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Modelling the spatial distribution of EUNIS forest habitats based on vegetation relevés and Copernicus HRL

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1 Background and objectives

1.1 Background

This report is part of the assignment of Alterra and ILE SAS for the European Topic Centre Biological Diversity (ETC/BD). The European Topic Centres (ETCs) are international consortia brought together to support the European Environment Agency (EEA) in its mandate on environmental information. ETCs are according to the EEA regulation and in practice, an important instrument in supporting the EEA through the execution of sizeable, continuous, well-defined tasks with the involvement of member countries. In particular ETCs support EEA data centres for the issues related to air, climate change, water, biodiversity and land use and may provide help to EEA in supporting other data centres coordinated by Eurostat and JRC. The ETC/BD is an international consortium working with the European Environment Agency under a framework partnership agreement. The main tasks of ETC/BD are to:

1. Assist the EEA in its task of reporting on Europe's environment by addressing state and trends of biodiversity in Europe.
2. Provide the relevant information to support the implementation of environmental and sustainable development policies in Europe in particular for EU nature and biodiversity policies (DG Environment: Nature and Biodiversity).
3. Build capacity for reporting on biodiversity in Europe, mainly through the European Information and Observation Network (Eionet).

More information about ETC/BD can be found at: http://bd.eionet.europa.eu/.

1.2 Objectives

This report is affiliated with task 1.7.5C from the ETC/BD Action Plan 2014. The general objectives of this task are:

- To contribute to EU-level ecosystem assessment with the finalisation of the MAES biophysical baseline.
- To support the preparation of assessments of ecosystems and their conditions based on existing information and data to support the 2015 mid-term review of the 2020 EU Biodiversity Strategy (and its targets), based on relevant data gathered from the Nature Directives, Agriculture and Forests, in close dialogue with the MAES process.
- To gather evidence on the main drivers of biodiversity loss.

Main objective report: **to test the use of the EVS (European Vegetation Survey) relevés for enhancing the spatial delineation of habitats and / or ecosystems.**

Therefore, the activities in this report are focused to find out to what extent the EVS relevés can support the spatial delineation of ecosystems, and more specifically targeted EUNIS habitat types. Overall, it should help to improve the ecosystem mapping in the future. Summarized in bullet points:

- Framework: EU Target 2 (Mapping and Assessment of Ecosystems and their Services: MAES et al., 2013) the Mapping and) and EU Target 3 (Agriculture and Forests)

- Goal: Progress on the use of EVS and additional data to improve ecosystem delineations and if relevant/possible ecosystem assessments
- Potential datasets: EVS vegetation relevés, Copernicus HRL layers, climate data, soil data, topographic data, and other in-situ data.
- Outputs: Improved generic habitat probability mapping according to EUNIS level 3.

Due to the recent availability of the EEA report '*Review of EUNIS forest habitat classification'* (Schaminée et al., 2014) it was decided in spring 2014 to concentrate all work on the EUNIS Forest habitats at level 3. So far a wall-to-wall ecosystem map has been produced for Europe at EUNIS level 2 (Banko et al., 2013)[1]. To enable amongst others the enhancement of such an ecosystem map, the exploitation of vegetation relevés in combination with Copernicus HRL, concentrated on the spatial modelling of EUNIS forest habitats at level 3, for which the following activities were identified:

1. Modelling the spatial distribution of EUNIS forest habitats at level 3 (37 types)

  a. Using the floristic composition of EUNIS habitat forest classes at EUNIS level 3 as described in the report '*Review of EUNIS forest habitat classification'* (Schaminée et al., 2014) as the point of departure. In-situ data for the EUNIS habitat forest classes will be obtained by classifying the obtained vegetation relevés from the European Vegetation Archive (EVA) into the habitat classes based on their floristic description in Schaminée et al., 2014.
  b. Spatial modelling of habitat suitability will be based on the integration of in-situ vegetation relevés, climate and other environmental data sets, e.g. elevation and soil information. Various statistical models can be used to determine the spatial distribution of species or habitats, such as MAXENT or GBM (TRIMmaps).
  c. Using the available vegetation relevés from the European Vegetation Archive (EVA)
  d. Downscaling of the habitat suitability maps to the actual land cover situation based on e.g. the 20m spatial resolution Copernicus HR layer Forest, phenological data as derived from remotely sensed time series, e.g. MODIS time series (HANTS), and EFI forest species distribution maps (TREEMAPS) derived from forest plot data.

2. Validation of the produced EUNIS forest habitat probability maps

  a. Validation for Slovakia

The list of EUNIS forest habitat types have been summarized in Table 1.1. It concerns 37 EUNIS forest habitat types at level 3. Due to limitations of data availability and sometimes a weak description of habitat type in terms of typical species, we were only able to produce 24 habitat probability maps. Table 1.1 shows also the 24 EUNIS forest habitat types at level 3 for which habitats vegetation relevés were available.

Table 1.1 Short summary of EUNIS forest habitat types at level 3 and amount of vegetation relevés available for each forest habitat.

EUNIS forest type	Subtype	Name	Nr vegetation relevés	Modelled
B1.7		Coastal dune woodland* [Coastal dune woods]	-	1
G1.1		Temperate and boreal softwood riparian woodland* [Riparian and gallery woodland, with dominant [Alnus], [Betula], [Populus] or [Salix]]	2163	2
G1.2		Temperate and boreal hardwood riparian woodland* [Mixed riparian floodplain and gallery woodland]	4363	3

[1] see also http://projects.eionet.europa.eu/eea-ecosystem-assessments/library/draft-ecosystem-map-europe/

G1.3		Mediterranean and Macaronesian riparian woodland* [Mediterranean riparian woodland]	1022	4
G1.4		Broadleaved swamp woodland on non-acid peat* [Broadleaved swamp woodland not on acid peat]	1013	5
G1.5		Broadleaved swamp woodland on acid peat* [Broadleaved swamp woodland on acid peat]	643	6
G1.6		[Fagus] woodland could be divided into two types, because of the high variation within the overall type and the possibility to make a clear division:	-	-
	G1.6a	Fagus woodland on non-acid soils	4275	7
	G1.6b	Fagus woodland on acid soils	3141	8
G1.7		Thermophilous deciduous woodland	3599	9
G1.8		Acidophilous Quercus woodland* [Acidophilous [Quercus]-dominated woodland]	2667	10
G1.9		Non-riverine woodland with [Betula], [Populus tremula] or [Sorbus aucuparia] has to be divided into two types:	-	-
	G1.9a	Mountain Betula and Populus tremula woodlands on mineral soils	138	11
	G1.9b	Lowland continental Betula and Populus tremula woodlands on mineral soil	-	
G1.A		Mesotrophic and eutrophic deciduous woodland, not dominated by Fagus* [Meso- and eutrophic [Quercus], [Carpinus], [Fraxinus], [Acer], [Tilia], [Ulmus] and related woodland]	5277	12
G1.B		Non-riverine Alnus woodland on mineral soil* [Non-riverine [Alnus] woodland]	-	-
G1.C		Broadleaved deciduous plantations of non site-native trees* [Highly artificial broadleaved deciduous forestry plantations]	-	-
G1.D		Fruit and nut tree orchards is not a woodland and should be removed (it could go into EUNIS group I)	-	-
G2.1		Mediterranean evergreen Quercus woodland* [Mediterranean evergreen [Quercus] woodland]	1274	13
G2.2		Mainland lauriphyllous woodland* [Eurasian continental sclerophyllous woodland]	-	-
G2.3		Macaronesian lauriphyllous woodland* [Macaronesian [Laurus] woodland]	-	-
G2.4		Olea oleaster-Ceratonia siliqua woodland* [Olea europaea] - [Ceratonia siliqua] woodland]	307	14
G2.5		Phoenix groves* [[Phoenix] groves]	-	-
G2.6		Ilex aquifolium woodland* [[Ilex aquifolium] woods]	207	15
G2.7		Macaronesian heathy woodland* [Canary Island heath woodland]	-	-
G2.8		Broadleaved evergreen plantations of non site-native trees* [Highly artificial broadleaved evergreen forestry plantations]	-	-
G2.9		Evergreen orchards and groves	-	-
G3.1		[Abies] and [Picea] woodland has to be divided into three types (according to dominant species and geographic distribution):	-	-
	G3.1a	Temperate mountain Picea woodland	1996	16
	G3.1b	Temperate mountain Abies woodland	1808	17
	G3.1c	Mediterranean mountain Abies woodland	-	-
G3.2		Temperate subalpine Larix-Pinus woodland* [Alpine [Larix] - [Pinus cembra] woodland]	575	18
G3.3		[Pinus uncinata] woodland should be merged into G3.2 [Alpine [Larix] - [Pinus cembra] woodland] (this category corresponds to the same phytosociological units, with Pinus species as the usual dominant)]	-	-
G3.4		[Pinus sylvestris] woodland south of the taiga has to be divided into three types:	-	-

	G3.4a	Temperate continental Pinus sylvestris woodland	1898	19
	G3.4b	Temperate and submediterranean montane Pinus sylvestris-nigra woodland	696	20
	G3.4c	Mediterranean montane Pinus sylvestris-nigra woodland	-	-
G3.5		[Pinus nigra] woodland should to be merged into the G3.4" and G3.4"' types	-	-
G3.6		Mediterranean and Balkan subalpine Pinus heldreichii-peucis woodland* [balpine mediterranean [Pinus] woodland]	-	-
G3.7		Mediterranean lowland to submontane Pinus woodland* [Lowland to montane mediterranean [Pinus] woodland (excluding [Pinus nigra])]	551	21
G3.8		Pinus canariensis woodland* [Canary Island [Pinus canariensis] woodland]	-	-
G3.9		Coniferous woodland dominated by [Cupressaceae] or [Taxaceae] should be divided into two types: Taxus baccata woodland and Juniperus-Cupressus woodland and further into mainland and Macaronesia.	-	-
	G3.9a	Taxus baccata woodland	270	22
	G3.9b	Mediterranean Cupressaceae woodland	765	23
	G3.9c	Macaronesian Juniperus woodland	-	-
G3.A		Picea taiga woodland* [[Picea] taiga woodland]	25	-
G3.B		Pinus sylvestris taiga woodland* [[Pinus] taiga woodland]	2	-
G3.C		Larix taiga woodland* [[Larix] taiga woodland]	-	-
G3.D		Boreal bog conifer woodland* [Boreal bog conifer woodland]	-	-
G3.E		Temperate bog conifer woodland* [Nemoral bog conifer woodland]	1047	24
G3.F		Conifer plantations of non site-native trees* [Highly artificial coniferous plantations]	-	-

1.3 Content of the report

Chapter 1 concerns the background and objectives in relation to the production of forest habitat probability maps based on vegetation relevés and amongst others the Copernicus high resolution layer forest.

Chapter 2 concerns an introduction to the spatial modelling of habitats.

Chapter 3 describes in detail the method used for the habitat suitability mapping based on vegetation relevés. These habitat suitability maps are used in Chapter 4 as an input to refine the maps towards habitat probability maps based on amongst other the Copernicus high resolution layer Forest

Chapter 4 describes the method used to produce the probability maps for the EUNIS forest habitat types at level 3.

Chapter 5 concerns the assessment of the EUNIS forest habitat probability maps for the whole of Slovakia.

Chapter 6 summarizes the conclusions.

2 Introduction to habitat modelling

2.1 Integration of bottom-up and top-down approach

The spatial modelling of ecosystems or habitats can be approached from a bottom-up perspective using vegetation relevés as the starting point or from a top-down approach based on the refinement of satellite derived land cover information, both with support of additional thematic geographic data layers. The methodology that we used in this report is inspired by combining the strength of both methods for the modelling of the spatial distribution of EUNIS forest habitat types, (see Figure 2.1).

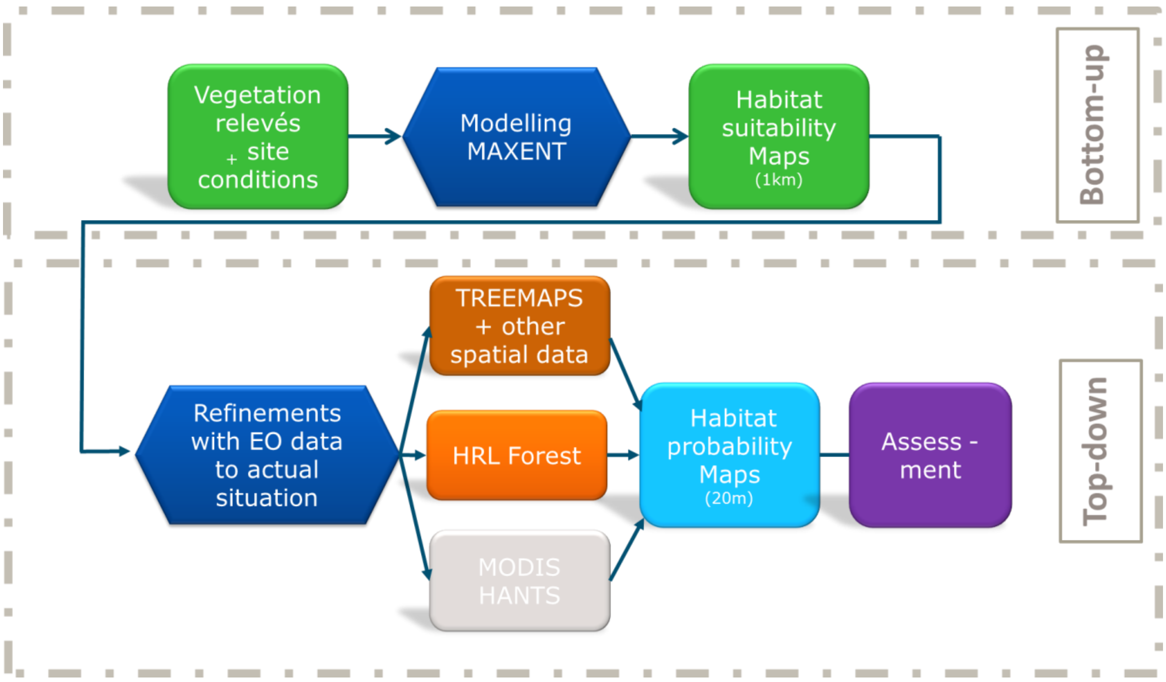


Figure 2.1 General workflow for the processing of EUNIS habitat probability maps. Starting with the exploitation of the European vegetation relevés in a bottom-up approach, succeeded by refinements into habitat probability maps based on amongst other actual land cover, in a top-down approach.

The habitat suitability maps have a 1 km spatial resolution and are the result from the MAXENT statistical modelling with the available European vegetation relevés and abiotic site conditions as an input. The habitat suitability maps were used as a starting point for further refinements into habitat probability maps (HPMs) based on amongst others actual land cover as represented by the Copernicus high resolution data layers (HRL). In this report, the enhancements are especially based on the Copernicus High Resolution Layer (HRL) Forest with a 20 meter spatial resolution, and other thematic maps such as topographic and forest maps (TREEMAPS). For each EUNIS habitat types models were made in ARCGIS 10.2.1 using the spatial model builder.

2.2 Bottom-up approach: distribution modelling using vegetation relevés

Vegetation relevés are increasingly becoming available across Europe, in a standardized way, and in large numbers (Schaminée et al., 2007). Schaminée et al. (2009) showed already that more than 1.8 million vegetation relevés had been computerised in Europe. European vegetation data are not only a source to determine the floristic composition of habitat types, but can also be an excellent repository for species and habitat distribution modelling (Mücher et al., 2009; Mücher, 2009). In Figure 2.2 the species distribution of Beech trees (*Fagus sylvatica*) is shown, which is based on the availability of approximately 20.000 phytosociological relevés. Although the distribution seems to cover a large part of Europe some areas are clearly unrepresented or not represented at all, like Scandinavia or Spain. However, when applying a species distribution model (in this case Maximum Entropy; Berger et al. 1996) beech is likely to be present in some parts of Scandinavia and Spain (see Figure 2.2b: colours varying from grey, over green to red, indicating an increasing probability). To model the distribution of the Beech th**e** MaxEnt software (Philips et al. 2006) was used, applying a number of environmental spatial layers (e.g. climate, topography and soil).

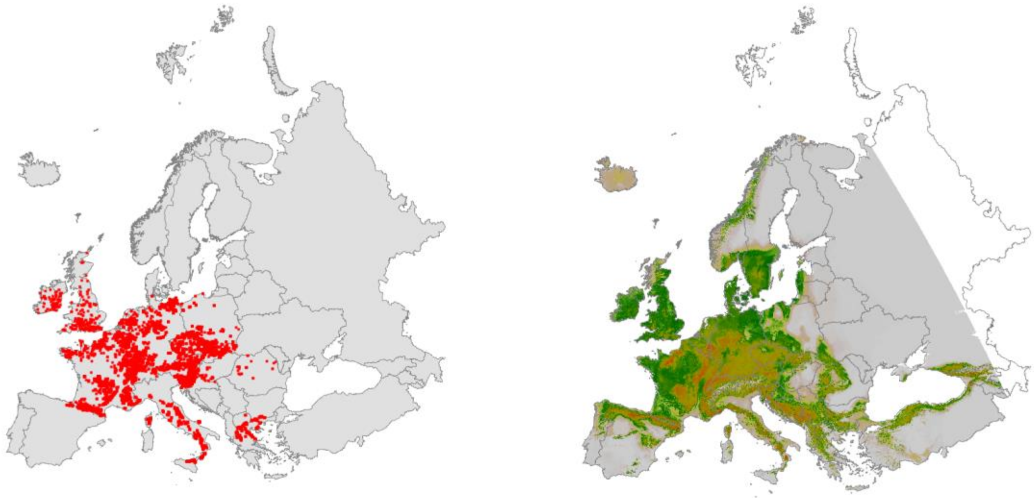


Figure 2.2 Left: Distribution of available phytosociological relevés with *Fagus sylvatica*.
Right: Habitat suitability map of the individual species, *Fagus sylvatica*, based on the distribution model MAXENT. Note that although relevés are missing for Scandinavia (left), the modelling result is covering part of Scandinavia.

Although this kind of species modelling is carried out already for many species on a European scale, there is also an urgent a need for more geo-referenced vegetation plot data for habitat distribution modelling. At this moment, geo-referenced vegetation plot data or in-situ habitat records are especially under-represented for areas like Scandinavia. This means that more effort has to be made to involve people from Nordic countries in the disclosure of in-situ recordings of vegetation and / or habitats for these regions. Furthermore a fully harmonised taxonomic reference list of plant species is needed, because the vegetation data comes from many different (mostly national) sources linked to different taxonomic concepts. Good examples of the application of vegetation plot data are the syntaxonomic descriptions of the EUNIS forest and heathland-scrub habitats (Schaminée et al, 2013; Schaminée et al, 2015). These EEA studies were based on crosswalks between two different European classification systems (syntaxa of the EuroVegChecklist and EUNIS habitats), which were developed more or less independently and for different purposes. On one hand there is the classification of vegetation types provided by phytosociology, the tradition which uses fine-scale vegetation-plot data on plant species composition and cover for a 'bottom-up' fine-grained delineation and characterisation of plant associations (Braun-Blanquet, 1928). On the other hand, there is the classification of habitat types, providing a pan-European reference system for policy making with a common unit description within a hierarchical classification, presently known as the EUNIS habitat classification (Moss 2008).

2.3 Top-down approach: refinement of land cover into habitat maps

The major objective here is to develop a refinement of land cover information into relevant ecological classes (read ecosystems or habitats). A good example is the ecological refinement of land cover information as produced for example within the EU FP6 project ECOCHANGE. The methodology used is based on the experience from the PEENHAB project (Mücher et al., 2004, 2005, Mücher, 2009), (see Figure 2.3). Land cover information, environmental data sets and ecological knowledge plays a crucial role in this methodology to set-up the spatial knowledge rules. When it became clear that in-situ information is also crucial next to information derived from remotely sensed information (Mücher 2009, Clerici et al. 2012), much effort was put in the collection of vegetation relevés across Europe. The land cover refinements in ECOCHANGE project targeted the forest and grassland habitats, since these formations had the main focus in the ECOCHANGE project. Much effort was made on the establishment of the knowledge rules for the relationship between CORINE land cover classes (CEC, 1994; Bossard et al, 2000; Büttner et al, 2004) and the Annex 1 Habitats (European Commission, 2013)[2]. The spatial knowledge rules were largely based the habitat description in the Annex I as well as on the ecological knowledge of Dr R.G.H. Bunce. Next to Natura 2000 habitats, EUNIS habitat types can be used as well, but a good definition of the habitat classes is required. The full syntaxonomic descriptions of the EUNIS forest and heathland-scrub habitats (Schaminée et al, 2013; Schaminée et al, 2015) were a major improvement, but preferably a description of the site conditions are needed as well (e.g soil types, terrain conditions, position in the landscape). This information can enhance the spatial decision rules and thresholds in the habitat models to further pinpoint the current spatial distribution of EUNIS habitats. Most habitats are very fragmented at a fine spatial resolution which makes their spatial delineation for the whole of Europe not easy.

