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Indicators of biodiversity in agroecosystems: insights from Article 17 of the Habitats Directive and IUCN Red List of Threatened Species

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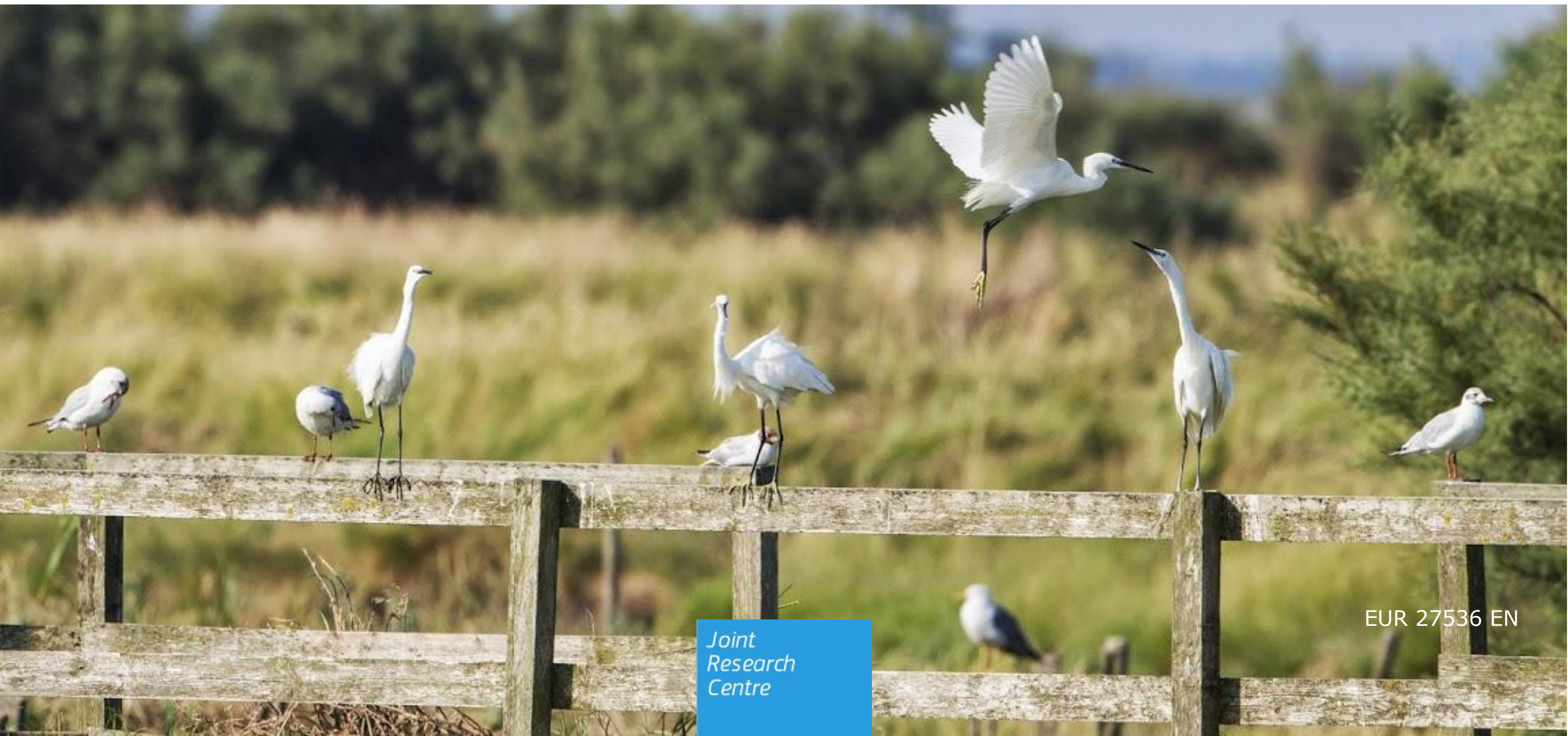

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Table of contents

Abstract

In the current decade, the main goals for biodiversity conservation and environmental protection at the level of the European Union are set in the EU Biodiversity Strategy to 2020: halting biodiversity loss and restoring ecosystem services. A key requirement for the implementation of the Strategy in terms of targeting measures and funds, and monitoring trends is the construction of a biodiversity knowledge base, including spatially explicit information on biodiversity distribution and ecosystem condition. The work presented in this report is based on the analysis of two primary datasets on biodiversity and habitat status. The first one is the Habitats assessment carried out by EU Members States under Art.17 of the Habitats and Birds Directive. Information reported by Member States is analysed to derive the links between pressures and conservation status, showing that agriculture-related habitats have, on average, a worse conservation status when compared to other habitats. Consequently, threats and pressures having most influenced the status of the agricultural-related habitats can be identified. The second one is the global dataset on species threat status elaborated by The International Union for Conservation of Nature (IUCN). Spatially explicit representations of species distribution, status and richness across the EU 28 are provided, and most importantly the identification of wide geographic variables linked to ecological theory is presented, that explain to a large extent the continental trend in species richness. Finally, an example is presented of how the two exploited datasets can be jointly used by cross-tabulating data on habitats assessments and species threat status in a spatially explicit way at 10 km resolution, aiming at identifying hotspots were policy intervention is needed.

