sv ys = 00
 &sv yi = 10
 &sv ye = 40

&do sc &list re
        &type %sc% scenario

&do y &list %ys% %ye%
&type year %y%

 &call Cover
 &call Total

&end /* years loop

/* &call Change

&end /* scenario loop

&watch &off
```

quit
&return
Quit

Appendix 7

File names and names beginning with 'Y:\Project\...' refer to places where the files can be found by PBL staff.

Figure A7. AML script for recreation (file name: NOL_NatureTourism).

```
*****************************************************************************
**************************************************
&type
&routine Cover
&type Calculate assets of land cover for nature based tourism
&type
/****************************************************************************
***************************************************
  /* Forest
      tmp1 = con(%indir%\lu_%sc%%y% == 10, 100, 0)
      tmp2 = int(focalmean(tmp1, circle, 3, data))
      tmp3 = con(tmp2 > 67, 100, 0)

      /* Peri-urban
      tmp4 = con(%indir%\lu_%sc%%y% == 0, 100, 0)
      tmp5 = int(focalmean(tmp4, circle, 5, data))
      tmp6 = con(tmp5 > 25, 100, 0)

      /* Open or agriculture
      tmp7 = con((%indir%\lu_%sc%%y% == 1 or %indir%\lu_%sc%%y% == 2 or
%indir%\lu_%sc%%y% == 6 or %indir%\lu_%sc%%y% == 8 or %indir%\lu_%sc%%y%
== 9 or %indir%\lu_%sc%%y% == 18), 100, 0)
      tmp8 = int(focalmean(tmp7, circle, 4, data))
      tmp9 = con(tmp8 > 80, 100, 0)

      /* Mosaic
      tmp10 = con((%indir%\lu_%sc%%y% == 3 or %indir%\lu_%sc%%y% == 4 or
%indir%\lu_%sc%%y% == 5 or %indir%\lu_%sc%%y% == 7 or %indir%\lu_%sc%%y%
== 11 or %indir%\lu_%sc%%y% == 12 or %indir%\lu_%sc%%y% == 13 or
%indir%\lu_%sc%%y% == 14 or %indir%\lu_%sc%%y% == 15 or
%indir%\lu_%sc%%y% == 16 or %indir%\lu_%sc%%y% == 17), 100, 0)
      tmp11 = int(focalmean(tmp10, circle, 4, data))
      tmp12 = con(tmp11 > 80, 100, 0)

      /*GLs
/* This is a placeholder. Values to be defined.
      tmp13 = con(%indir%\GL_%sc%%y% < 1, 0, con(%indir%\GL_%sc%%y% < 2, 0,
con(%indir%\GL_%sc%%y% < 3, 0, con(%indir%\GL_%sc%%y% < 4, 0, 0))))

      /* Combine
      &type land cover factor %y% %sc% scenario
      tmp14 = con(tmp6 == 100, 0, con(tmp9 == 100, 30, con(tmp12 == 100, 70,
tmp3)))
```

```
        %sc%%y%NTLC = max(tmp13, tmp14)

&return

************************************************************************
************************************************
&type
&routine Total
&type Combine static with dynamic factors, summarize and write tables.
&type
/***********************************************************************
************************************************

        tmp13 = sum(%sc%%y%NTLC, %basedir%\NTwater, %basedir%\NTgeo,
%indir%\np_%sc%%y%, %basedir%\NTHNV, %basedir%\NTattr) /*NP is scenario specific
protected area.

DOCELL
 max }= tmp13
 min {= tmp13
END

&SET maxnt [SHOW max]
&SET minnt [SHOW min]

&type tourism in year %y% for scenario %sc% ranges between %minnt% and %maxnt%

        %outdir%\%sc%1knt%y% = ((tmp13 * 100) / 6)
/*      %outdir%\%sc%n2nt%y% = int(zonalmean(%basedir%\nuts2grid,
%outdir%\%sc%1knt%y%))
/*   %outdir%\%sc%cynt%y% = int(zonalmean(%basedir%\countries,
%outdir%\%sc%1knt%y%))

&return

************************************************************************
************************************************
&type
&routine Change
&type Calculate change in tourism provision
&type
/***********************************************************************
************************************************

        %outdir%\%sc%1kdifntse = %outdir%\%sc%1knt%ye% -
%outdir%\%sc%1knt%ys%
        %outdir%\%sc%n2difntse =
int(zonalmean(%basedir%\nuts2grid,%outdir%\%sc%1kdifntse))

&return
```