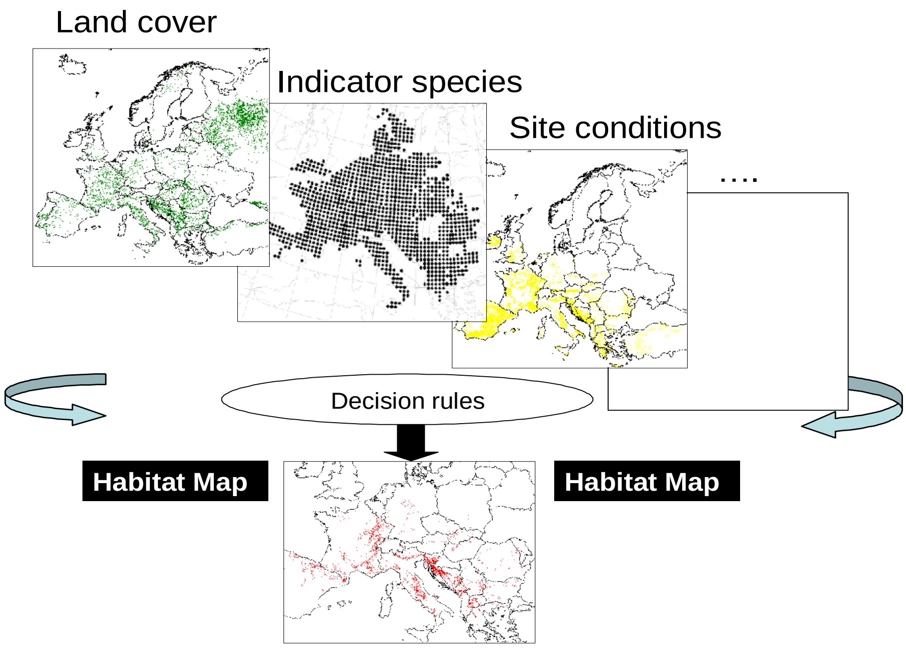


Figure 2.3 Flowchart of a top-down approach (Mücher et al 2009) to identify the spatial distribution of European Habitats starting with land cover information and refinements based on ecological based knowledge rules.

[2] see http://www.synbiosys.alterra.nl/ecochange/singleclasses.aspx

3 Bottom-up: habitat suitability maps based on vegetation relevés

As shown in Figure 3.1 the spatial modelling starts with the exploitation of the vegetation relevés classified into EUNIS habitats (see also section 3.3 for more details).

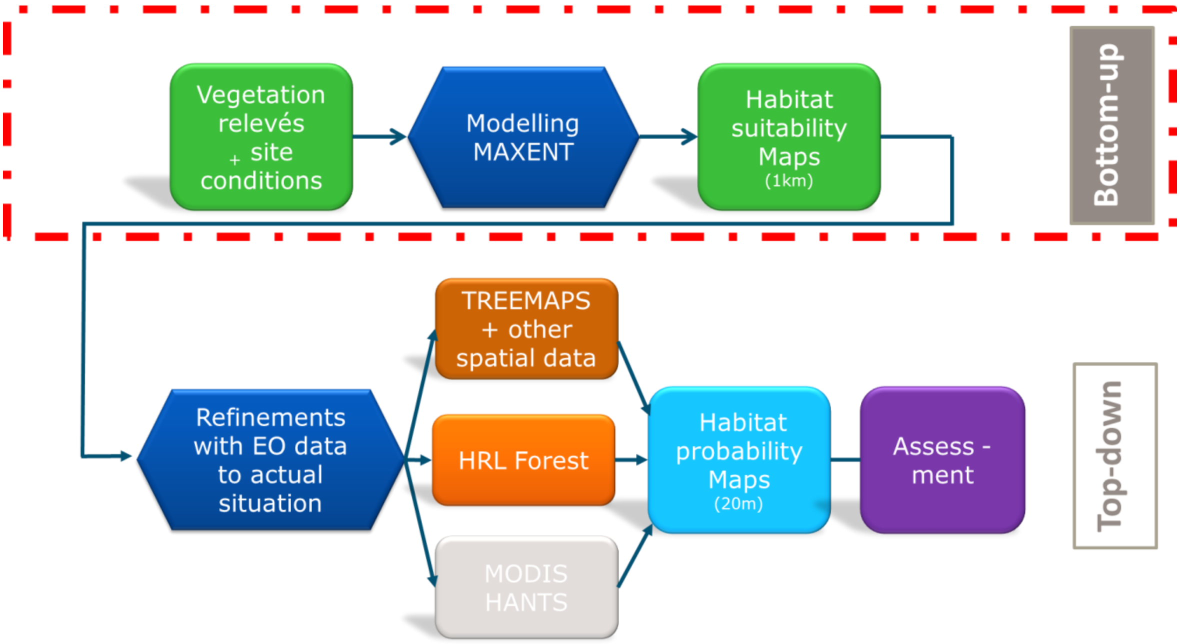


Figure 3.1 The bottom-up approach is the first part of the habitat modelling (outlined by red dashes).

3.1 Introduction to the European vegetation data

3.1.1 The vegetation classification and the European Vegetation Survey (EVS)

The classification of vegetation is facing a new era, as a result of the current availability of high-capacity computers and software packages for the processing of phytosociological data. During the last century, numerous studies have resulted in a large number of formally described associations, alliances, orders and classes throughout Europe. However, their delimitation usually remained incomplete and contentious due to various theoretical constraints and methodological problems. In an attempt to achieve a respectable level of stability, the European Vegetation Survey (EVS) developed in the early years of the 21st century the first overview of European vegetation units at the levels of alliances, orders and classes, published as The Diversity of European Vegetation (Rodwell et al. 2002). From that moment onwards, the overview of European syntaxa has undergone substantial expert revision by a team under the leadership of Prof. Ladislav Mucina. The new product, the EuroVegChecklist, is now a more comprehensive product covering all Europe as well as outer territories such as the Azores, Canary Islands, Cyprus, Caucasus and Greenland, scientifically robust, better grounded within current phytosociological understanding, and more meaningful for application within the user community. The 2013 version of this EuroVegChecklist was used for the EUNIS forest habitat revision (Schaminée et al. 2013) and, after further revision, it was submitted for publication in 2013 and resubmitted after review in June 2014 (Mucina et al. 2015).

3.1.2 The floristic composition

The floristic composition is being determined for the EUNIS forest habitats, using all available vegetation relevés (Schaminée et al. 2013). With regard to the definition of forest habitats, the following major EUNIS types have been taken into account (at level 2): G1 "Deciduous", G2 "Broadleaved evergreen" and G3 "Coniferous"" and one type from the dunes (B1.7 "Coastal dune woods"). The subtypes from G4 "Mixed deciduous and coniferous woodland" have been discarded, since they cannot be easily described in terms of phytosociological associations. The procedure consisted of two methodological steps. In a first step, the relevés of these regional and national datasets have been classified at the level of alliances of the 2013 version of the EuroVegChecklist. This was done by matching the regional and national classification systems, to which the relevés in the datasets of the data providers were assigned, with the European overview. In a second step, the assignment to the EUNIS forest habitat types was performed by merging the datasets of the alliances to the corresponding EUNIS type (according to the EUNIS-syntaxa crosswalk), by averaging based on national constancy columns (not by simply adding up). This results also in a frequency table of the individual plant species within a EUNIS habitat type. The syntaxa of the EuroVegChecklist that have been considered were selected on the basis of the crosswalks (see Figure 3.2.).

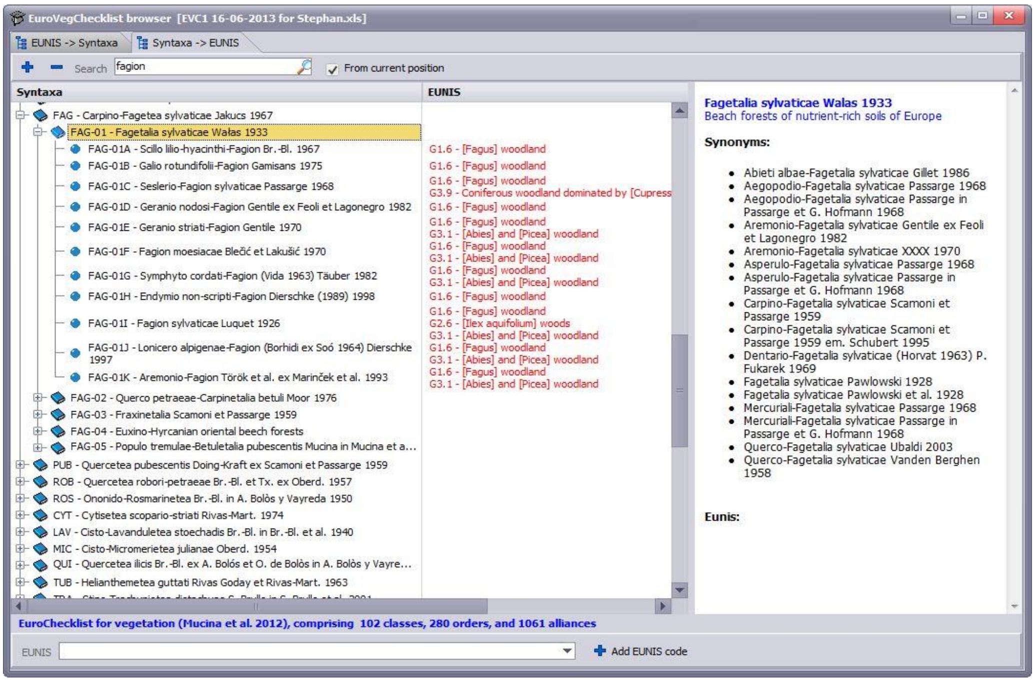


Figure 3.2 EuroVegChecklist browser which shows the crosslink between European syntaxa and EUNIS level 3 classes.

3.1.3 Vegetation plot samples

Vegetation plot samples, as collected by so called phytosociologists, provide the most numerous and widely dispersed in-situ records of vegetation across Europe. Comprising at minimum a list of vascular plant species with an estimate of cover-abundance in plots ranging from less than 1 m^2 to a few hundred m^2, such samples are dated and spatially located in a way that gives a record of the composition of vegetation at a particular time and place. In phytosociology, they have formed the basis of the classification of vegetation into associations organised into hierarchical systems, and have thus helped to furnish inventories and maps of sites and accounts of the vegetation of countries and regions.

3.1.4 TURBOVEG and the European Vegetation Archive (EVA)

The development of compatible software tools, has greatly encouraged the development of national and regional vegetation databases and fostered the creation of a network facilitating data exchange and research collaborations, and assisted the emergence of supra-national vegetation revisions and overviews over the last twenty years. The major software tool for database development has been **TURBOVEG** (Hennekens & Schaminée 2001), now accepted as an international standard for data input, storage, management and retrieval, and installed in over 30 countries in Europe and beyond. Complementary to TURBOVEG, the JUICE program (Tichý 2002) has added a wide range of analytical tools for data sets that can comprise thousands of relevés. The most recent study designed to collect estimates of the total number of vegetation plots in Europe (Schaminée et al. 2009), revealed that more than 1.8 million relevés had been already computerised, 75% of which were found in centralised databases of countries or regions. Of all captured relevés, 59% were available in TURBOVEG format. Further key steps have now been taken by many members of the European Vegetation Survey (EVS) to locate and capture additional plots, and to centralise data storage of such plots. In 2011, the Global Index of Vegetation-Plot Databases platform (GIVD) was launched (Dengler et al. 2011) to provide a meta-resource of electronic databases whose hosts are willing in principle to share the captured data. At present[3], 209 databases with 3,148,605 vegetation plots have been registered, a large part of them with records of European vegetation. The GIVD platform[4] also assists in revealing gaps in the coverage and/or availability of the vegetation plot data.

Another recent initiative – the European Vegetation Archive (EVA[5]) – yielded a centralised database of vegetation plots by storing copies of national and regional databases on a single software platform using a unified taxonomic reference database. Data storing in EVA does not affect the ongoing independent development of the source databases. EVA Data Property and Governance Rules approved in 2012, guarantee that data property rights of the original contributors are respected. By November 2014, 41 databases from all European regions, including the largest ones, joined EVA. These databases contained in total 619,315 vegetation plots from most European regions, especially from western, central and southern Europe. However, there is a remarkable lack of data from Scandinavia and eastern European countries, i.e. European regions with less strong or interrupted phytosociological tradition. Vegetation-plot records are stored in EVA in three access regimes: free (available to anybody), semi-restricted (available in principle to the group of other data contributors) and restricted (available in principle to the group of other data contributors based on specific consent). These three access regimes are represented in turn by 6%, 82% and 12% of the total EVA database.

A prototype of the database management software TURBOVEG 3 was developed for joint management of multiple databases, which are linked to different species lists. This software also includes procedures for handling data requests, selections and provisions according to the approved EVA Rules. A specific challenge for EVA is combining multiple species lists based on different taxonomies used in national and regional databases. This is managed using the SynBioSys Taxon Database, which was initially established for the purposes of the SynBioSys Europe project and is now further developed and extended within the framework of EVA. Each vegetation relevé in this archive has a unique global unified identifier (GUID) and the version control will be used to keep track of database changes. Several specific projects devoted to detailed diversity assessment of selected vegetation types started within the EVA initiative in 2014. A prototype project for the EVA initiative is the Braun-Blanquet Project, aiming at the compilation and analysis of floristic and geographical information on European vegetation types, and was led by Dr. Borja Jiménez-Alfaro[6].

The vegetation-plot data used in the Braun-Blanquet Project forms the basis for determining and providing the floristic composition of heathland, scrub and tundra vegetation data, in a similar fashion as in the EEA 2013 project on forest habitat types (Schaminée et al. 2013). As indicated before, the main input has come from computerized databases set up at many places across Europe.

[3] 29.01.2015
[4] http://www.givd.info/
[5] http://euroveg.org/eva-database
[6] for more information: http://www.sci.muni.cz/botany/vegsci/braun_blanquet.php.

3.2 Data selection

The locations of vegetation relevés available for the Braun-Blanquet Project were used for the habitat suitability modelling of the EUNIS forest types. The selection of relevés belonging to the individual EUNIS forest types has been done on the basis of a supervised classification of more than 500,000 relevés in JUICE 7.0 (Tichý 2002). This supervised classification was performed using a computer expert system newly developed to identify relevés belonging to the individual EUNIS forest types. The procedure followed these steps:

(1) Relevés identified during the preparation of the 2013 report (Schaminée et al. 2013) as belonging to the particular EUNIS types based on their syntaxon assignment were marked and grouped in this dataset.

(2) The degree of occurrence of each species within each group of relevés (i.e. each EUNIS type) was calculated using the phi coefficient of association (Sokal & Rohlf 1995) standardized for the identical number of relevés across all groups, which was arbitrarily set to 1% of the total data set (Tichý & Chytrý 2006). The species with the highest values of phi were considered as diagnostic for each EUNIS type.

(3) Lists of European species of trees and shrubs occurring in this data set were compiled.

(4) The functional species groups were created using an expert judgement based on the lists of diagnostic species for EUNIS types and lists of trees and shrubs. These functional groups were defined in such a way that they could clearly separate the EUNIS forest habitat types based on their occurrence and total cover of their species. In general some functional groups included woody species and others included herb-layer species. Each group included species of similar ecology and distribution. The concept of functional species groups used here is described in Landucci et al. (submitted).

(5) Total cover of each functional species group was calculated assuming the random overlap of covers of their individual species based on the approach proposed by Chytrý et al. (2005) and newly formally described by Fischer (2015).

(6) Formal definitions of all EUNIS forest habitat types (Level 3, with modifications proposed by Schaminée et al. 2013) were prepared in a form of logical formulas. These formulas combined total covers of individual species or species groups using logical operators AND, OR and AND not, following the proposals of Bruelheide (1997). Details of the approach used here are described in Landucci et al. (submitted). For example, the logical formula for the habitat type G1.8 Acidophilous *Quercus* woodland is the following:

((<#TC Quercus petraea-robur GR15>AND<#TC Quercus petraea-robur GR #TC Trees EXCEPT #TC Quercus petraea-robur>)AND<#TC Quercion roboris GR15>)NOT<#TC Quercus-thermo-herbs GR05>

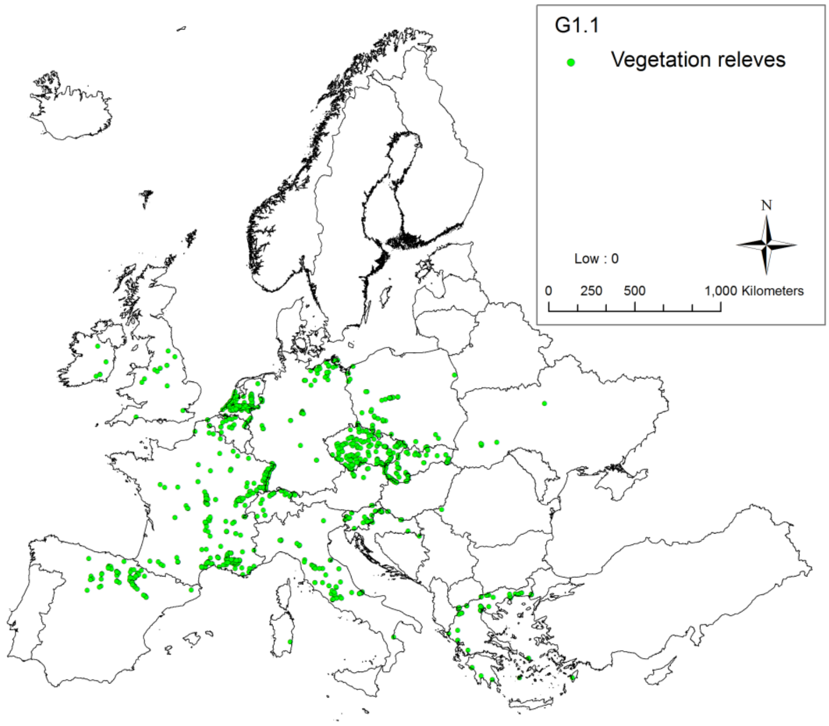
This means that the total cover (#TC) of the functional species group *Quercus petraea-robur* (includes deciduous temperate oak species *Quercus petreaea* and *Q. robur*) is greater than 15% (GR15) and at the same time the total cover of this group is greater than the total cover of any other tree species (#TC Trees EXCEPT #TC Quercus petraea-robur) and at the same time the total cover of the functional group Quercion roboris (includes herb species diagnostic of acidophilous *Quercus* woodlands) is greater than 15% and at the same time the functional group *Quercus*-thermo-herbs (includes herb species diagnostic of thermophilous *Quercus* woodlands) is not greater than 5%.

(7) Lists of species belonging to each functional species group, formal definitions of all EUNIS forest habitat types and instructions for handling taxonomic concepts and nomenclature of individual species were included in a single file with a computer code that can be read by JUICE 7.

(8) All relevés in the data set were assessed whether they meet conditions of each logical formula, using JUICE 7, and based on this, they were assigned to individual EUNIS forest habitat types.

In total more than 140,000 relevés were assigned to EUNIS forest habitat types in this way. The advantage of this procedure was that (i) relevés not assigned to syntaxa could be classified, (ii) new relevés obtained since the last year could be included and (iii) assignments of relevés to the types were based on uniform criteria applied consistently across the whole European data set. This data set was then used to create maps of known distributions and to serve as an input for the habitat suitability modelling. Where more than 5,000 relevés were available for a habitat type the data set was restricted to only one location per each grid cell of 5km x 5 km (see the example below of the vegetation relevés for the EUNIS forest habitat type G1.1 'Temperate and boreal softwood riparian woodland', in Map 3.1).