1. Introduction

Europe is facing unprecedented global challenges as delineated in the Europe 2020 Strategy: a severe and prolonged economic crisis, ageing population and increasing pressures on natural resources. In response, the Strategy sets three mutually reinforcing priorities – smart, sustainable and inclusive growth, pointing to a greener and more resource efficient economy as a key objective. The flagship initiative "Resource efficient Europe" aims to decouple economic growth from the use of resources, support the shift towards a low carbon economy, increase the use of renewable energy sources, modernise the transport sector and promote energy efficiency. (EC, 2010).

Within this frame, biodiversity loss and habitat degradation are acknowledged as the most critical global environmental threat alongside climate change —the two being closely interlinked (Parmesan, 2006; Bellard et al. 2012). Biodiversity and habitats functions underpin our economy and wellbeing: their loss would imply huge costs to human societies. Biodiversity is essential to maintain ecosystems' functionality, which in turn is key for the delivery of the wide array of benefits they supply to humankind: food, fuel, pollution mitigation, climate regulation, protection from natural disaster, leisure and recreation, just to mention the main ones.

The European Union and Members States have committed to several ambitious and important projects for biodiversity conservation and environmental protection (e.g. Natura 2000 network, environmental payments under the Common Agriculture Policy). Some of the main objectives are resumed within the EU Biodiversity Strategy to 2020 (EC, 2011), which sets the goal to halt biodiversity loss and restore ecosystem services by the end of the current decade. The Biodiversity Strategy is an integral part of Europe 2020 Strategy, and in particular the resource efficient Europe flagship initiative. It is articulated in six main targets aiming at protecting and restoring biodiversity and associated ecosystem services (Targets 1 and 2), enhancing the positive contribution of agriculture and forestry and reducing key pressures on EU biodiversity (Targets 3, 4 and 5), and stepping up the EU's contribution to global biodiversity (Target 6).

Building on the biodiversity knowledge base is acknowledged in the Biodiversity Strategy as a key requirement for its implementation, and the European Commission committed to develop an integrated framework for monitoring, assessing and reporting on that. The Strategy also clearly acknowledges that the achievement of established targets will depend on the availability and efficient use of financial resources, which in turn implies a better uptake and distribution of existing funds for biodiversity, as well as more concentrated efforts (EC, 2011, section 4.2).

To this end, the availability of spatially explicit information highlighting both wide ongoing trend and areas with particular conditions is key to target measures, funding, and enhancing the effectiveness of policy design, implementation and evaluation. This needs, among many other things, to be based on consistent datasets on biodiversity, which should be integrated with data on drivers of habitat change and pressures on biodiversity in modelling efforts, but also suitable for quick mapping, and easy to use to provide biodiversity trends to policy makers and the wide public. In this report, we try to make a contribution in this direction by presenting elaborations and analyses based on two primary datasets on biodiversity and habitat status: the first one is the Habitats assessment carried out by EU Members States under the Habitats and Birds Directive. The second one is the global dataset on species threat status elaborated by The International Union for Conservation of Nature (IUCN).

Directives 79/409/EEC and 92/43/EEC, known respectively as the "Birds" and "Habitats" Directives, form the basis of the European Union nature and biodiversity policy. They aim to guarantee the preservation of Europe's most valuable and threatened species and habitats through the establishment of an EU-wide network of nature protection areas known as Natura 2000. They thus underpin the whole Biodiversity Strategy which, in turn, establishes under target 1 that their full implementation is critical to prevent further biodiversity loss in the EU.

Article 11 of the Habitats Directive requires Member States to undertake surveillance of the conservation status of the natural habitats and species listed in the Directive. This provision doesn't concern only Natura 2000 areas as information needs to be collected on the whole EU territory to achieve an overall assessment of habitats and species. Overall, the Directive covers 231 habitats (Annex I) and 1,875 species (Annexes II, IV, V). Article 17 requires Member States to report every six years about the progress made with the implementation of conservation measures and the main results of monitoring activities pursuant Article 11. In particular, the report shall provide information on the conservation status of habitats and species in absolute terms and in comparison with previous periods.

The first report was released in 2000 and focused on implementation of the Directive; the second one was issued in 2007 and covered the period 2001-2006. It focused on the conservation status of habitats and species, based on a guidance document aimed to ensure as much as possible harmonised data collection between Member States. The evaluation of this second report brought out the need to improve the guidance and the report format for the next report, covering the period 2007-2012. Therefore, new guidelines have been elaborated by the European Topic Centre on Biological Diversity (Evans and Arvela, 2011) to provide for a standard methodology for data collection and reporting.

The third report was released in May 2015[1], based on the Technical Report elaborated by the European Environmental Agency (EEA, 2015) and, as the previous one, focuses on the assessment of conservation status of relevant habitat types and species. In addition to an overview on species and habitats status, both at national and EU levels, it provides separate analyses per main ecosystem types and examines the status of the Natura 2000 network and its contribution to species and habitats. Finally, it reports on progress towards the achievement of Targets 1 and 3 of the EU Biodiversity Strategy. Overall, results indicate a slight progresses in species conservation status and non-significant progress in habitat conservation status, meaning that unless significant improvements of current trend occur in the next few years, targets 1 and 3 of the Biodiversity Strategy will not be reached. This is also confirmed by the mid-term evaluation of the Biodiversity Strategy (EC, 2015), which adds that also progress towards Targets 2 and 4 are currently occurring at an insufficient rate for the targets to be reached by 2020.