Excluded from the classification process were forest types located outside the geographic scope (Macaronesia), or floristically difficult to define according to the national classifications (B1.7, G1.D, G2.8, G2.9). However, B1.7 has been included by taking into account all forest relevés (selected by the expert system) that are located within the coastal dune area of the Map of the Natural Vegetation of Europe (Bohn et al. 2000-2004) with a buffer of 1 km.



Map 3.1 Example of the available vegetation relevés for EUNIS level 3 forest habitat type G1.1 'Temperate and boreal softwood riparian woodland*' used as an input in the MAXENT statistical modelling.

3.3 Habitat suitability modelling using MAXENT

For the habitat suitability modelling, the widely used software Maxent for maximum entropy modelling of species' geographic distributions was used. Maxent is a general-purpose machine-learning method with a simple and precise mathematical formulation, and has a number of aspects that make it well-suited for species distribution modelling when only presence (occurrence) data but not absence data are available (Philips et al. 2006). Because EUNIS habitats have a particular species composition, they are assumed to respond to specific ecological requirements, allowing us to generate correlative estimates of their geographic distributions. Modelling habitats that have been floristically defined is a well-known procedure for ecological modelling at local scales, and a promising technique to be applied also at the continental scales. The vegetation releves have been classified into EUNIS habitat types based on the floristic composition of the EUNIS forest habitat types as described in (Schaminée et al. 2013). The way we used the MAXENT model for habitat suitability mapping is summarized below in Figure 3.3.

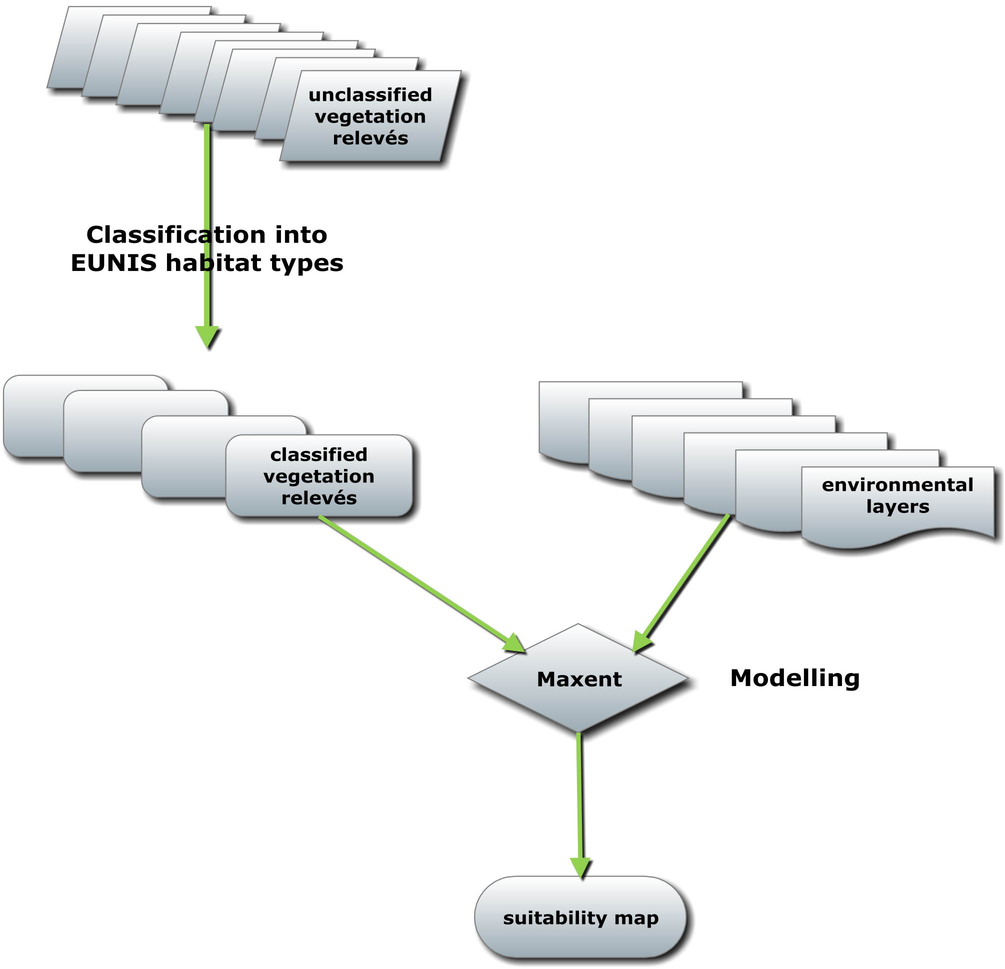


Figure 3.3 Flowchart of methodology used for the habitat suitability mapping (bottom-up approach)

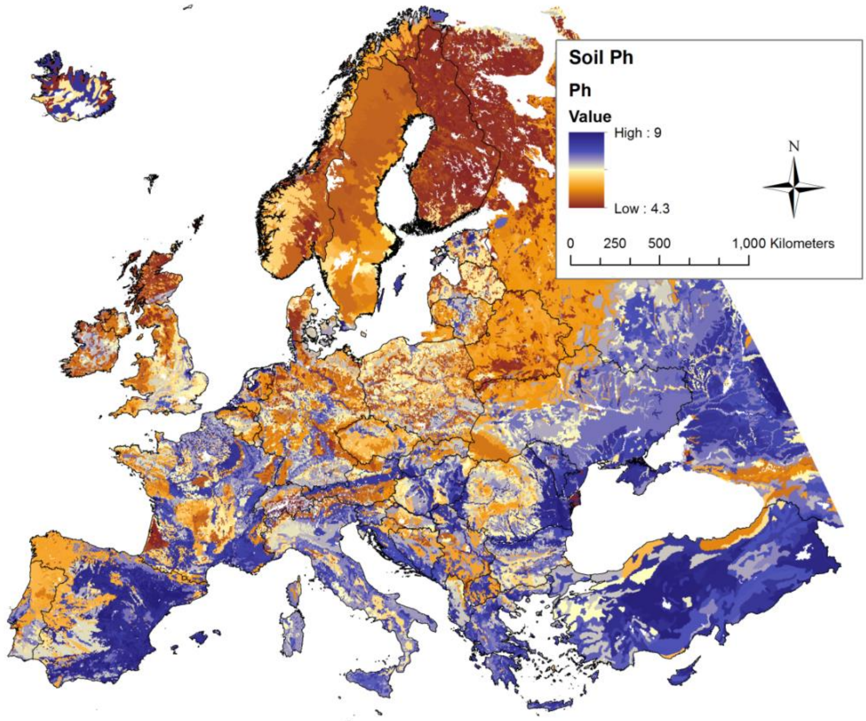
The Maxent method considers presence data (known observations of a given entity) and the so-called background data. Background data comprise a set of points used to describe the environmental variation of the study area according to the available environmental layers. It is assumed that these layers can represent the site conditions of these habitats on a European scale. These layers were selected from the most meaningful environmental predictors commonly used for modelling non-tropical plant and vegetation diversity, and are mutually not strongly correlated. As environmental data (and their sources) the following layers have been used:

- Potential Evapotranspiration (PET)
    - Source: http://www.cgiar-csi.org/data/global-aridity-and-pet-database
- Topsoil pH (Soil_pH), (see Map 3.2)
    - Source: www.isric.org

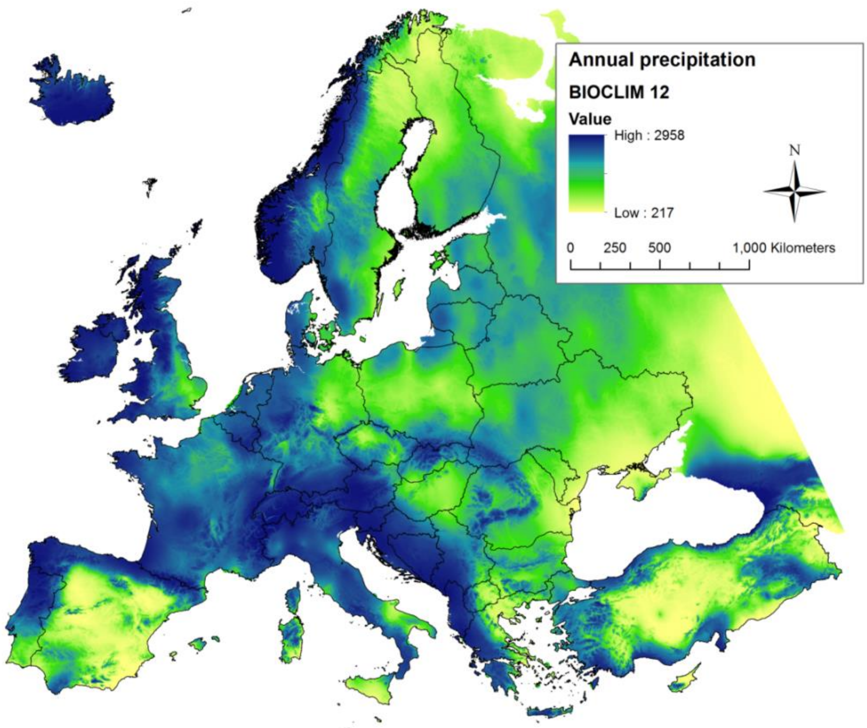
- Solar radiation (Solar)
    - Source: http://www.worldgrids.org/doku.php?id=wiki:inmsre3
- Temperature Seasonality (BioClim 4)
    - Source: http://www.worldclim.org/bioclim
- Mean Temperature of Wettest Quarter (BioClim 8)
    - Source: http://www.worldclim.org/bioclim
- Annual Precipitation (BioClim 12)
    - Source: http://www.worldclim.org/bioclim
- Precipitation Seasonality (BioClim 15)
    - Source: http://www.worldclim.org/bioclim
- Precipitation of Warmest Quarter (BioClim 18)
    - Source: http://www.worldclim.org/bioclim
- the Maximum NDVI (NDVI peak)
    - Source: Alterra, HANTS 2012 (Roerink et al., 2000, Roerink et al., 2003, Clereci et al., 2012)
- Distance to water (water: rivers, lakes, sea)
    - Source: Rivers from Bartholomew topographic maps, lakes and sea from Corine Land Cover 2006

WorldClim is a set of global climatic data layers (climate grids) with a spatial resolution of 1 square kilometre. The bioclimatic variables (BIOCLIM) are derived from the monthly temperature and rainfall values in order to generate more biologically meaningful variables (see Map 3.3 below as an example). These are often used in ecological niche modelling. The bioclimatic variables represent annual trends (e.g., mean annual temperature, annual precipitation) seasonality (e.g., annual range in temperature and precipitation) and extreme or limiting environmental factors (e.g., temperature of the coldest and warmest month, and precipitation of the wet and dry quarters). A complete overview is given in Hijmans et al., 2005.

Maxent is expected to perform well for estimating the geographic distribution of EUNIS habitats in Europe. However, this method is sensitive to sampling bias, i.e. when the spatial distribution of presence data is reflecting an unequal sampling effort in different geographic regions as with any other modelling technique. In Maxent, it has been proposed that the best way to account for sampling bias (when bias is known or expected to occur) is to generate background data reflecting the same bias of the presence data. When a complete set of presence data is available, a general recommendation is to generate background points from the occurrences of other species/communities that were sampled in a similar way (Elith et al. 2011).Two different approaches have been followed for the selection of a maximum of 10,000 locations for the background data, assuming biased and non-biased presence data. For the first approach, 10,000 locations were randomly selected from the forest plot database, assuming that they reflect the general geographic bias of forest sampling in Europe. The second approach concerns a random selection of 10,000 background points in the whole study area, assuming that the presence data describe a representative subset of the real distribution range of the target habitat.



Map 3.2 Example of Soil pH (source: ISRIC)

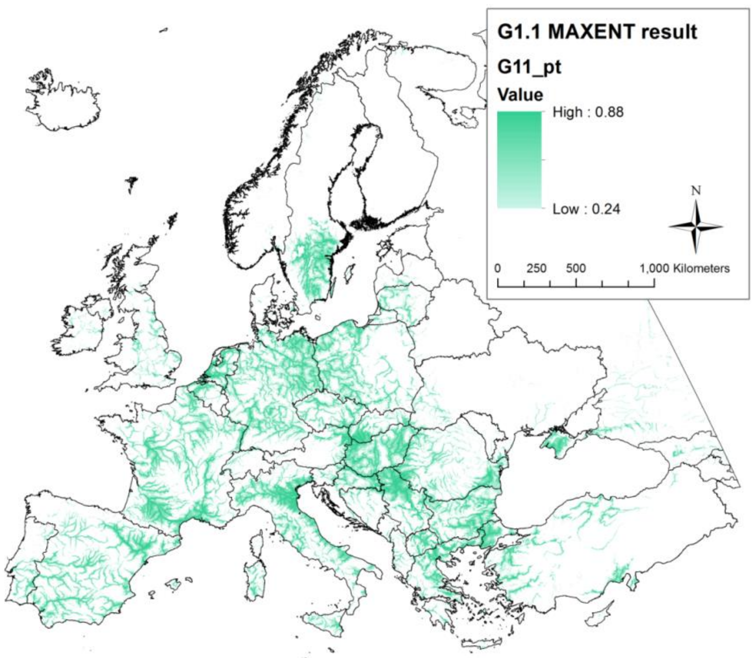


Map 3.3 Example of BIOCLIM 12 'Annual precipitation' (Hijmans et al., 2005) as an input in MAXENT.

In Annex I the results of the modelling with Maxent are presented. The two modelling approaches (assuming biased and non-biased data) were evaluated for each of the EUNIS habitat types in order to estimate which assumption is more likely. This evaluation was based on the expert knowledge of the team members in the distribution of European forest types by assessing (i) the distribution of the available presence data as an estimate of geographic bias, (ii) the realism of the habitat suitability maps to reflect known distribution of forests, and (iii) the environmental predictors that contribute most substantially to the models. The best performing model was then selected by consensus of the expert team for each habitat type. In the overview of forest types on the first page of the Appendix, the preference for one of the two outputs is indicated in the columns 'Forest' (assuming biased data) and 'Random' (assuming non-biased data).

For each EUNIS forest type the following data are presented:

- A habitat suitability map, see Map 3.4 as an example, indicating increasingly favourable ecological conditions for the type (expressing the logistic output of the model between 0 and 1).
- A distribution map showing the location of the relevés that have been assigned to the EUNIS forest type concerned and therefore used as presence data.
- The AUC, or the Area Under the Curve, as a general estimate of model performance. This is the probability that the classifier correctly orders two points (a random positive example and a random negative example). In general, AUC values in the range 0.5-0.7 were considered low, 0.7-0.9 were moderate and >0.9 were high, suggesting poor, good and very good model performances, respectively. We provide two estimates of the AUC as calculated by Maxent. 'AUC training' reflects the internal fit between observed and predicted occurrences in the computed model. 'AUC test' provides the mean AUC obtained from a 10-fold cross-validation procedure in which ten different models were computed with a random selection of 90% of data (calibration data set) and 10% for testing the model (validation data set).
- Contribution variables to the Maxent model (%). Indicates to what extent the environmental variables contribute to the model.



Map 3.4 Example of the suitability map for the EUNIS forest habitat type G1.1 'Temperate and boreal softwood riparian woodland*' as a result of the MAXENT statistical modelling.

4 Top-down: habitat probability maps based actual land cover

The habitat modelling continues with the refinement of the habitat suitability maps (as derived from the bottom-up approach) based on, amongst others, satellite derived land cover information (top-down approach). The outline with the red dots in Figure 4.1 gives a simplified overview of the top-down approach, which is the second part of our methodology.

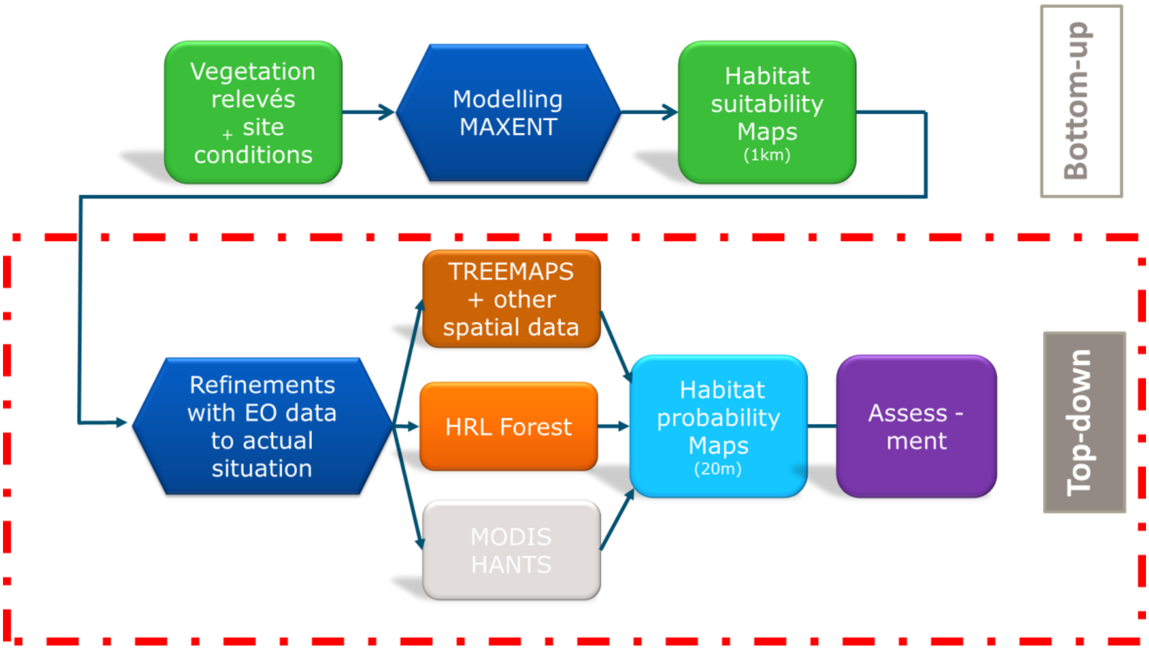


FIgure 4.1 The refinement of the habitat suitability maps (as derived from the bottom-up approach) into habitat probability maps is mainly based on actual land cover information (top-down approach, outlined with red dots).