The International Union for Conservation of Nature (IUCN) is an international non-governmental organisation (NGO) active in nature conservation and in providing governments and other NGO with scientific evidence and advice on global challenges on environmental, food and development issues. Within it, the IUCN Global Species Programme elaborates, maintains and periodically updates the IUCN Red List of Threatened Species (IUCN, 2014), a comprehensive compendium of information of the conservation status of more than 73,000 fungi, plants and animal species. The list was initially developed to assess the extinction risk to species, but currently, despite its name, provides a comprehensive database of conservation status of a wide array of species, not limited to the most endangered ones. The list is now being used for a variety of purposes, including conservation planning, environmental impact assessment, policy and management, prioritizing sites for conservation, biodiversity evaluation, and monitoring (Wuczyński et al, 2014; Rodrigues et al. 2006; Hoffmann et al. 2008). IUCN data are capable to meet conservation policy needs at EU level, while providing a consistent, large-scale dataset for scientific investigation at the same time.

Taken together, the Art. 17 assessments and IUCN data represent two powerful and comprehensive datasets that can be exploited for deriving information at continental scale, which can contribute to the knowledge base called for by the Biodiversity Strategy. The purpose of this study is mainly exploratory: it does not aim to provide an ultimate indicator for biodiversity, but to show the potentialities of resorting to the more recent datasets in providing elaborations to inform policy making, implementation and monitoring. This is

[1] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2015:219:FIN

done by carrying out and some in-depth analyses on habitat status and species status across Europe with a focus on the spatial dimensions.

In particular:

- in Section 2 we present a spatially explicit assessment at a 10 km x 10 km spatial resolution of all terrestrial habitats conservation status based on Art. 17 data and a comparison with a subset of agricultural-related habitats. We then investigate which are the main pressure and threats likely to affect conservation status through statistical elaborations.
- In Section 3 we turn to IUCN data on species and present some spatially explicit elaborations on species richness, distribution and number per location (occupancy analysis). We processed original data to derive and map several indicators on species threat status and its spatial distribution across Europe. An insight on species richness is presented (detailed in Annex 2), featuring the identification of wide geographic trends acting at the continental scale and the development of an empirical model able to describe them and to de-trend the absolute data to gain a better understanding of underlying process possibly related to human activities.
- In Section 4, we combine Art. 17 and IUCN data to identify, again in a spatially explicit way, areas in different situations as regards the combination of habitat conservation status and (global) species threat status.
- In Section 5 we draw the main conclusions and points to possible research developments.

2. Analysis based on Article 17 habitats assessment

2.1 Data from Art.17 reporting on habitats and species: characteristics and limitations

In the frame of Art. 17 assessment, habitats conservation status is classified as either 'Favourable' (FV), 'Unfavourable-inadequate' (U1) and 'Unfavourable-bad' (U2). 'Favourable Conservation Status' is defined in the Directive as a situation where the habitat or species is prospering (in both quality and extent/population) and this trend is expected to continue in the future. 'Unfavourable-Inadequate' describes a situation where a change in management or policy is required to return the habitat/species to favourable status but there is no danger of extinction in the foreseeable future; 'Unfavourable-Bad' is for habitats or species in serious danger of becoming extinct, at least regionally. The whole Europe is subdivided in nine different Biogeographical Regions each with specific characteristics with regard to climate, vegetation and geology. If a same habitat in a Members State is found in two or more biogeographical regions, separate assessments are required for each of them.

The assessment is based on four parameters: as for habitats: i) range, ii) area, iii) structure and functions, iv) future prospects; as for species: i) range, ii) population, iii) habitat of species, iv) future prospects. In case of high uncertainty or lack of data, the conservation status may be classified as 'Unknown'. For both habitats and species, the assessment is firstly carried out for each of the four parameters. Subsequently, these are combined to obtain the overall assessment, according to the following rule: all parameters need to be assessed as "Favourable" for the conclusive assessment to be "Favourable"; if one or more parameters are assessed as Unfavourable-bad' (U2), the overall assessment will be Unfavourable-bad; for any other combination the assessment will be 'Unfavourable-inadequate' (U1)

Qualifiers '+' (plus), '=' (stable) or '-' (minus) are added to an assessment of Conservation Status' (or parameter) to indicate 'improving', 'stable' or 'declining'. For example 'U1+' means 'Unfavourable-Inadequate but improving' while 'U2=' indicates 'Unfavourable-Bad but stable'. The assessment for range, population (species), and area (habitat) is based on the comparison with an established threshold value referred to as 'Favourable Reference Values', calculated by taking into account the habitat/species historic distribution, natural variation, potential distribution and ongoing dynamics.

Beyond status, Member States should also provide information on main pressures and threats affecting habitats and species. Pressures are factors acting now or that have been acting during the reporting period, while threats are factors expected to act in the future. For the 2007-2012 assessment, a revised list of pressures and threats was provided in the aforementioned guidance. The relative importance of pressures and threats is assessed using a three categories scale: high, medium or low importance/impact. The maximum number of pressures/threats to be reported is 20, of which maximum 5 can be classified as "High Importance".