4.1 Copernicus HRL Forest

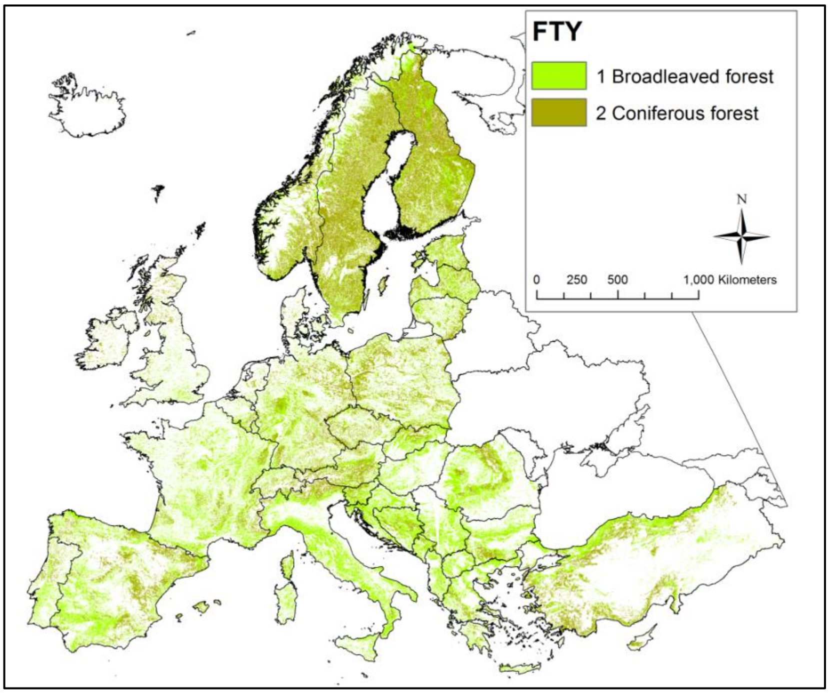
The Copernicus Land Monitoring Services has, next to a global, local and in-situ component, a Pan-European component and within that context five European high resolution data layers are being produced, namely:

1. Imperviousness
2. Forests
3. Permanent grasslands
4. Wetlands
5. Water bodies

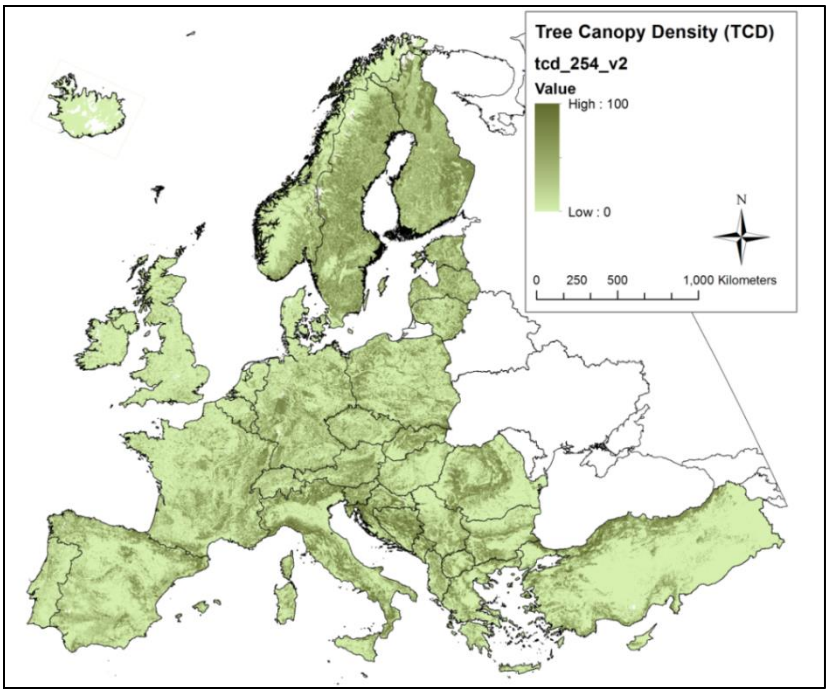
The HRL forest areas consist of two main forest products:

a) Tree cover presence/absence with dominant leaf type (FTY)
b) Tree cover density (TCD)

The forest type map (FTY) has two major categories: broadleaved and coniferous forest (see also Map 4.1). The tree cover density (TCD) ranges from 0-100%. A threshold of 30% is used in general to distinguish forest from non-forest (see Map 4.2). The HRL forest products that were made available by the EEA for this study, concern draft versions of the Copernicus HRL and are certainly not the final products. Evaluations and enhancements are still being made by the individual member states on the HRL forest. Final version of the HRL Forest is expected to be ready by the end of 2015. Since the obtained products had some serious data gaps the HRL forest products were enhanced by us by filling the data gaps with CORINE land cover 2006.



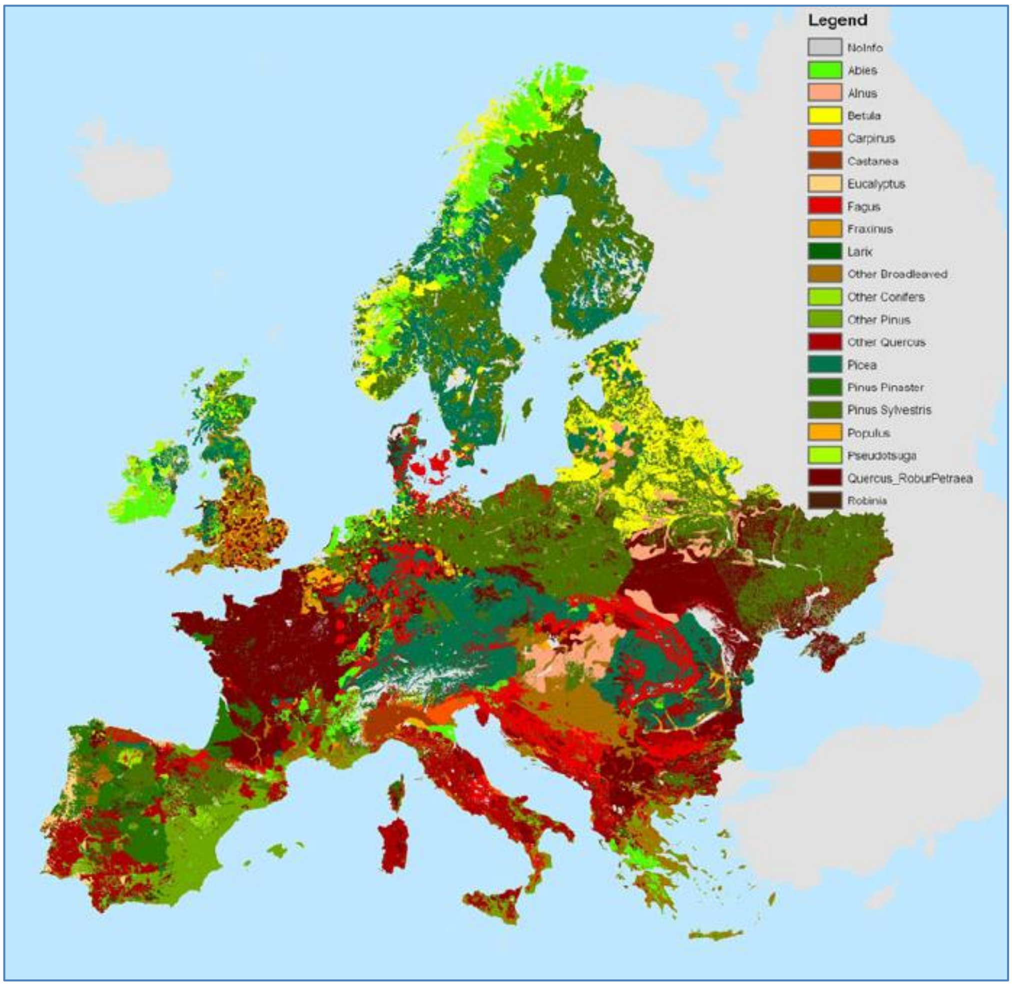
Map 4.1 Forest Type Map from the Copernicus HRL Forest (source: EEA). Notice that datagaps have been filled with CLC2006.



Map 4.2 Forest Cover Density Map from the Copernicus HRL Forest (source: EEA). Notice that data gaps have been filled with CLC2006.

4.2 TREEMAPS

In order to map the spatial distribution of 20 tree species groups over Europe at 1 km x 1 km resolution, the ICP-Forest Level-I plot data were extended with the National Forest Inventory (NFI), comprising plot data of 18 countries. In areas with NFI plot data, the proportions of the land area covered by the tree species were mapped by compositional kriging. Outside these areas, these proportions were mapped with a multinomial multiple logistic regression model. A soil map, a biogeographical map and bio-indicators derived from temperature and precipitation data were used as predictors. For more detailed information on the method used, see Brus et al., 2012. Map 4.3 shows the overall compilation into a wall-to-wall map with the dominant species. In our methodology we only used the individual tree species maps when appropriate.



Map 4.3 Map of predicted dominant tree species based on ICP-Forest Level-I plot data and National Forest Inventory (NFI) plot data (source: Brus et al., 2012).

4.3 Results

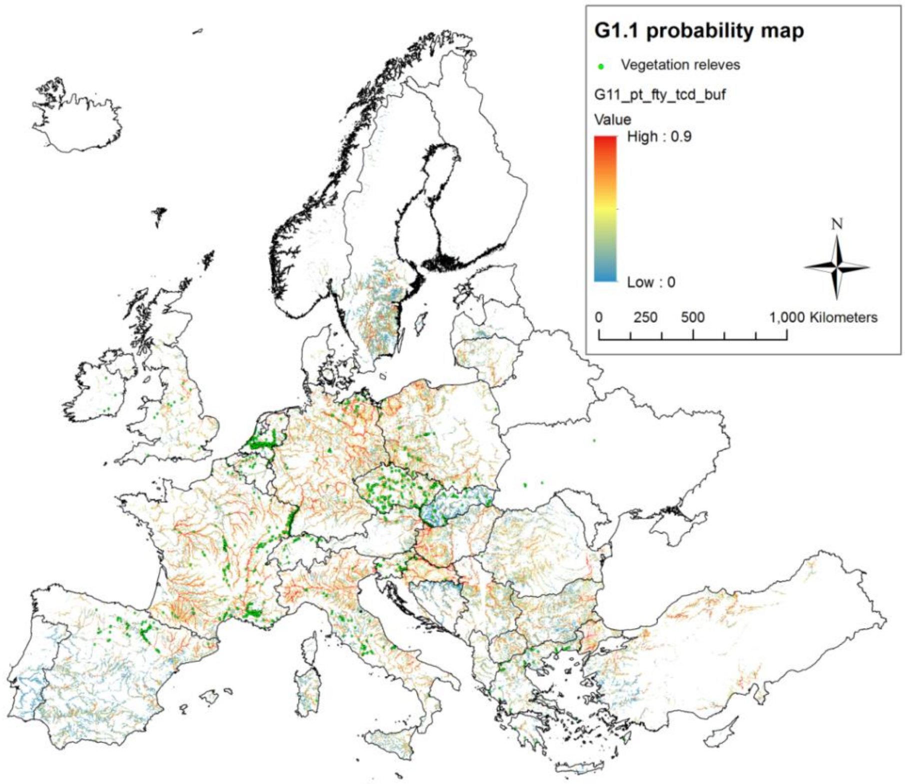
In Annex 1 all the decision rules can be found that have been applied for the production of the 24 EUNIS Forest habitat probability maps. All scripts have been made within the model builder of ARCGIS 10.2.1.The maps have a spatial resolution of 20 meters and a probability between 0 and 1. All probabilities are relative and do not have an absolute value. The habitat probability maps have been assessed by ILE SAS, with emphasis on Slovakia, for which detailed reference data was available. The assessment is described in the next chapter.

Table 2.1 List of EUNIS forest habitat types for which probability maps have been produced.

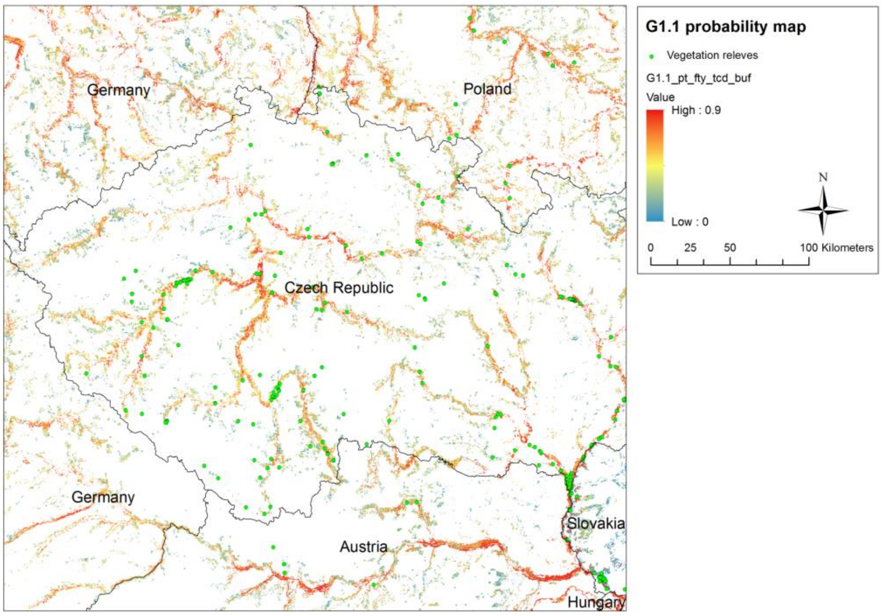
Forest Type	Subtype	Name	Nr veg releves
B1.7		Coastal dune woodland* [Coastal dune woods]	-
G1.1		Temperate and boreal softwood riparian woodland* [Riparian and gallery	2163

		woodland, with dominant [Alnus], [Betula], [Populus] or [Salix]]	
G1.2		Temperate and boreal hardwood riparian woodland* [Mixed riparian floodplain and gallery woodland]	4363
G1.3		Mediterranean and Macaronesian riparian woodland* [Mediterranean riparian woodland]	1022
G1.4		Broadleaved swamp woodland on non-acid peat* [Broadleaved swamp woodland not on acid peat]	1013
G1.5		Broadleaved swamp woodland on acid peat* [Broadleaved swamp woodland on acid peat]	643
G1.6		[Fagus] woodland could be divided into two types, because of the high variation within the overall type and the possibility to make a clear division:	-
	G1.6a	Fagus woodland on non-acid soils	4275
	G1.6b	Fagus woodland on acid soils	3141
G1.7		Thermophilous deciduous woodland	3599
G1.8		Acidophilous Quercus woodland* [Acidophilous [Quercus]-dominated woodland]	2667
G1.9		Non-riverine woodland with [Betula], [Populus tremula] or [Sorbus aucuparia] has to be divided into two types:	-
	G1.9a	Mountain Betula and Populus tremula woodlands on mineral soils	138
G1.A		Mesotrophic and eutrophic deciduous woodland, not dominated by Fagus* [Meso- and eutrophic [Quercus], [Carpinus], [Fraxinus], [Acer], [Tilia], [Ulmus] and related woodland]	5277
G2.1		Mediterranean evergreen Quercus woodland* [Mediterranean evergreen [Quercus] woodland]	1274
G2.4		Olea oleaster-Ceratonia siliqua woodland* [Olea europaea] - [Ceratonia siliqua] woodland]	307
G2.6		Ilex aquifolium woodland* [[Ilex aquifolium] woods]	207
G3.1		[Abies] and [Picea] woodland has to be divided into three types (according to dominant species and geographic distribution):	-
	G3.1a	Temperate mountain Picea woodland	1996
	G3.1b	Temperate mountain Abies woodland	1808
G3.2		Temperate subalpine Larix-Pinus woodland* [Alpine [Larix] - [Pinus cembra] woodland]	575
G3.4		[Pinus sylvestris] woodland south of the taiga has to be divided into three types:	-
	G3.4a	Temperate continental Pinus sylvestris woodland	1898
	G3.4b	Temperate and submediterranean montane Pinus sylvestris-nigra woodland	696
G3.7		Mediterranean lowland to submontane Pinus woodland* [Lowland to montane mediterranean [Pinus] woodland (excluding [Pinus nigra])]	551
G3.9		Coniferous woodland dominated by [Cupressaceae] or [Taxaceae] should be divided into two types: Taxus baccata woodland and Juniperus-Cupressus woodland and further into mainland and Macaronesia.	-
	G3.9a	Taxus baccata woodland	270
	G3.9b	Mediterranean Cupressaceae woodland	765
G3.E		Temperate bog conifer woodland* [Nemoral bog conifer woodland]	1047

Map 4.4 shows an example of a final habitat probability map for G.1.1 ‘Temperate and boreal softwood riparian woodland’. Map 4.5 shows the fine spatial resolution of 20 meter for the western part of Czech Republic and direct surroundings. Map 4.6, 4.7 and 4.8 show examples of the local details of final probability map for EUNIS forest habitat type G.1.1.

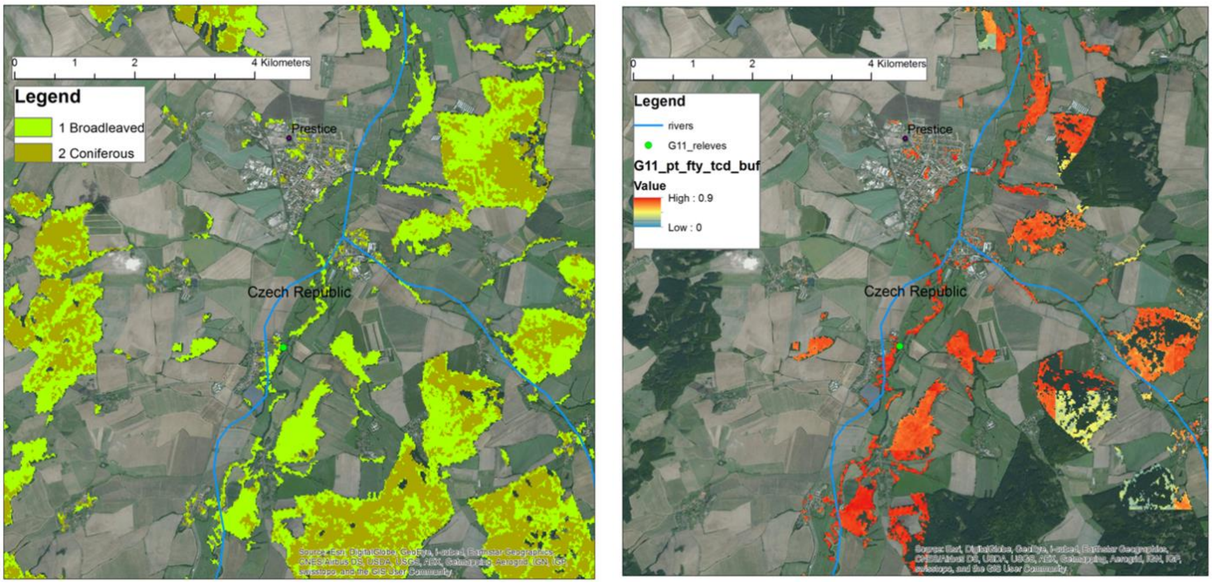


Map 4.4 Example of a final probability map for EUNIS forest habitat type G.1.1. 'Temperate and boreal softwood riparian woodland*'. Original relevés for this habitat type are displayed in green.



Map 4.5 Example of the regional detail of final probability map for EUNIS forest habitat type G.1.1. 'Temperate and boreal softwood riparian woodland*'. Original relevés for this habitat type are displayed in green.

Map 4.6 Example of the local details of final probability map for EUNIS forest habitat type G.1.1. ' Temperate and boreal softwood riparian woodland*'. On the left, the local aerial photographs. On the right, the final result on top of aerial photographs.



Map 4.7 Example of the local details of final probability map for EUNIS forest habitat type G.1.1. ' Temperate and boreal softwood riparian woodland*'. On the left, the HRL Forest on top of aerial photographs. On the right, the final result on top of aerial photographs.

Map 4.8 Example of the local details of final probability map for EUNIS forest habitat type G.1.1. ‘ Temperate and boreal softwood riparian woodland*’. On the left, the original MAXENT modelling result with a 1 km spatial resolution. On the right, the final result with a 20 meter on top of aerial photographs.

Especially from Map 4.8 it is clear that a further refinement of the MAXENT modelling results on basis of the Copernicus HRL Forest makes sense. However, the accuracy of these habitat maps is still unknown and these maps are being assessed in the next chapter.

5 Assessment of the EUNIS forest habitat probability maps

5.1 Introduction

The main objective of this chapter was to assess the performance of European wide HPM (Habitat Probability Maps) for Slovakia. Slovakia represents a quite diverse range of environmental conditions driven by heterogeneous geological formations, soils, terrain and regional climate. Therefore there is quite a high diversity of forest types and some of them are unevenly distributed reflecting specific local conditions. This could lead in a diverse patchy mosaic of forest habitats in Slovakia. In this respect we aimed here to analyse if the European wide HPM can sufficiently describe the distribution of the main forest types at a local to regional scale and thus could be used potentially for national applications. The assessment was performed independently by ILE SAS.

5.2 Data and methods

For the sake of consistency, the same performance indicator was used for Slovakia to assess the HPM results as it was done at the European scale, namely, the AUC (Area under Curve). The presence data for each forest type was derived from the Slovak national forest data sets (described below). The absence data was randomly sampled from the forest background (forest area where each forest type did not occur). This background data was done by combination of Slovak national forest mask and HRL Forest data in order to minimize the effect of discrepancies of these two data sets for the HPM assessment. These discrepancies were derived mainly from a) absence of the "military forest areas" in Slovak national forest mask, b) absence of forest on agricultural land in Slovak national forest mask and c) accuracy of Copernicus HRL forest. The modelling approach that was applied on the EU level, used as input data the vegetation relevés describing well developed forest stands, usually of natural composition. The probability maps represent the final product of the spatial modelling. Therefore these maps refer in some sense rather to the potential than to the actual vegetation. For this reason, we used data on forest types for our analysis, i.e. climax forest habitats that should occur in the site in a given climatic and soil condition. The system and detailed description of the forest types was prepared by Hančinský (1972). This system was used for detailed field mapping of forest types in Slovakia and the maps were developed in scale 1:10,000. We used the digital map of the Slovak forests that contains also information about forest types mapped in individual forest parcels. This map does not include all forests of Slovakia, as it does not include forests on agricultural land and forests in the military training areas. This situation was reflected in preparation of the Slovak national forest mask. In the next step, the forest types were reclassified to EUNIS habitat types. Out of a total number of 478 forest types, 394 forest types represent broadleaved deciduous forests and coniferous forests (276 and 118 types respectively). The remaining 84 forest types are either mixed forests (77 types) or dwarf pine shrub stands (7 types).

5.3 Results

Out of the 24 EUNIS Forest habitat types, for which the probability maps were produced in this report, 15 habitat types were present in the Slovak forest dataset and therefore the assessment was restricted to these 15 EUNIS types at level 3, namely G1.1, G1.2, G1.4, G1.5, G1.6a, G1.6b, G1.7, G1.8, G1.A, G3.1a, G3.1b, G3.2, G3.4a, G3.4b and G3.E. The presence of another two habitat types was expected in Slovakia, namely *G1.9 Mountain Betula and Populus tremula woodlands on mineral soils* and *G3.9a Taxus baccata woodland*, but they were not found in the Slovak dataset. While the habitat type G1.9 could occur in small patches that were not recorded or in young forests outside the forest land, the habitat type G3.9a certainly does not occur in Slovakia; *Taxus baccata* does occur, but does not form forest stands. This species can be found in restricted area in low abundance in beech forests. Figure 5.1 provides the overall picture of the degree of correspondence between the modelled distribution of 14 EUNIS Forest habitat types at level 3 and their distribution according the Slovak forest dataset. For the general expression of the AUC values we used the same categories that were used for probability maps (i.e. AUC values 0.5-0.7 suggested low, 0.7-0.9 moderate and >0.9 high correspondence). The values of AUC indicate moderate correspondence for 8 forest habitat types (G3.2, G1.4, G3.1a, G3.E, G1.7, G3.4b, G3.1b, G1.A) and poor correspondence for 7 forest habitat types G1.1, G1.2, G1.5, G1.6a, G1.6b, G1.8, G3.4a). We did not record any perfect correspondence, although G3.2 was very close to the threshold.

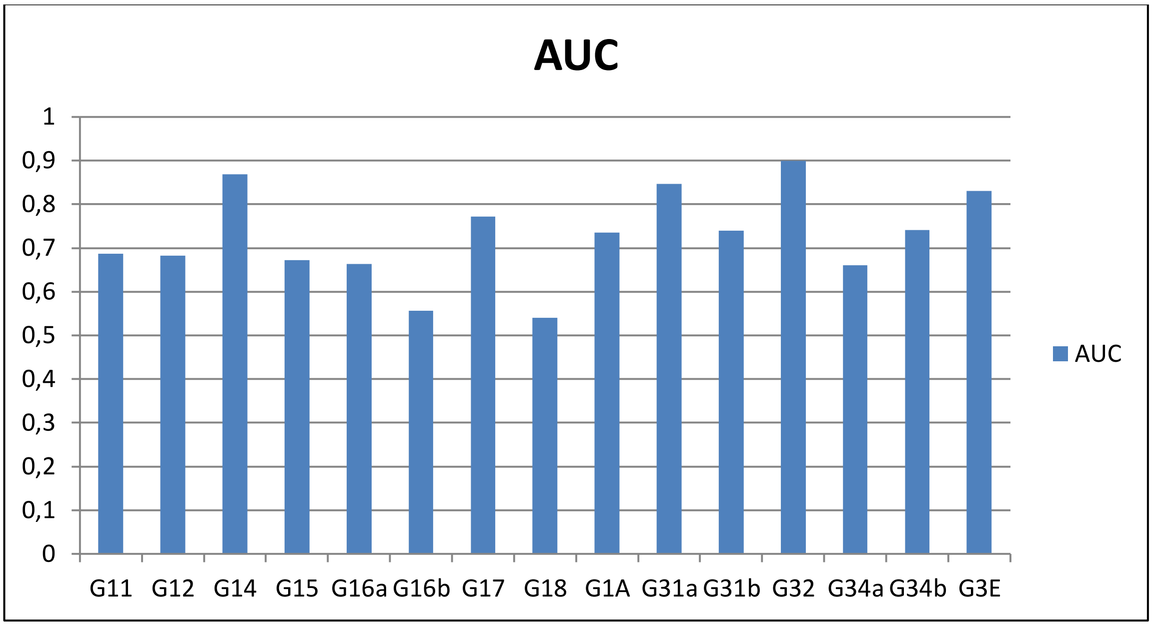
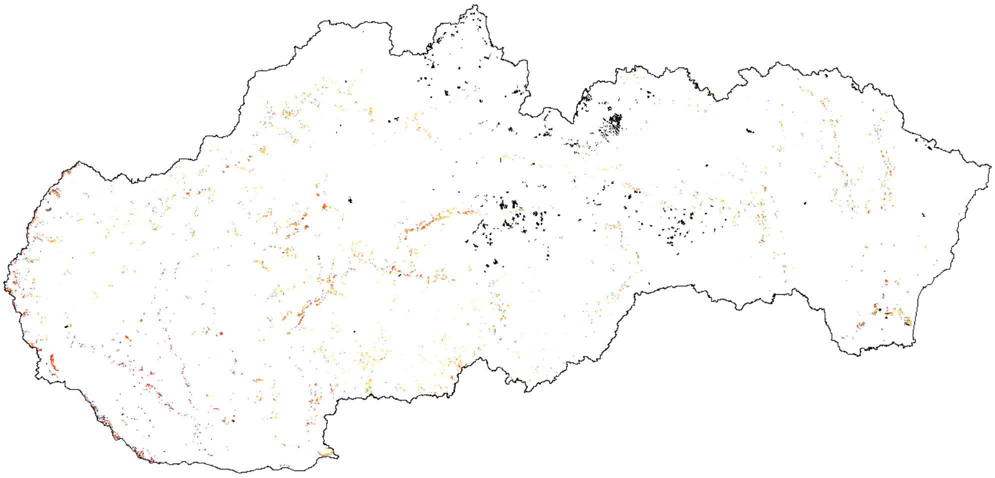


Figure 5.1 Area Under Curve (AUC) as a performance indicator for the studied EUNIS Forest habitat types (European wide habitat probability maps versus Slovakian national forest dataset).

In the section below we provide for each forest type the value of the AUC measure, detailed maps and short comments.

G1.1 Temperate and boreal softwood riparian woodland (Riparian and gallery woodland, with dominant [Alnus], [Betula], [Populus] or [Salix])

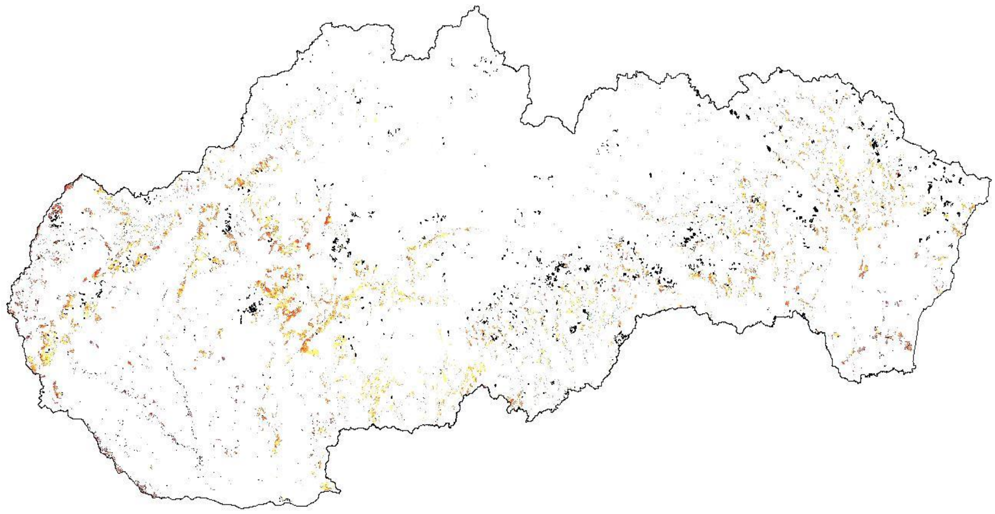
The AUC value was 0.687, which represents a low correspondence between the modelled distribution and distribution suggested by the Slovak forest dataset. Comparison of both layers indicated that in northwest and Central Slovakia the probability map does not model the occurrence of G1.1 while the Slovak dataset shows occurrence of the mountain alder riparian forests (see Map 5.1). For this habitat type, the distance from water represents the most important variable. The mountain alder forests are linked to small streams that possibly are not included in the Bartholomew topographic maps and thus they are not detected by the modelling (HPM assumed that the G1.1 habitat was within 1500 meters bufferzone from any stream). On the other hand, the model predicts the habitat occurrence along main rivers in sites that are not included to the Slovak forestry data. The possible explanation is that these forests are either narrow strips along the water courses that are outside of the forest land or they are classified as the hardwood floodplain forests (G1.2) in the SK forest dataset.



Map 5.1 Modelled distribution (red- high probability; blue – low probability) and occurrence indicated by forest dataset that was not detected by modelling approach (black) for habitat G1.1.

G1.2 Temperate and boreal hardwood riparian woodland (Mixed riparian floodplain and gallery woodland)

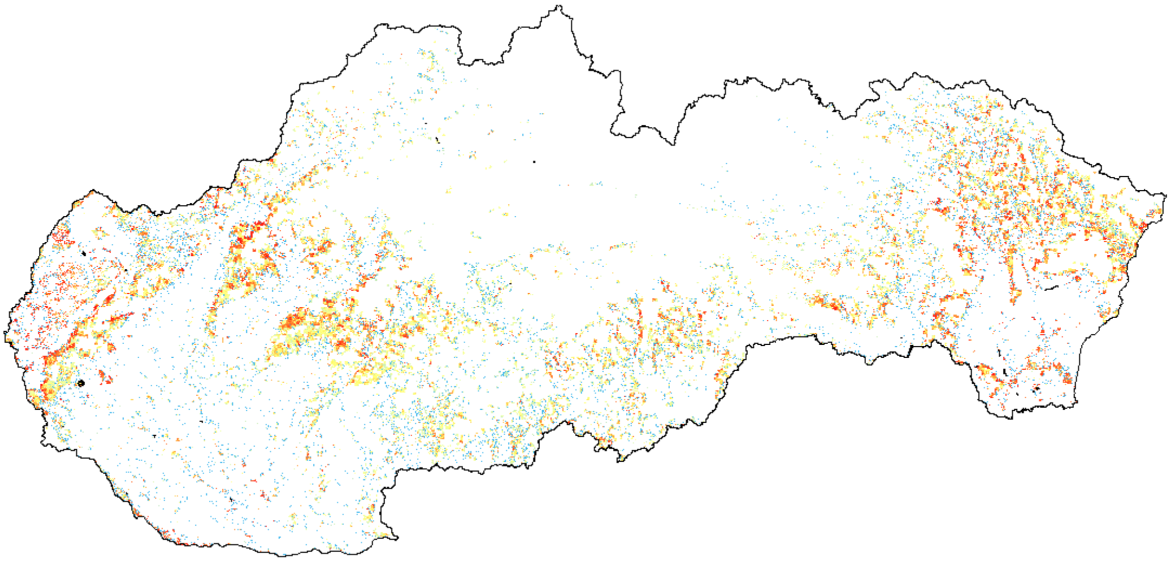
The AUC value was 0.683, which represents a low correspondence between the modelled distribution and distribution suggested by the Slovak forest dataset. The general pattern of distribution is quite similar between the modelled and SK forest dataset, but the probability map indicates significantly larger area in compact forests of the low-altitude mountains, where the SK forest dataset indicates a much scarcer distribution (see Map 5.2). It seems that the modelling approach classified as well some oak- or oak-hornbeam forests as hardwood floodplain forests, and therefore also non-riparian forests were included in the probability map. This assumption supports also the predictors used by the suitability model – the main variables are climatic parameters, the distance to water has very low contribution to the suitability model (less than 1%) while in the probability modelling threshold value for distance to water was used at 3,000 m. Such a distance threshold could be correct in the large floodplains, but in the hilly and diverse landscape it is too wide and allows including large areas of non-alluvial landscape.



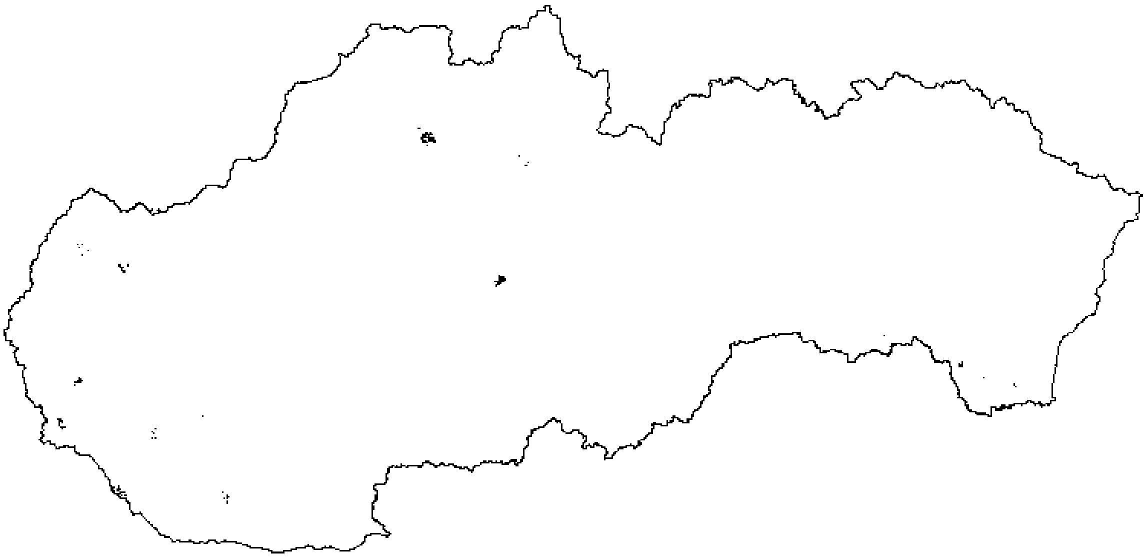
Map 5.2 Modelled distribution (red- high probability; blue – low probability) and occurrence indicated by forest dataset that was not detected by modelling approach (black) for habitat G1.2.

G1.4 Broadleaved swamp woodland on non-acid peat

The AUC value was 0.869 which represents moderate correspondence between the modelled distribution and distribution suggested by the Slovak forest dataset. However, for this habitat type, the modelling and the SK forest dataset provides very different results. This habitat type is considered very rare in Slovakia and the SK forest dataset indicates its occurrence in a few scattered patches only (Map 5.4). The modelling resulted in the probability map indicating broad distribution across whole Slovakia except higher altitudes in the north part of the country (Map 5.3). It captured all sites of this habitat in the SK forest dataset, but indicated probable occurrence also in many other sites which might lead to the high commission error, which were not used for the validation report here.



Map 5.3 Modelled distribution (red- high probability; blue – low probability) and all occurrence indicated by forest dataset (black) for habitat G1.4.

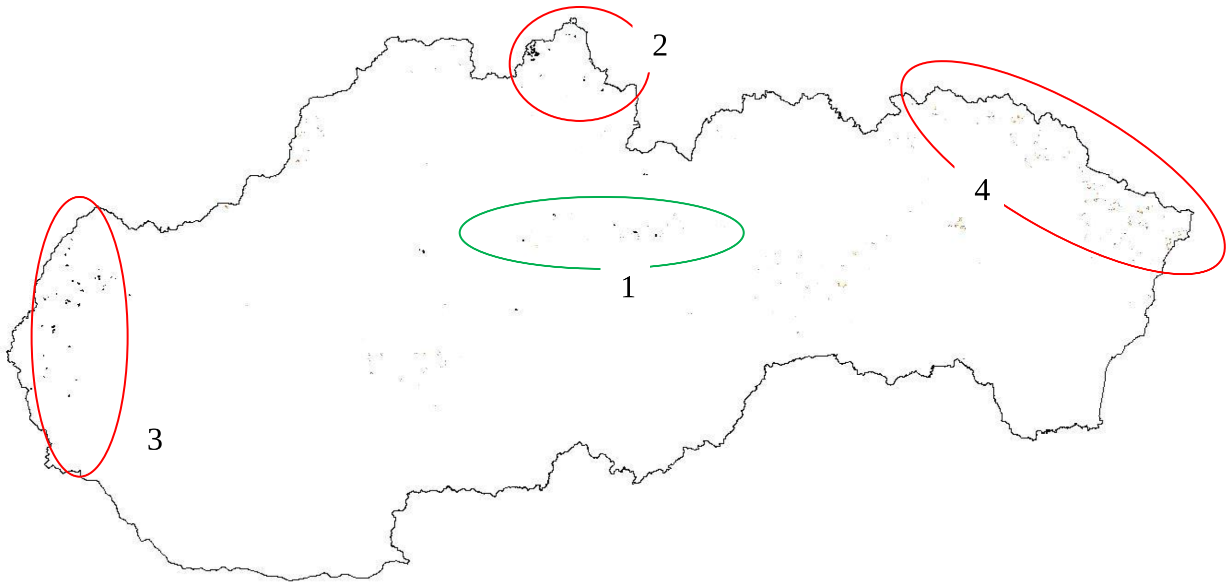


Map 5.4 Distribution of the G1.4 in the SK forest dataset.

It seems that for modelling of "azonal" habitat types it is crucial to include to the model the main environmental factors that determine their occurrence – in this case non-acidic peaty soils in sufficient resolution. In the model was used the only soil parameter – pH, other parameters were related to climate.

G1.5 Broadleaved swamp woodland on acid peat

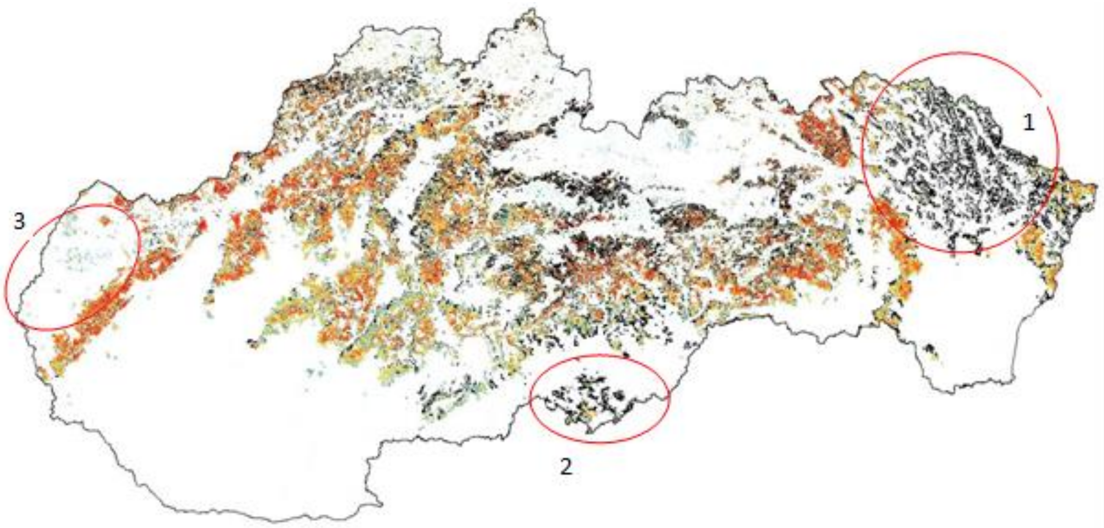
The AUC value was 0.672, which represents low correspondence between the modelled distribution and distribution suggested by the Slovak forest dataset. The correspondence between modelled distribution and SK forest dataset is quite weak. Both sources indicated the habitat occurrence in the middle Slovakia (1). The SK forest dataset indicates two main regions for this habitat type: Orava region (NW Slovakia; 2) and Záhorská nížina lowland (SW Slovakia; 3), what is consistent also with other national data sources. However, the probability map indicates the main distribution of the habitat type in NE Slovakia (Map 5.5). Here we can repeat the comment from G1.4 on the need to include the crucial environmental variables.