Member States must provide information on distribution and range in an spatially explicit way using the standard 10 x 10 km ETRS grid, projection ETRS LAEA 5210 , elaborated by the European Environmental Agency following the INSPIRE Directive's specifications. The minimum spatial resolution of data is therefore 10 km; nevertheless Member States may also submit additional and more detailed maps, which must be accompanied by the relevant metadata and details of the projection used. All national assessments are collected by the European Topic Centre on Biological Diversity and then made available in a single dataset containing 5804 habitats assessments covering the EU27 (all EU Member States except Croatia). Each assessment is identified as a single polygon made up of all the 10 km cells where the habitats are found within a Member State and a single Biogeographic region. Figure 1 shows the European biogeographic regions (left) and an example of this data, namely the spatial distribution and final assessment of habitat 6210

"Semi-natural dry grasslands and scrubland facies on calcareous substrates" (Festuco-Brometalia) (right).

Currently, such data represent the most up-to-date and detailed information on conservation status of habitats and species at the EU level. Their main limitation concerns the difference of quality across Member States. A great effort has been made towards the harmonisation of data with the issue of the 2011 guidelines, based on the experience gained during the previous assessment period. Therefore, it may be expected that significant improvements have been achieved with respect to the shortcomings highlighted for example by Maes (2013) in relation to the 2000-2006 assessment, concerning data quality, spatial detail of the assessment and differences between Member States.

However, as said before, the assessment for habitat ranges and area is made by comparing current values with Favourable Reference Values, in turn determined by Member States by taking into account a plurality of factors such as current and potential extent, historic range and causes of variation, requirements of typical species (including gene flow). As stated in the same guidelines, whilst for some habitats/species there is enough information, for many others it is not easy to establish such values based on current knowledge. In these cases, the only option is to resort to 'expert judgement'. Therefore, it is likely that the heterogeneity in the background data, previous researches and studies across Europe, as well as differences in specific methodologies used to carry out the assessment, all represent data quality issues to be considered.

A final consideration in the context of this study regards the concept of 'Conservation Status' and its link with the IUCN data. Although they have similar aims and rationale, the main difference is that while Red Lists assess the distance from extinction, the three conservation status categories under the Article 17 report aim at assessing the distance from a defined favourable situation (Evans and Arvela, 2011).