Map 5.5 Modelled distribution (red- high probability; blue – low probability) and occurrence indicated by forest dataset that was not detected by modelling approach (black) for habitat G1.5.

G1.6a Fagus woodland on non-acid soils

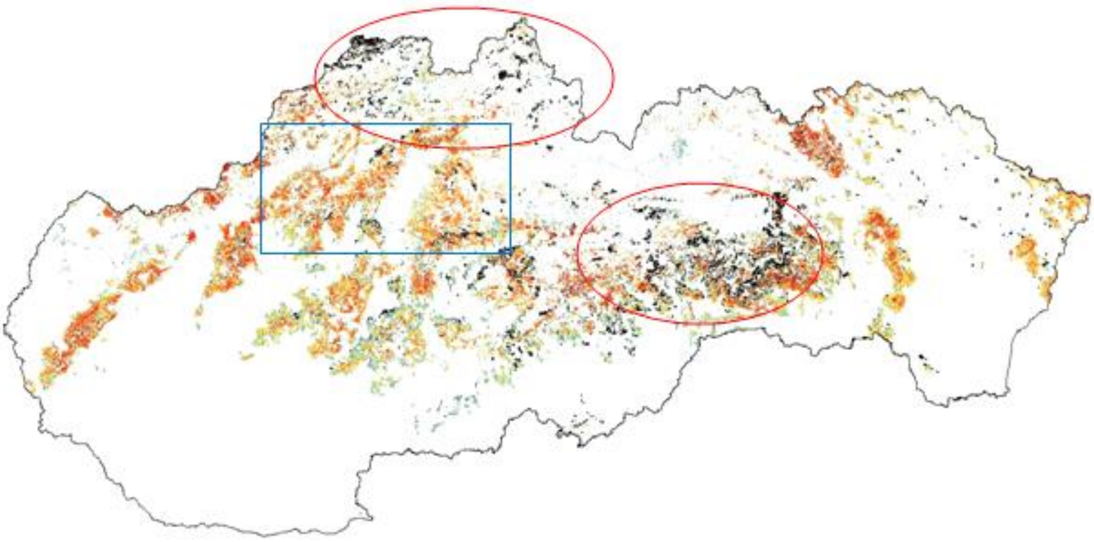
The AUC value was 0.664, which represents low correspondence between the modelled distribution and distribution suggested by the Slovak forest dataset. The correspondence between the probability map and the SK forest dataset is quite good as the distribution patterns in both datasets across Slovakia are similar. The probability map does not reflect two areas of abundant occurrence of the habitat type: NE Slovakia (Laborecká vrchovina Mts., 1) and south Slovakia (Cerová vrchovina Mts., 2). On the other hand, the probability map indicates occurrence (usually either scattered or with low probability) in regions where this habitat type is not recorded in the SK forest dataset: SW Slovakia (Záhorská nížina Mts., 3) and almost whole north periphery of the country (except NE), see Map 5.6. The climatic variables contributed mostly to the model, very low value of the soil pH significance (0,24 %) is surprising – especially when two types of beech forests differing in the requirements for pH are distinguished (G1.6a, G1.6b). Taken into account this low value of the soil pH, it is difficult to estimate which factors influenced the absence or low representation of two above mentioned areas in the probability map. There are no crucial differences in the climate against surrounding areas where the model predicts the habitat occurrence.



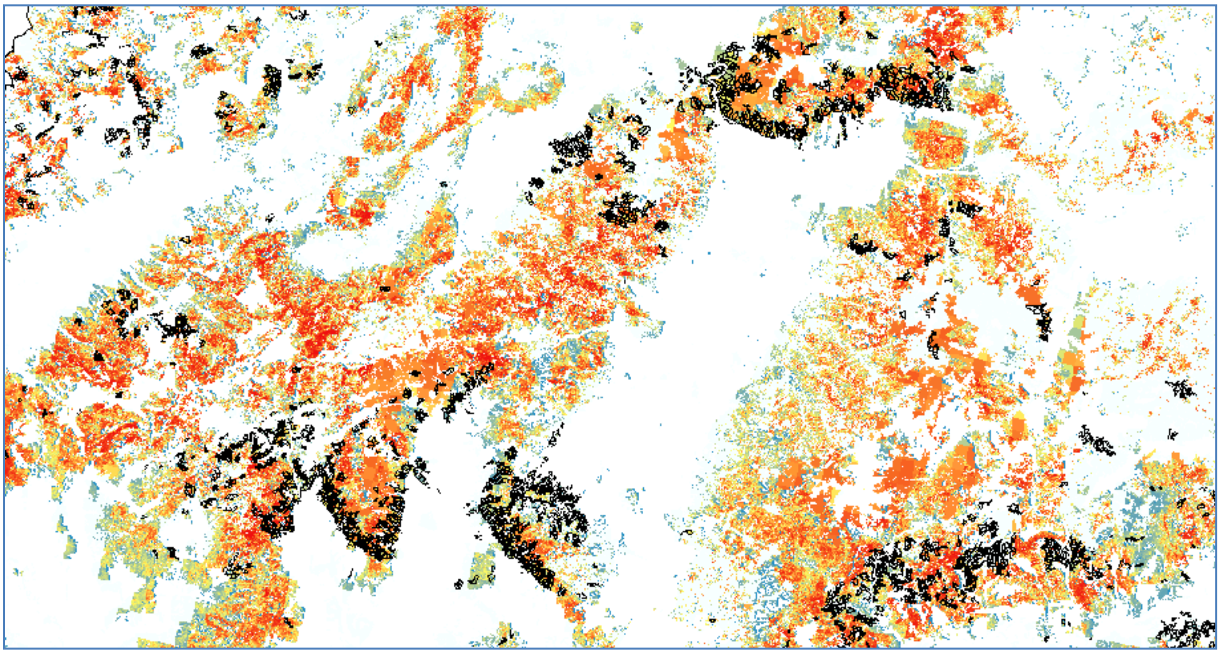
Map 5.6 Modelled distribution (red- high probability; blue – low probability) and occurrence indicated by forest dataset that was not detected by modelling approach (black) for habitat G1.6a.

G1.6b Fagus woodland on acid soils

The AUC value was 0.556, which represents low correspondence between the modelled distribution and distribution suggested by the Slovak forest dataset. The general distribution pattern across Slovakia is similar in both probability map and the SK forest dataset. There is lower prediction of occurrence in some regions than SK forest dataset indicates, e.g. NW Slovakia (Kysuce, Orava) and south-central part of Slovakia (Slovenské rudohorie Mts.). However, the model predicts in these entire regions occurrence, only more fragmented and in smaller patches than the SK forest dataset. On the other hand, the model predicts a much broader distribution of the habitat type in the middle-altitude mountains, especially in the west part of Slovakia. One example is highlighted below in the Map 5.8. As for the model, it is valid the same as for G1.6a above. In addition, *Fagus sylvatica* from TREEMAPS source should have been used as an additional filter in the rules for modelling as was done for G1.6a. Nevertheless, it could also mean that the AUC could further decrease.



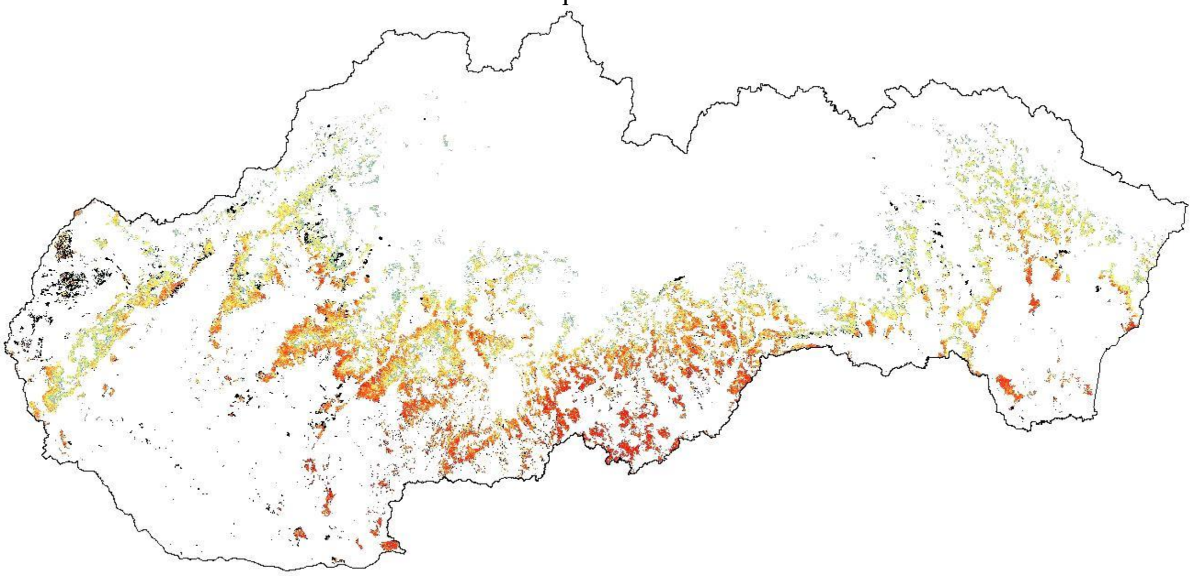
Map 5.7 Modelled distribution (red- high probability; blue – low probability) and occurrence indicated by forest dataset that was not detected by modelling approach (black) for habitat G1.6b.



Map 5.8 All patches of G1.6b in the SK forest dataset and the predicted distribution of the same habitat type in the region indicated in the Map 5.7 by blue rectangle.

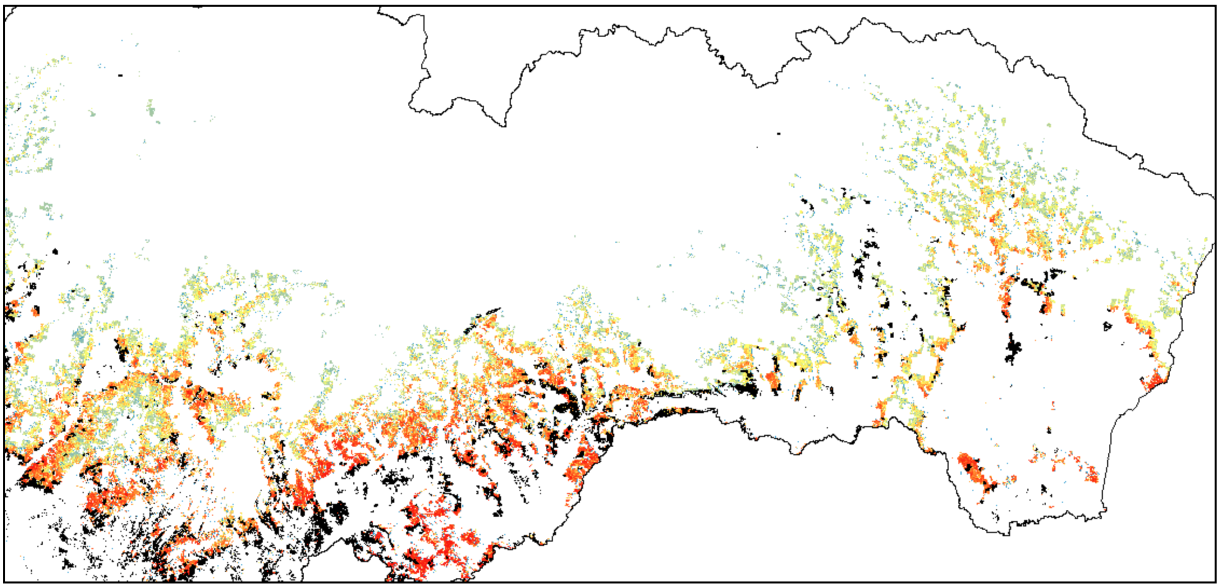
G1.7 Thermophilous deciduous woodland

The AUC value was 0.772, which represents moderate correspondence between the modelled distribution and distribution suggested by the Slovak forest dataset. The general distribution pattern is very similar in both dataset, the only significant difference is in SW Slovakia (Záhorská nížina Mts.), (see Map 5.9), where the modelling approach foresees small patches with low probability of occurrence while the SK forest dataset indicates quite broad distribution.



Map 5.9 Modelled distribution (red- high probability; blue – low probability) and occurrence indicated by forest dataset that was not detected by modelling approach (black) for habitat G1.7.

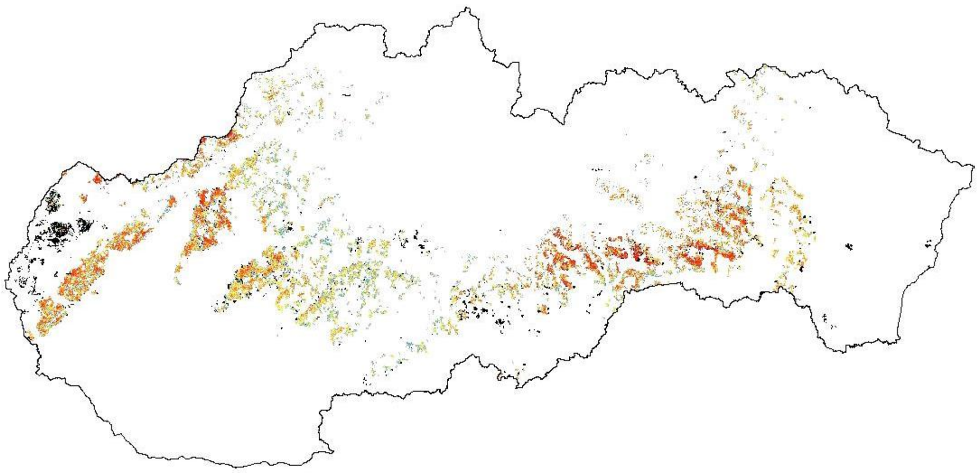
A possible explanation is that this lowland differs from other lowlands in Slovakia by cooler climate, but the oak is still able to grow there, e.g. the Habitat Directive Annex I. type 91I0 is distributed in this lowland. In the middle and eastern Slovakia, the model predicts distribution of this habitat type consistently slightly northern than the SK forest dataset indicates (Map5.10).



Map 5.20 The habitat occurrence indicated by SK forest dataset and probability map (red- high probability; blue – low probability) for habitat G1.7 – detail of south Slovakia.

G1.8 Acidophilous Quercus woodland (Acidophilous [Quercus]-dominated woodland)

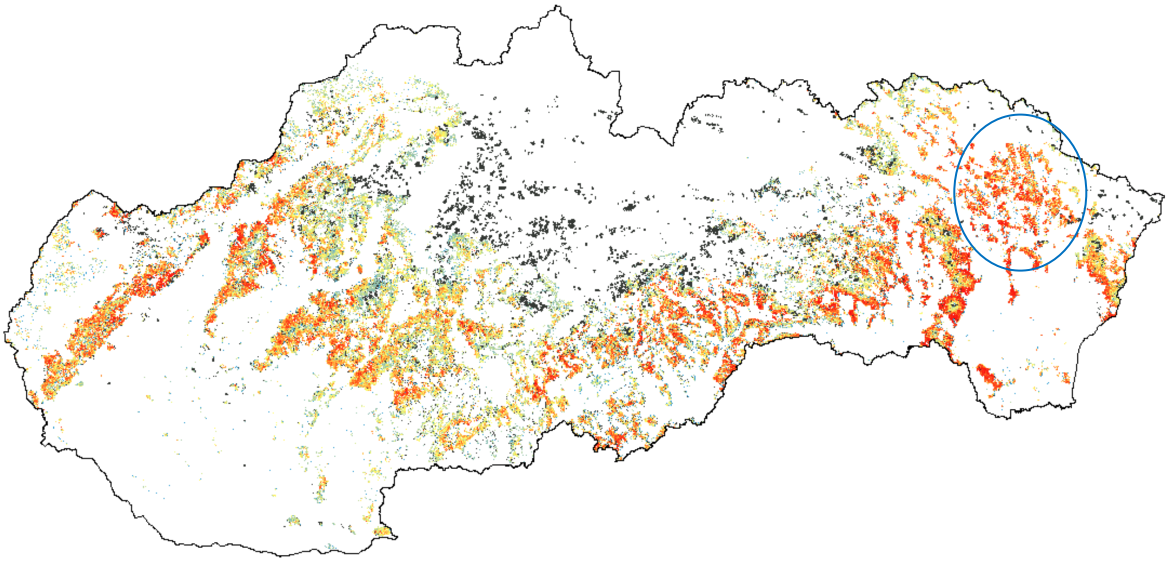
The AUC value was 0.540, which represents low correspondence between the modelled distribution and distribution suggested by the Slovak forest dataset. The general pattern of distribution is very similar in both probability map and the SK forest dataset. Both datasets indicate larger areas (and high probability) as well as fragmented/scattered distribution (and low probability) in the same regions (Map 5.11). As for habitat type occurrence in SW Slovakia (Záhorská nížina lowland) and partly also the shift northwards, we can conclude the same as for G1.7. This habitat type differs especially in pH from the related *Quercus* woodland. From this perspective the low contribution of the soil pH to the model (0,72%) is surprisingly low.



Map 5.11 Modelled distribution (red- high probability; blue – low probability) and occurrence indicated by forest dataset that was not detected by modelling approach (black) for habitat G1.8.

G1.A Mesotrophic and eutrophic deciduous woodland, not dominated by Fagus* (Meso- and eutrophic [Quercus], [Carpinus], [Fraxinus], [Acer], [Tilia], [Ulmus] and related woodland)

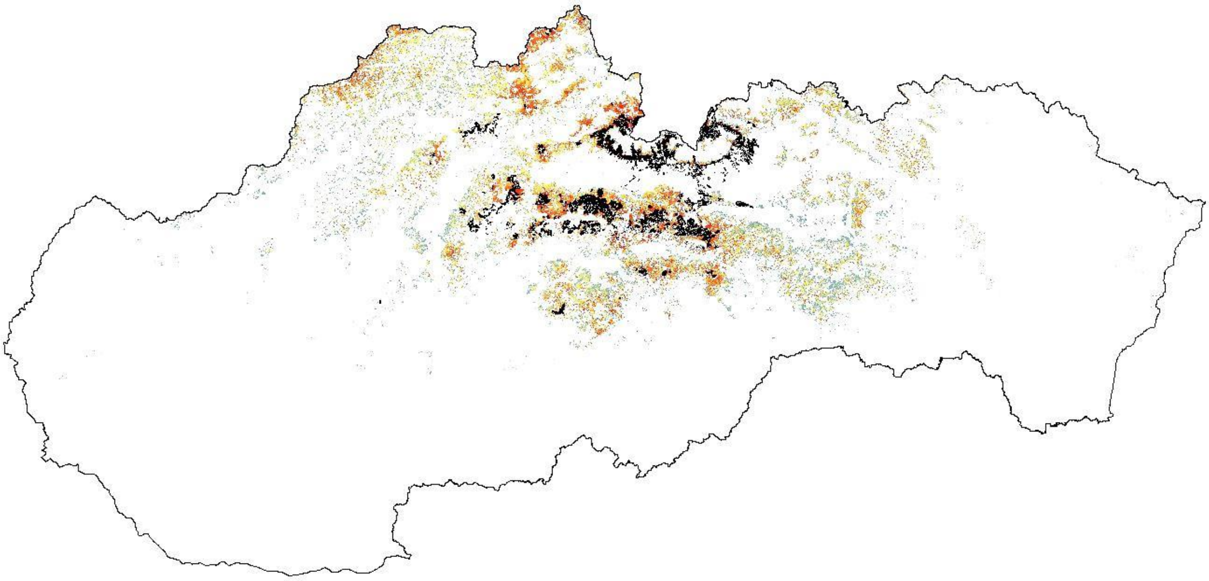
The AUC value was 0.735, which represents moderate correspondence between the modelled distribution and distribution suggested by the Slovak forest dataset. The general pattern of the habitat type distribution is quite similar in both dataset. The main difference is in absence of the habitat type in large part of the middle and north part of Central Slovakia as well as in northeast corner of Slovakia (Poloniny) in the probability map, see Map 5.12 (SK forest dataset indicates quite abundant occurrence there). These regions have a colder climate than rest of Slovakia, what could explain the difference. In addition, the probability map predicts quite large areas of high probability of the habitat type occurrence in NE Slovakia (Laborecka vrchovina – Map 5.12, blue circle), while the SK forest datasets indicate a much scattered distribution. This is the region where the model did not predict acid beech forests (G1.6b), while the SK forest dataset indicates abundant occurrence. Probably the same factor(s) that is responsible for absence of this region in the probability map for G1.6b, is also responsible for high probability of G1.A.



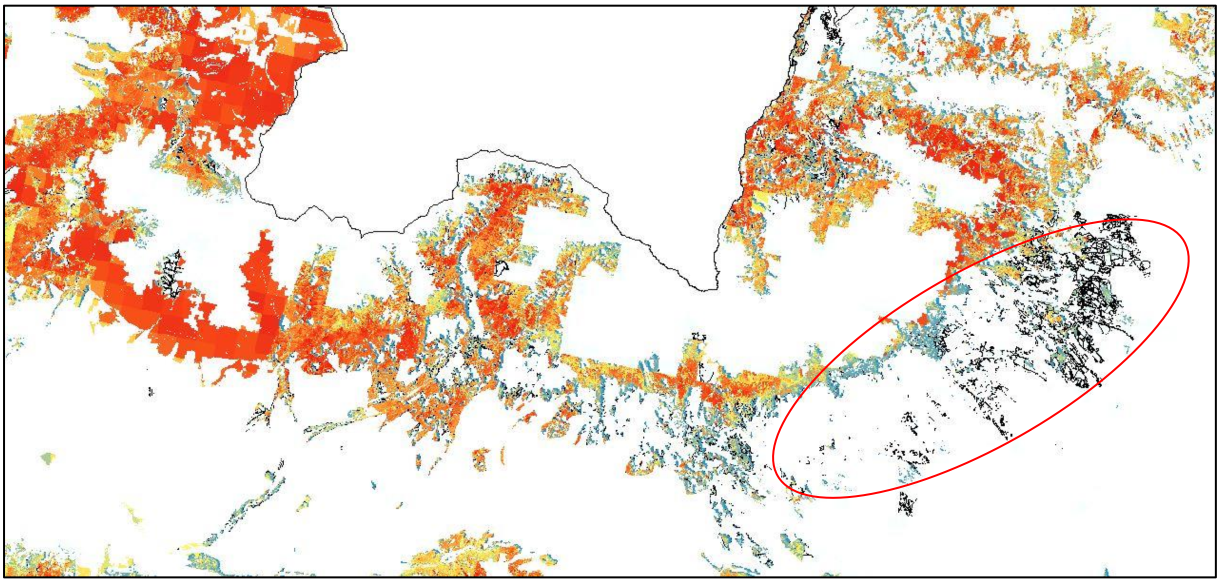
Map 5.3 Modelled distribution (red- high probability; blue – low probability) and occurrence indicated by forest dataset that was not detected by modelling approach (black) for habitat G1.A.

G3.1a Temperate mountain Picea woodland

The AUC value was 0.846, which represents moderate correspondence between the modelled distribution and distribution suggested by the Slovak forest dataset. The modelling predicts larger distribution of this habitat type than the SK forest dataset indicates. There could be different reasons for the difference. The classification for a part of these forests as mixed beech-spruce-fir forests in the SK forest dataset is one of possible reasons of such difference. An incorrect conversion between SK forest types and EUNIS habitat classes could be another one. In this habitat type there is a visible impact of disturbances to the modelling. The forests of the High Tatra Mts. which were severely damaged by the wind storm in 2004 in a very large area. The damaged areas were classified as non-forest in the HRL layer. Therefore they were not included in the modelling - this is visible in the enlarged map (Map 5.14, red circle).



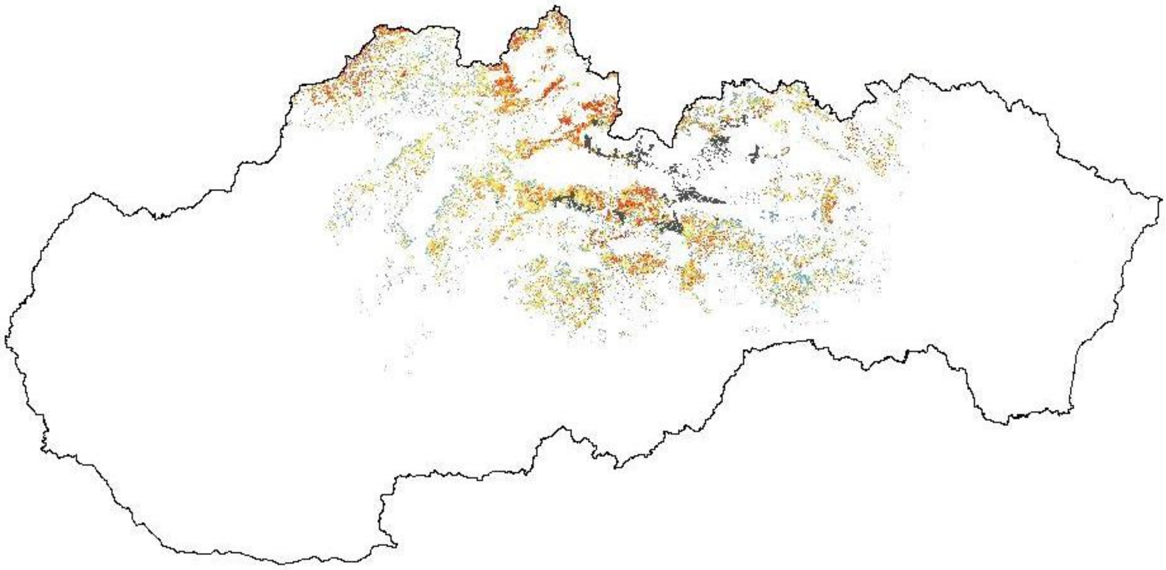
Map 5.13 The habitat occurrence indicated by SK forest dataset and probability map (red- high probability; blue – low probability) for habitat G3.1a.



Map 5.4 The damaged forests in Tatra Mts were not detected as forest (red circle)

G3.1b Temperate mountain Abies woodland

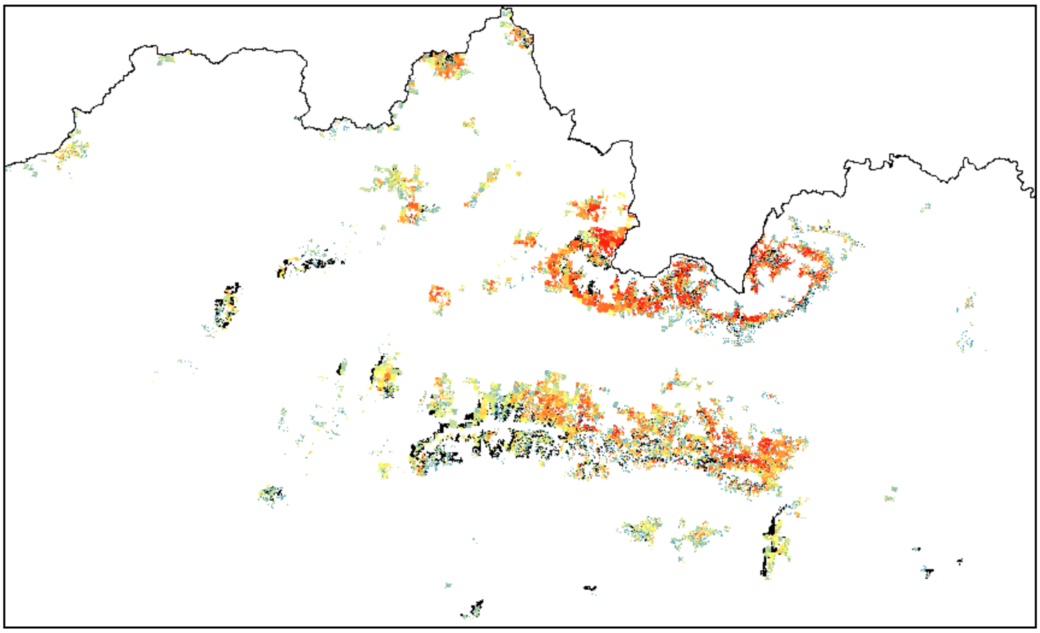
The AUC value was 0.740 which represents moderate correspondence between the modelled distribution and distribution suggested by the Slovak forest dataset. The similar commentary to the correspondence of both datasets as to the previous habitat type could also be applied here. The distribution of fir mountain forests is smaller than the distribution of mountain spruce forests. The fir occurs especially in mixed forests, therefore in the SK forest datasets forests with fir are mostly classified as mixed beech-fir-spruce forests.



Map 5.15 The habitat occurrence indicated by SK forest dataset and probability map (red- high probability; blue – low probability) for habitat G3.1b.

G3.2 Temperate subalpine Larix-Pinus woodland (Alpine [Larix] - [Pinus cembra] woodland)

The AUC value was 0.899, which represents moderate correspondence between the modelled distribution and distribution suggested by the Slovak forest dataset. This is the highest correspondence that we recorded (very close to threshold for the good correspondence). Here the correspondence of both probability map and the SK forest dataset are very good – the probability map captured almost all patches where the habitat type reports the SK forest dataset and indicates very few patches where the SK forest dataset does not indicate the occurrence of the habitat type (Map 5.16). The habitat type is very specific, restricted to a narrow belt of specific climatic conditions. Probably this climate dependency is the main reason of very good correspondence - the climate parameters represent the main variables used in the model.



Map 5.56 Modelled distribution (red- high probability; blue – low probability) and occurrence indicated by forest dataset that was not detected by modelling approach (black) for habitat G3.2.

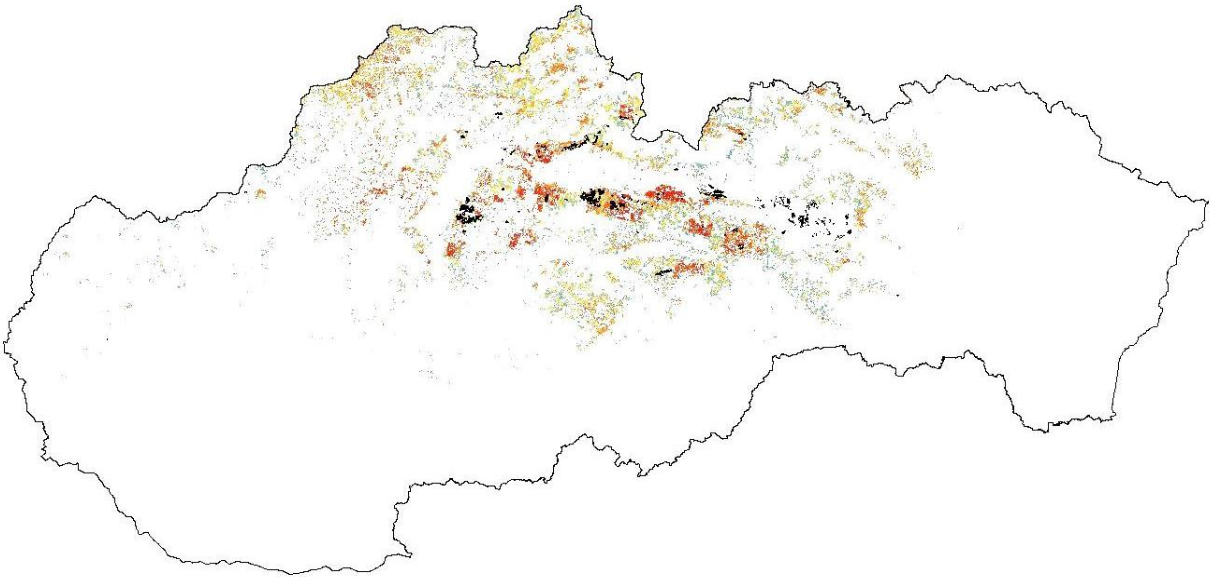
G3.4a Temperate continental *Pinus sylvestris* woodland

The AUC value was 0.661, which represents low correspondence between the modelled distribution and distribution suggested by the Slovak forest dataset. The probability map captured all regions from which the occurrence of this habitat type is indicated in the SK forest dataset, the difference is in abundance and distribution within regions. The main area of this habitat type is in SW Slovakia (Záhorská nížina lowland) and the correspondence between these two datasets in this region is very good, except for the northernmost patch (Gbelský les, 1) where the probability map predicts large occurrence and high probability, while the SK forest dataset indicate only small patch of this habitat type (Map 5.17). The probability map indicates also broader distribution in NW Slovakia (Biele Karpaty Mts., Javorníky, 2) and the western part of East Slovakia (Spiš and surrounding areas, 3) than SK forest dataset in the same region. It is difficult to identify the reason for the difference. It is also questionable if the re-classification of the SK forest types was correct – it is possible that all distribution, except for Záhorská nížina lowland, belong to G3.4b.

Map 5.17 Modelled distribution (red- high probability; blue – low probability) and occurrence indicated by forest dataset that was not detected by modelling approach (black) for habitat G3.4a.

G3.4b Temperate and submediterranean montane *Pinus sylvestris-nigra* woodland

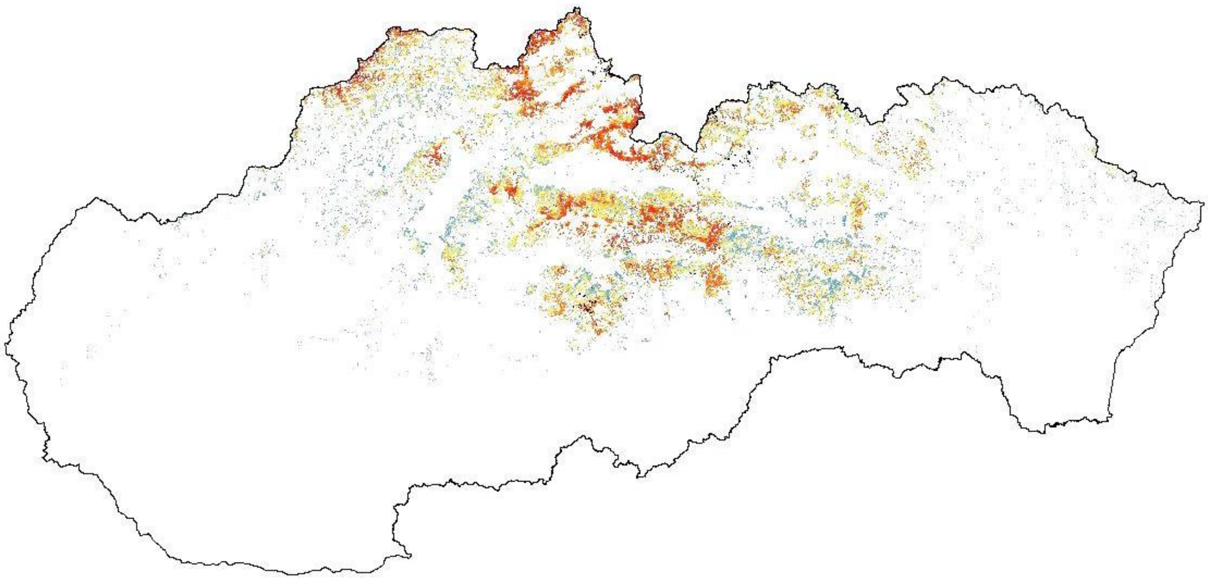
The AUC value was 0.741 which represents moderate correspondence between the modelled distribution and distribution suggested by the Slovak forest dataset. The correspondence between the probability map and the SK forest dataset is not very good – the probability map indicates much broader distribution than the SK forest dataset (Map 5.18). The reason for this difference could lie in the ecological requirement of the dominant species. The pine has a broad ecological amplitude, it can grow in a broad range of environments. However, it has also low competition ability, and it grows especially on places not suitable for other tree species. This could be reason why the modelling based especially on climatic parameters (here more than 99.8 % of climatic variables contribution) results in a broad predicted distribution, broader than actual occurrence of the habitat type.



Map 5.68 Modelled distribution (red- high probability; blue – low probability) and habitat distribution indicated by the SK forest dataset (black) for habitat G3.4b.

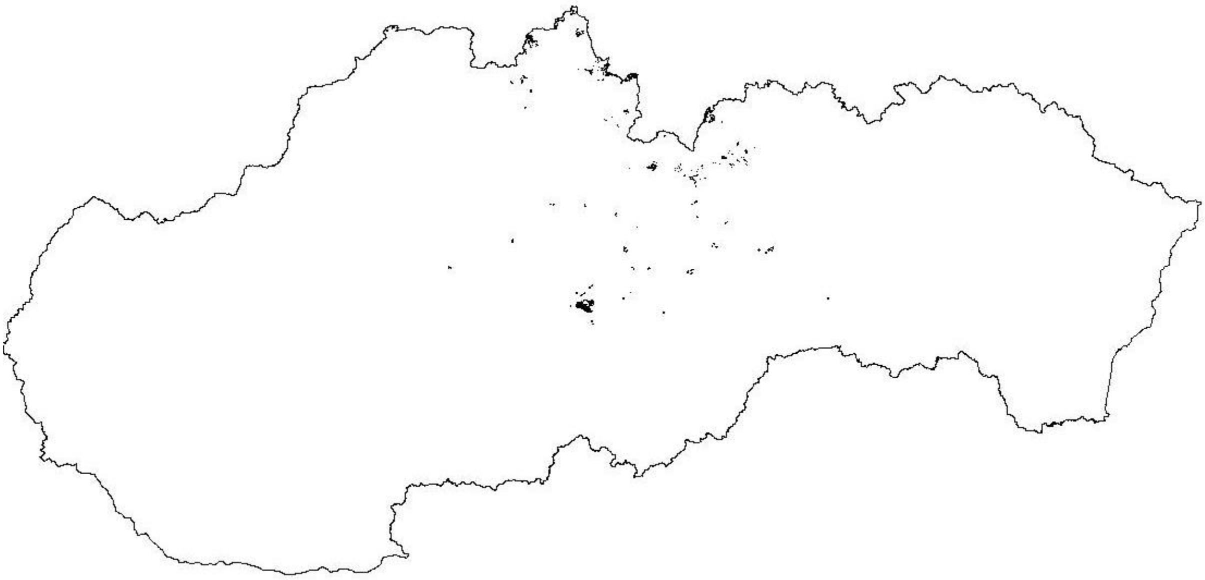
G3.E Temperate bog conifer woodland* [Nemoral bog conifer woodland]

The AUC value was 0.830 which represents moderate correspondence between the modelled distribution and distribution suggested by the Slovak forest dataset. Despite this quite high AUC value, the differences between the probability map and SK forest dataset is considerable. The probability map captured all sites for which the SK forest dataset indicates the habitat type (Map 5.19), but the probability map predicts a much broader distribution and abundance than in the SK forest dataset (see maps). This habitat type is very rare in Slovakia and its distribution mostly corresponds to distribution indicated by the SK forest dataset.



Map 5.19 Modelled distribution (red - high probability; blue – low probability) and occurrence indicated by SK forest dataset (black) for habitat G3.E.

The reason for differences between these two datasets is probably the same as we indicated for G1.4 above, the model does not include the main environmental factor that determine the habitat occurrence, in this case acidic bog soils in sufficient resolution. The soil pH (the only soil parameter used) has very low contribution to the model (1,47%). The use of mostly climatic parameters (here more than 98.4 % contribution to the model) resulted in prediction of broad distribution of the habitat type in climatically suitable regions.