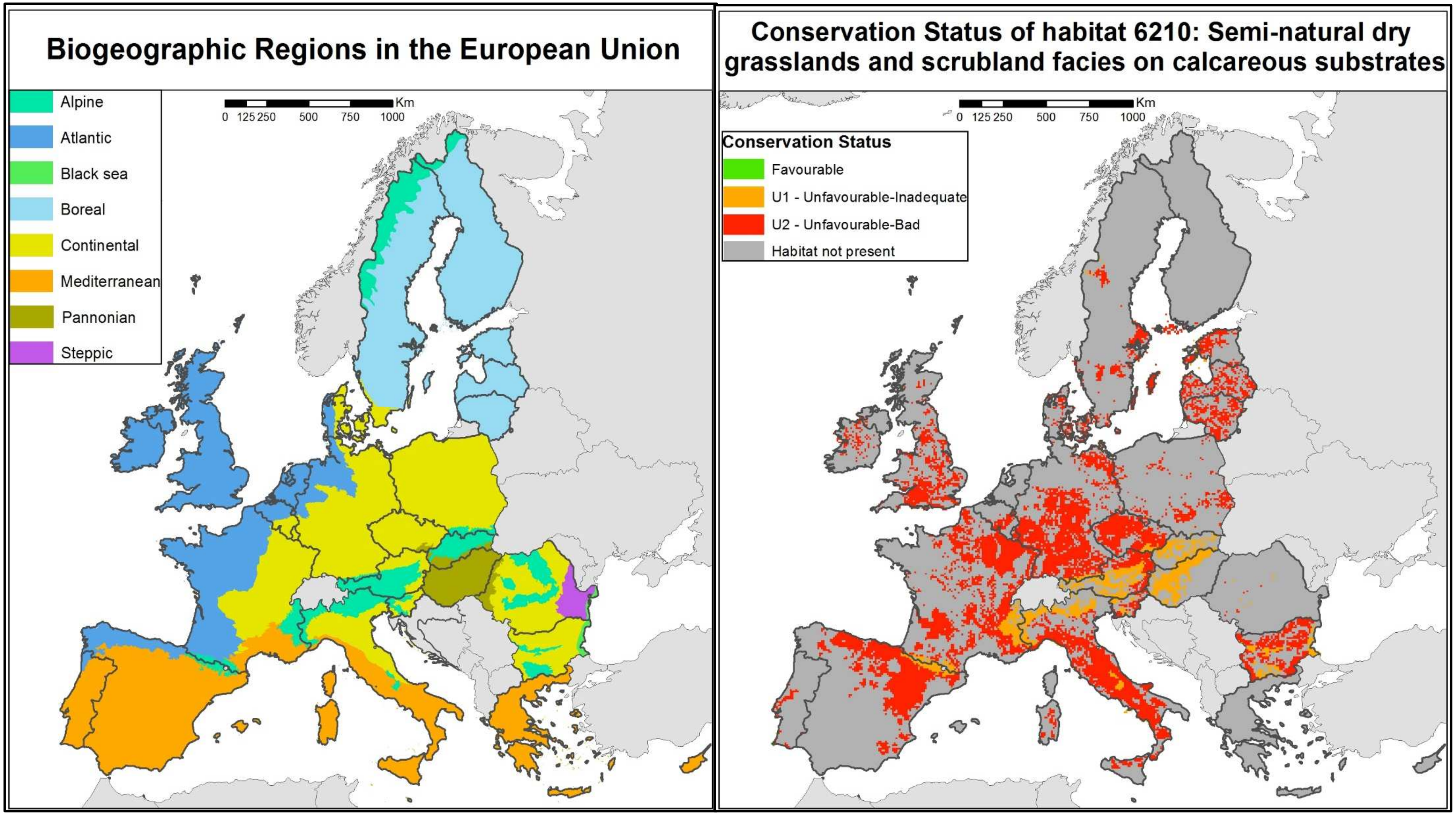


Figure 1 Left: Biogeographical Regions in Continental Europe. Right: Spatial distribution and reported Conservation Status of habitat 6210

2.2 Overview of terrestrial status and agricultural-related habitats' conservation status

In this section, we provide an overview of Habitats conservation status with a focus on habitats related to agricultural practices. These appear particularly important since Target 3 of the Biodiversity strategy specifically envisages that by 2020 "a measurable improvement in the conservation status of species and habitats that depend on or are affected by agriculture" is brought about. Several habitats listed in Annex I of Habitats Directive in fact depend on agricultural management and are associated, in particular, to low-intensive farming. A first identification of such habitats was carried out by Ostermann (1998) who analysed the 198 habitat types then listed on Annex I and identified 28 habitat types "whose Favourable Conservation Status is likely to be threatened by the abandonment of rural practices". Following the changes to Annex I of the Directive and the EU enlargement, a later study by Halada et al (2011) revised the original list and provided a new list of habitats whose conservation is fully or partly dependent on agricultural management.

The identified habitats meet one of the following criteria:

- their existence depends on the continuation of appropriate agricultural activities;
- their existence is maintained or spatially enlarged by agricultural activities which block or reduce secondary succession;
- the habitat type contains both natural and semi-natural habitats, the second ones requiring agricultural management for their existence.

The application of these criteria resulted in the identification of 63 habitat types of European importance that depend on agricultural activities or can profit from them. The authors distinguish between habitats types "fully" and "partly" depending on agricultural management.

The first group contains semi-natural habitats established under regular, usually low-intensity, agricultural management. These habitats are the results of many decades or centuries of mutual adaptation between site conditions and type and intensity of human management. Both cessation of or significant changes in the management would alter habitat structure and species composition leading to a change to other habitat types. This group contains 23 habitat types, mainly meadows and pastures (16 habitat types), followed by heath and scrubs (4 habitats types), sand dunes (2 types) and forests (1 type).

The second group comprises habitats that profit from agricultural management measures because they either prolong the existence of the habitat, usually by blocking/reducing secondary succession, or enlarge/maintain an enlarged area of habitat distribution. A typical example is cessation of grazing that would lead to a transition from meadows to a shrub- or woodland habitat type. This group is made of 40 habitat types. Hereinafter, we refer to the whole set of 63 habitat types identified by Halada et al (2011) as 'agriculture-related habitats'; the full list of such habitats is provided in Table 2 below.

Table 1 List of agriculture-related habitats in Europe. Source: Halada et al, 2011

Code	Habitats name	Code	Habitats name
1330	Atlantic salt meadows (Glauco-Puccinellietalia maritimae)	2330	Inland dunes with open *Corynephorus* and *Agrostis* grasslands
1340	Inland salt meadows	2340	Pannonic inland dunes
1530	Pannonic salt steppes and salt marshes	4010	Northern Atlantic wet heaths with *Erica tetralix*
1630	Boreal Baltic coastal meadows	4020	Temperate Atlantic wet heaths with *Erica ciliaris* and *Erica tetralix*
2130	Fixed coastal dunes with herbaceous vegetation (grey dunes)	4030	European dry heaths
2140	Decalcified fixed dunes with *Empetrum nigrum*	4040	Dry Atlantic coastal heaths with Erica vagans
2150	Atlantic decalcified fixed dunes (*Calluno-Ulicetea*)	4060	Alpine and Boreal heaths
2160	Dunes with Hippophaë rhamnoides	4090	Endemic oro-Mediterranean heaths with gorse
2170	Dunes with *Salix repens* ssp. *argentea (Salicion arenariae*)	5120	Mountain *Cytisus purgans* formations
2190	Humid dune slacks	5130	*Juniperus communis* formations on heaths or calcareous grasslands
21A0	Machairs	5210	Arborescent matorral with *Juniperus* spp.
2250	Coastal dunes with *Juniperus* spp.	5330	Thermo-Mediterranean and pre-desert scrub
2310	Dry sandy heaths with *Calluna* and *Genista*	5420	Sarcopoterium spinosum phryganas
2320	Dry sandy heaths with *Calluna* and *Empetrum nigrum*	5430	Endemic phryganas of the Euphorbio-Verbascion
6110	Rupicolous calcareous or basophilic grasslands of the *Alysso-Sedion albi*	62D0	Oro-Moesian acidophilous grasslands
6120	Xeric sand calcareous grasslands	6310	Dehesas with evergreen Quercus spp.
6140	Siliceous Pyrenean *Festuca eskia* grasslands	6410	*Molinia* meadows on calcareous, peaty or clayey-silt-laden soils (*Molinion caeruleae*)
6150	Siliceous alpine and boreal grasslands	6420	Mediterranean tall humid herb grasslands of the *Molinio-Holoschoenion*
6160	Oro-Iberian Festuca indigesta grasslands	6430	Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels

Code	Habitats name	Code	Habitats name
6170	Alpine and subalpine calcareous grasslands	6440	Alluvial meadows of river valleys of the Cnidion dubii
6180	Macaronesian mesophile grasslands	6450	Northern boreal alluvial meadows
6190	Rupicolous pannonic grasslands (Stipo-Festucetalia pallentis)	6510	Lowland hay meadows (Alopecurus pratensis, Sanguisorba officinalis)
6210	Semi-natural dry grasslands and scrubland facies on calcareous substrates (Festuco-Brometalia)	6520	Mountain hay meadows
6220	Pseudo-steppe with grasses and annuals of the Thero-Brachypodietea	6530	Fennoscandian wooded meadows
6230	Species-rich Nardus grasslands, on siliceous substrates in mountain areas (and sub-mountain areas, in continental Europe)	7140	Transition mires and quaking bogs
6240	Sub-pannonic steppic grassland	7150	Depressions on peat substrates of the Rhynchosporion
6250	Pannonic loess steppic grasslands	7210	Calcareous fens with Cladium mariscus and species of the Caricion davallianae
6260	Pannonic sand steppes	7230	Alkaline fens
6270	Fennoscandian lowland species-rich dry to mesic grasslands	8230	Siliceous rock with pioneer vegetation of the Sedo-Scleranthion or of the Sedo albi-Veronicion dillenii
6280	Nordic alvar and precambrian calcareous flatrocks	8240	Limestone pavements
62A0	Eastern sub-Mediterranean dry grasslands (Scorzoneratalia villosae)	9070	Fennoscandian wooded pastures
62C0	Ponto-Sarmatic steppes		

Figure 2 below depicts the spatial coverage of the assessment of agricultural-related habitats carried out by Member States during the 2007-2012 period, showing that these habitats are spread across all Member States and biogeographic regions (green area).