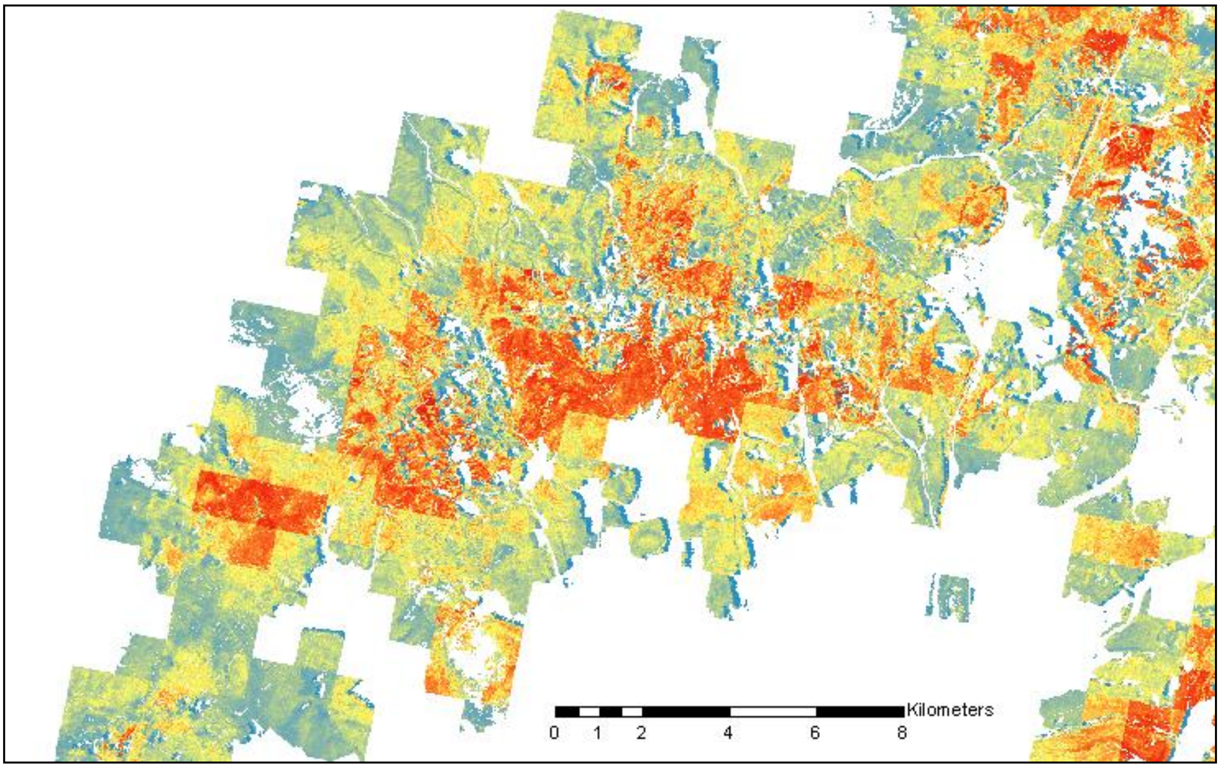


Map 5.70 Distribution of habitat G3.E indicated by SK forest dataset.

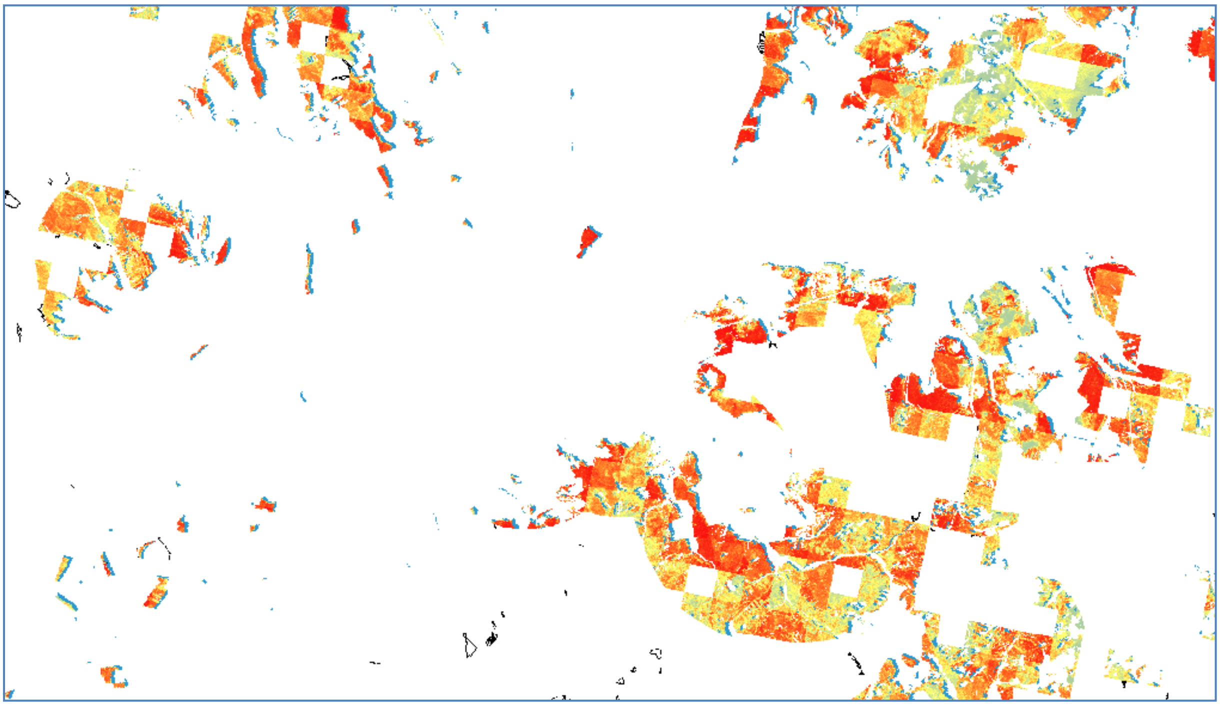
5.4 Discussion

Several factors do affect the performance of the European wide HPM at national scale conditions. In this section the focus is on some of these issues, namely: spatial resolution, selection of predictive variables, crosswalks from one vegetation system to another, and accuracy of HRL forest data set. The spatial resolution of the predictive variables that were used as an input for the suitability modelling significantly influenced the results of several habitat types. The HPM final results are provided at a 20 m spatial resolution that corresponds to the HRL forest layer, while the climatic input parameters with which the modelling started did have a spatial resolution of 1 km. In some cases the 1 km grid is still visible in the probability maps, as it is shown in Maps 5.21 and 5.22 for habitat types G1.6a and G1.2 respectively. As such, the resolution of the probability maps should be considered as 1 km^2 in many places, although the outer boundaries of individual patches have often the fragmented shape of the HRL boundaries. The selection of the input environmental variables is crucial for the final HPM results as well. For the habitat suitability modelling in this report, 7 climate parameters were used, next to one soil parameter, soil pH, and one distance parameter, namely distance to water. This is considered as an unbalanced composition of input parameters with a high overrepresentation of climatic parameters. However, we understand that the selection of environmental parameters for modelling is heavily restricted, due to a lack of consistent environmental data at the EU scale with sufficient spatial resolution. Because the HRL forest data set represents the basic layer for the final habitat probability modelling, its accuracy is important. We found a quite high number of sites where the SK forest dataset reports forest land and forest stands, where the HRL does not identify these as forest. A quick check of some sites showed that these sites represent either clear cuts or young forest stands that probably were present during preparation of HRL. It is possible that also other sources of discrepancies exist. This means that the enhancement of the Copernicus HRLs by the individual member states, as planned by the EEA, is really necessary.

Another source of possible source of errors in the assessment could be mistakes made when re-classifying the forest types of the SK forest dataset to EUNIS habitat types. And finally some habitat types represent a transition between two EUNIS habitat classes.



Map 5.21 The effect of spatial resolution of input data (here climate) to results - G1.6A



Map 5.22 The effect of spatial resolution of input data (here climate) to results - G1.2

In some case, it looks as if the AUC (used in this assessment) does not sufficiently reflect the consistency between the two datasets, and that UAC is not a fully suitable measure for assessing the habitat probability maps based on in-situ data. For example, in several cases we found for a habitat type with a low AUC, a good correspondence between the distribution patterns and vice versa. Another measure than UAC that describes better the spatial configuration and habitat abundance could be beneficial.

5.5 Conclusion

The European wide EUNIS forest habitat probability maps have been assessed in detail with respect to the heterogeneous conditions in Slovakia. At the regional level more detailed environmental maps should be used as is now the case with the existing European abiotic environmental data layers such as the soil map. In cases where the most predictive variables have a sufficient detailed spatial resolution at a European scale, the final probability maps (HPMs) sufficiently describe their spatial distribution even at national scale.

In this chapter, ILE SAS, made an independent assessment for Slovakia and they compared HPM results with national in-situ forest data, originating from field mapping. ILE SAS considers the modelling approach described in the report as correct, well implemented and useful on the EU level. However, when assessing and using the results at a regional scale, the user should be aware that the methodological approach used in this report produces habitat probability maps that are still largely related to the potential vegetation. The actual vegetation often correspond as well to HPM results, but can be also be quite different due to the current forest management applied on the spot.

6 Conclusions and outlook

The objective of this report was to test the use of the EVS (European Vegetation Survey) relevés and Copernicus HRLs for enhancing the spatial delineation of ecosystems. Together with ETC/BD and EEA it was decided to use the EUNIS forest habitats at level 3 as the targeted classes, and to enhance the identification of their spatial distribution. From the existing 37 EUNIS forest habitat types at level 3 we were only able to produce 24 habitat probability maps at a 20 meter spatial resolution for the whole of Europe. This was due to limitations in the availability of vegetation relevés. In general, the vegetation relevés for the Nordic countries are significantly underrepresented. Before this report, the spatial modelling of habitats was very much a top-down approach, based on the refinement of satellite derived land cover information, with the support of additional thematic geographic data layers and ecological soundly based decision rules. However, it would be a mistake to ignore nowadays the wider availability of European vegetation relevés in a bottom-up approach. The methodology that we developed in this report for the modelling of the spatial distribution of EUNIS forest habitat types is inspired by combining the strength of both methods (bottom-up and top-down).

The first methodological step consisted of a bottom-up approach for which the vegetation relevés were classified into the relevant EUNIS habitat classes, and 10 highly relevant environmental data layers were selected, all of which were used as an input in MAXENT statistical modelling, resulting in habitat suitability maps at a 1km spatial resolution. These habitat suitability maps were refined into habitat probability maps based on the actual land cover as derived from the Copernicus high resolution layer (HRL) Forest at a 20 meter spatial detail. Next to the Tree Crown Density (TCD) and Forest Types (FTY: broadleaved and coniferous) from the HRL, we used spatial explicit rules, such as distance to rivers, and tree species maps (TREEMAPS). The final results were 24 forest habitat probability maps at a 20 meter spatial resolution for the whole of Europe, which were assessed in detail for Slovakia based on national forest data and local environmental knowledge. The independent assessment showed that the modelling approach described in the report is correct, well implemented and useful at the EU level. However, the assessment also showed the limitations, namely that due to the actual forest management the actual EUNIS forest habitats are often more limited in their extent, and in that sense the current forest habitat probability maps (HPM) are often showing their potential distribution within the current forests.

And although the Copernicus HRL Forest still needs to be enhanced by most member states, and as such the HRL is still a draft with small spatial and thematic errors, the major limitation considered in the overall methodology is the limited spatial resolution of the abiotic environmental layers such as the European soil database (scale 1: 1M) and the European topographic information on e.g. small rivers, and the lack of in-situ habitat data from the Nordic countries. If these problems are solved the method can be easily applied to other EUNIS habitats and could be used amongst others as an input to improve the wall -to-wall European Ecosystem Map at EUNIS level 2.

Summarising weaknesses and strength of the current method and results:

Strength:

- Forest habitat probability maps (HPMs) have been produced with a high thematic resolution (EUNIS level 3) and spatial resolution (20m).
- The spatial modelling method in this report is based on the phytosociological description of the EUNIS habitat classes, and as such has a sound floristic basis.
- Integration of vegetation relevés and Copernicus HRLs is the strength in the proposed methodology.

Limitations:

- Underrepresentation of vegetation relevés or in-situ habitat data for Nordic countries.
- The abiotic environmental data sets of Europe (e.g. soil) are too poor in spatial and thematic details for fine resolution habitat probability maps.
- Lack of information on land use (forest) management in general.

Opportunities

- If the above mentioned limitations are solved the method can be easily applied to other EUNIS habitats at level 3.
- Possible improvement of the wall-to-wall EUNIS Ecosystem map.
- Direct input of the HPMs at EUNIS level 3 in the assessment of ecosystem services.

References

Gebhard Banko, Michael Weiss, Dietmar Moser, Raquel Ubach, Dania Abdul Malak, Lubos Halada, Gerbert Roerink, Gerard Hazeu, Sander Mucher, Stephan Hennekens, Joop Schaminée, Lukas Brodsky, 2013. *Developing Conceptual Framework For Ecosystem Mapping*. EEA Draft Report.

Berger, A.L., Pietra, S.A.D., & Pietra, V.J.D., 1996. A maximum entropy approach to natural language processing. Computational Linguistics, 22, 39–71.

Bruelheide, H., 1997. Using formal logic to classify vegetation. Folia Geobotanica et Phytotaxonomica 32: 41–46.

Braun-Blanquet, J., 1928. Pflanzensoziologie. Grundzüge der Vegetationskunde. Springer-Verlag, Berlin.

Brus, D. J., Hengeveld, G. M., Walvoort, D. J. J., Goedhart, P. W., Heidema, A. H., Nabuurs, G. J., & Gunia, K. (2012). Statistical mapping of tree species over europe. *European Journal of Forest Research*, *131*(1), 145-157.

Büttner, G., Feranec, J., Jaffrain, G., Mari, L., Maucha, G. & Soukup, T. 2004. The CORINE Land Cover 2000 Project. in R. Reuter, (Editor). EARSeL eProceedings, 3, (3). EARSeL0, Paris, pp. 331-346.

Bossard, M., Feranec, J., Oťaheľ, J., 2000. CORINE land cover technical guide – Addendum 2000. Technical report, 40. European Environment Agency, Copenhagen. http://terrestrial.eionet.eea.int.

Chytrý, M., Pyšek, P., Tichý, L., Knollová, I. & Danihelka, J., 2005. Invasions by alien plants in the Czech Republic: a quantitative assessment across habitats. Preslia 77: 339–354.

Clerici, N., Weissteiner, C.J., Halabuk, A. , Hazeu, G., Roerink, G., Mücher, C.A., 2012. Phenology related measures and indicators at varying spatial scales. Investigation of phenology information for habitat classification using SPOT VGT and MODIS NDVI data. Edited by C.A. Mücher. Alterra Report 2259, Alterra, part of Wageningen UR, Wageningen, 2012.

Commission of the European Communities, 1994. CORINE land cover. Technical guide. Office for Official Publications of European Communities, Luxembourg.

Davies C.E, Moss, D., Hill, M., 2004. EUNIS Habitat Classification Revised 2004. Available from http://eunis.eea.europa.eu/upload/EUNIS2004_ report.pdf.

Dengler, J., Jansen F., Glöckler F., Peet R.K., De Cáceres M., Chytrý M., Ewald J., Oldeland J., Lopez-Gonzalez G., Finckh M., Mucina L., Rodwell J.S., Schaminée J.H.J., & Spencer N. 2011. The Global Index of Vegetation-Plot Databases (GIVD): a new resource for vegetation science. Journal of Vegetation Science 22: 582–597.

Elith, J., Phillips, S., Hastie, T., Dudík, M., En Chee, Y.,Yates, C., 2011. A statistical explanation of MaxEnt for ecologists. Divers. Distrib. 17: 43–57.

Evans, D., 2006. "The habitats of the European union habitats directive." Proceedings of the Royal Irish Academy - Section B, Biol. Environ. 106 (3): 167-173.

European Commission, 2013. Interpretation Manual of European Union habitats – EUR28. European Commission DG Environment, Brussels, 146 pp.

Fischer, H.S., 2015. On the combination of species cover values from different vegetation layers. Applied Vegetation Science 18: 169–170.

Hennekens, S. M., Schaminée, J.H.J., 2001. TURBOVEG, a comprehensive data base management system for vegetation data. Journal of Vegetation Science 12: 589–591.

Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978.

Maes J., et al., 2013. Mapping and Assessment of Ecosystems and their Services. An analytical framework for ecosystem assessments under action 5 of the EU biodiversity strategy to 2020. Publications office of the European Union, Luxembourg.

Moss, D., 2008. EUNIS Habitat Classification – a guide for users. Paris: European Topic Centre on Biological Diversity. European Environment Agency, Copenhagen.

Mücher, C.A., S.M. Hennekens, R.G.H. Bunce and J.H.J. Schaminée, 2004. Mapping European Habitats to support the design and implementation of a Pan-European Ecological Network. The PEENHAB project. Alterra report 952, Wageningen.

Mücher, C.A., S.M. Hennekens, R.G.H. Bunce and J.H.J. Schaminée, 2005. Spatial indentification of European habitats to support the design and implementation of a Pan-European Ecological Network. In: Planning, People and Practice. The landscape ecology of sustainable landscapes. Proceeding of the 13th Annual IALE(UK) Conference, held at the University of Northampton, 2005 (Edited by Duncan McCollin and Janet I. Jackson). Pages 217-225.

Mücher, C.A., Hennekens, S.M., Bunce, R.G.H., Schaminée, J.H.J., Schaepman, M.E., 2009. Modelling the spatial distribution of Natura 2000 habitats across Europe. Landscape Urban Plan. 92 (2), 148-159.

Mücher, C.A., 2009. Geo-spatial modelling and monitoring of European landscapes and habitats using remote sensing and field surveys. PhD thesis Wageningen University, Wageningen, The Netherlands, ISBN 978-90-8585-453-1, 269 pp.

Mucina, L., Bültmann, H., Dierßen, K., Theurillat, J-P., Raus, T., Čarni, A., Šumberová, K., Willner, W., Dengler, D., Gavilán García, R., Chytrý, M., Hájek, M., Di Pietro, R., Iakushenko, D., Pallas, J., Daniëls, F.A.J., Bergmeier, E., Santos Guerra, A., Ermakov, N., Valachovič, M., Schaminée, J.H.J., Lysenko, T., Didukh, Y.P., Pignatti, S., Rodwell, J.S., Capelo, J., Weber, H.E., Solomeshch, A., Dimopoulos, P., Aguiar, C., Freitag, H., Hennekens, S.M., & Tichý, L. Vegetation of Europe: Hierarchical floristic classification system of vascular plant, bryophyte, lichen, and algal communities. Journal of Applied Ecology 2015 (in prep.).

Phillips, S.J., R.P. Anderson & R.E. Schapire, 2006. Maximum entropy modelling of species geographic distributions. Ecological Modelling 190: 231–259.

Rodwell, J.S., Schaminée, J.H.J., Mucina L., Pignatti, S., Dring, J., & Moss, D., 2002. The Diversity of European Vegetation. An overview of phytosociological alliances and their relationships to EUNIS habitats. EC-LNV, Wageningen.

Roerink, G.J., Menenti, M., Verhoef, W., 2000. Reconstructing cloudfree NDVI composites using Fourier analysis of time series. Int. J. Remote Sensing, Vol. 21, No. 9: 1911-1917.

Roerink, G.J.; Menenti, M.; Soepboer, W.; Su, Z., 2003. Assessment of climate impact on vegetation dynamics by using remote sensing. Physics and Chemistry of the Earth 28 (2003). - ISSN 1474-7065 - p. 103 - 109.

Schaminée, J.H.J., Hennekens, S.M., Ozinga, W.A., 2007. Use of the ecological information system SynBioSys for the analysis of large databases. Journal of Vegetation Science 18: 463–470.

Schaminée J.H.J., Hennekens S.M., Chytrý M., Rodwell, J.S., 2009. Vegetation-plot data and databases in Europe: an overview. Preslia 81: 173–185.

Schaminée, J.H.J., Chytrý, M, Hennekens, S.M., Jiménez-Alfaro, B. Mucina, L., Rodwell, J.S., Tichý, L., 2013. Review of EUNIS forest habitat classification. Report for the European Environmental Agency, Copenhagen.

Schaminée, J.H.J., Chytrý, M, Hennekens, S.M., Jiménez-Alfaro, B., Knollova, I., Mucina, L., Rodwell, J.S., & Tichý, L., 2015.Vegetation analysis and distribution maps for EUNIS habitats – Task 1 & 2. Report EEA/NSV/14/006.

Sokal, R.R., Rohlf, F.J., 1995. Biometry. 3rd ed. Freeman, New York, NY.

Tichý, L., 2002. JUICE, software for vegetation classification. Journal of Vegetation Science 13: 451–453.

Tichý, L., & Chytrý, M., 2006. Statistical determination of diagnostic species for site groups of unequal size. Journal of Vegetation Science 17: 809–818.

Annex 1 The results: the EUNIS forest habitat probability maps

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