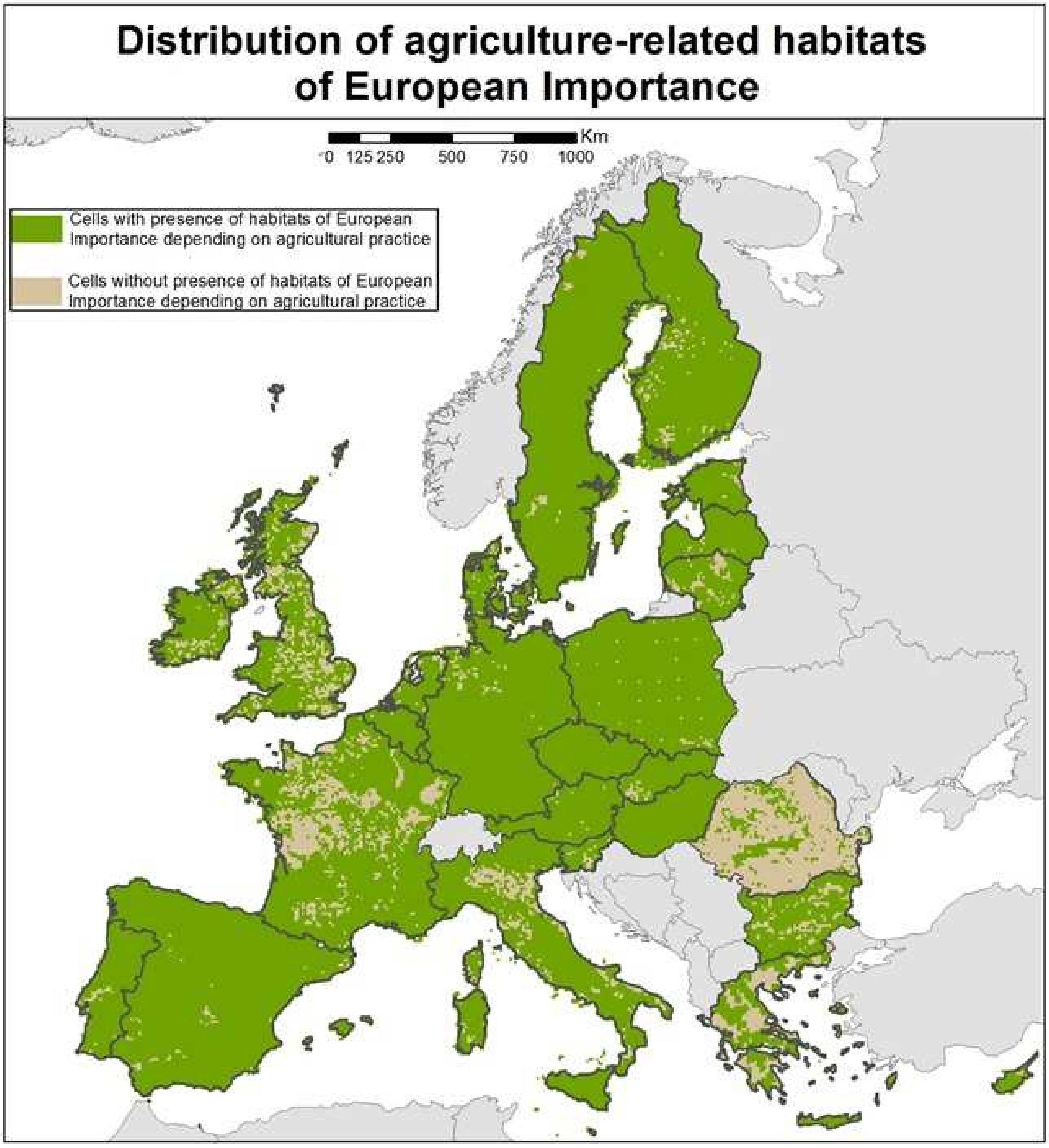
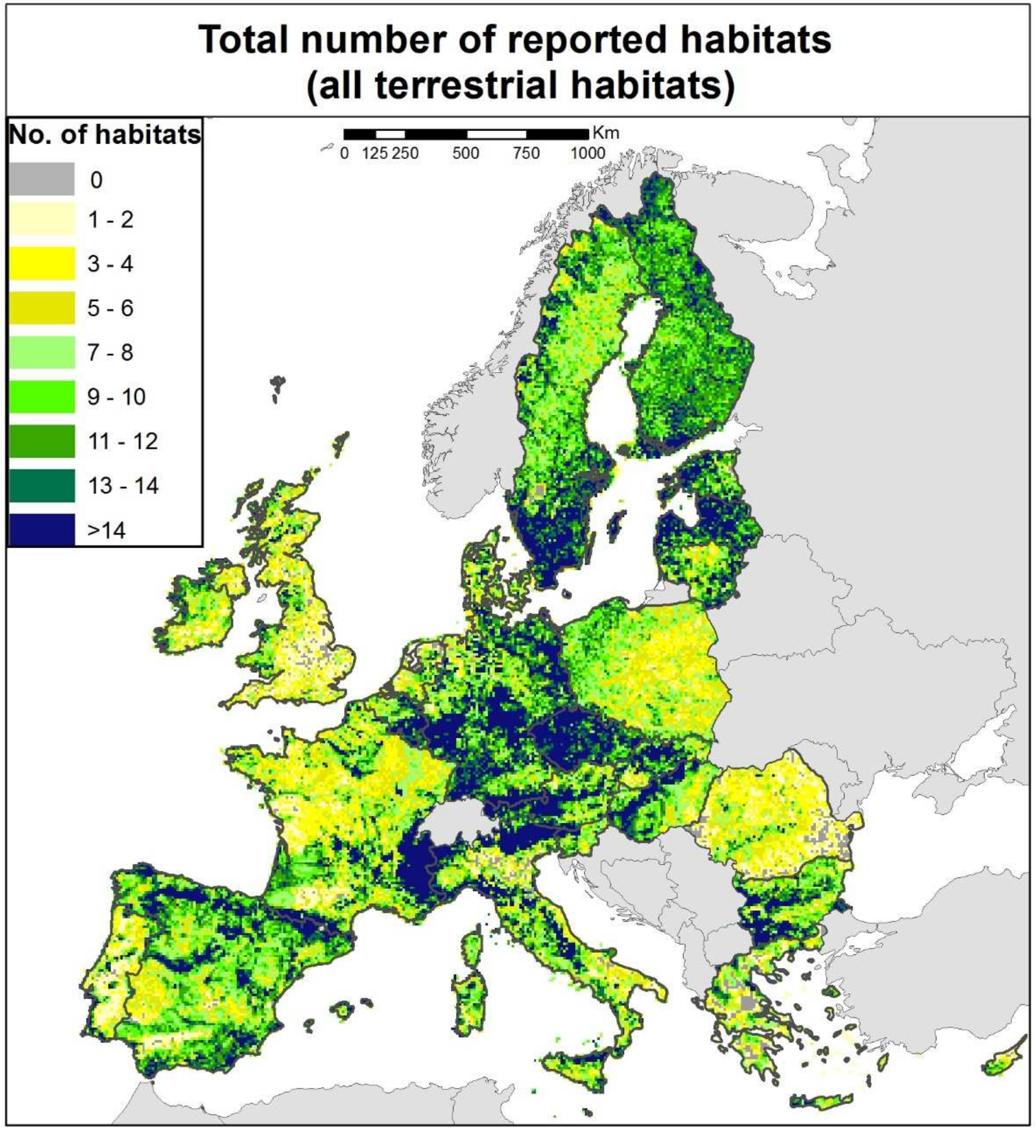


Figure 2: Spatial distribution of habitats of European Importance (Annex I Directive 92/43/EC) assessed in the 2007-2012 Art. 17 Report whose conservation depends on agriculture (as identified by Halada et al, 2011)

As several habitats may occur in a single 10 km cell, original data were processed to know habitats abundance across the EU. Figure 3 below depicts the total number of assessed habitats in each cell: the left maps refers to all terrestrial habitats, the right one to agricultural-related habitats only. Whilst it can be reasonably assumed that the maps provide a good overall picture of the actual abundance habitats across the EU27, some discrepancies between Member States methods in collecting data cannot be excluded.



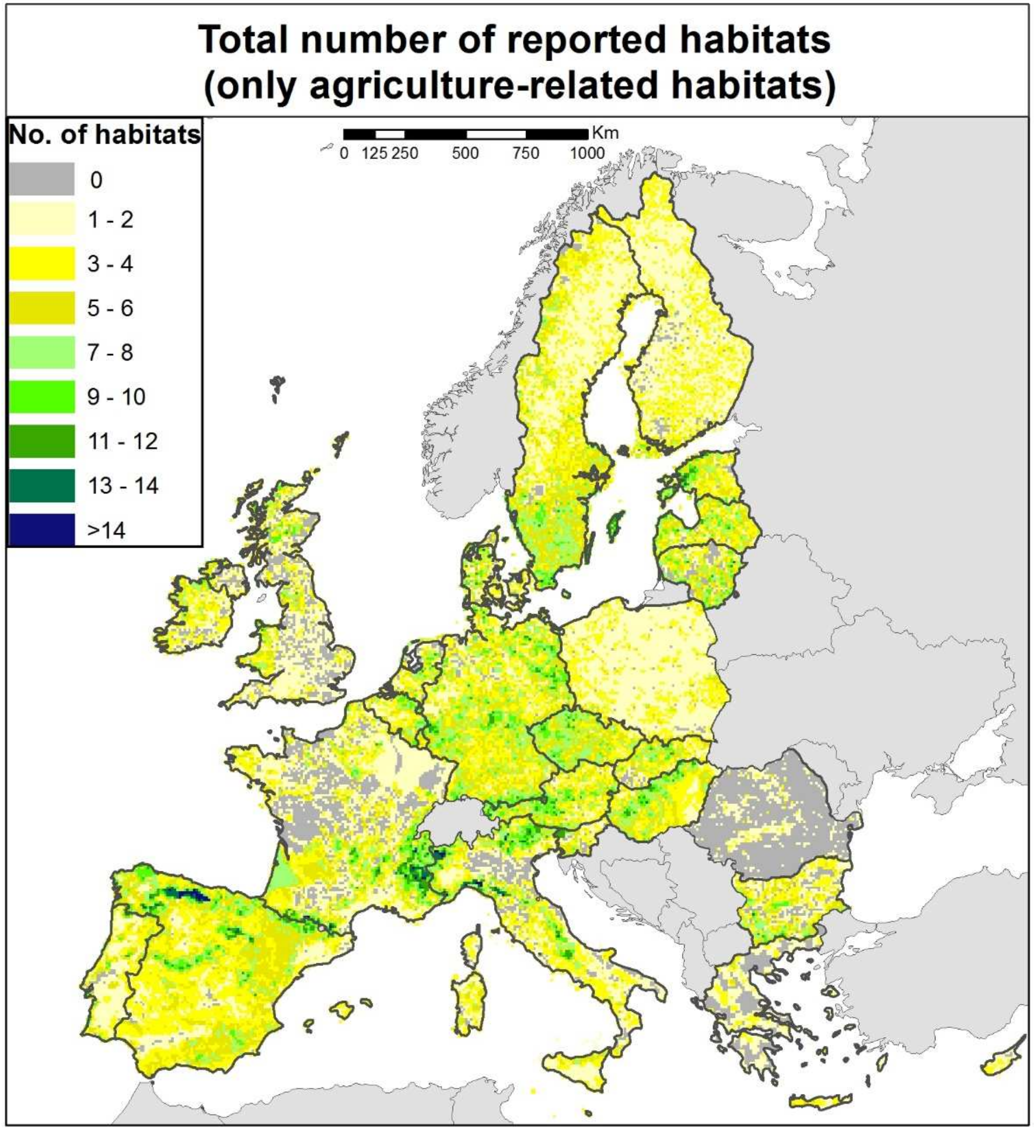


Figure 3: Number of Art. 17 assessed habitats per 10 km cell. Left: all terrestrial habitats; right: agriculture-related habitats

In the following, we provide a spatially explicit representation of the conservation status of all habitats and agriculture-related habitats based on reported assessments. For each cell, a numeric value was assigned to all habitats found within it based on their assessment: Favourable = 1; Unfavourable-inadequate = 2; Unfavourable-bad = 3 (qualifiers and 'Unknown' assessments are not considered at this stage). In Figure 4, we show the average value of Conservation Status obtained for each cell.

The general identifiable pattern emerging from the figure is a relation between habitats mean conservation status and their localisation in different bioregions. This is particularly evident for agriculture-related habitats, for example in Northern Spain, along the border between the Mediterranean and the Atlantic regions as well as in France, Benelux and North West Germany, along the Atlantic/Continental edge, with Atlantic habitats showing a worse state. The same applies along the Alpine range in France, Italy and Austria along the Alpine/Continental border, and in Fennoscandia along the Boreal/Alpine division. Such divisions mainly occur within Members States, so differences in reported conservation status are not ascribable solely to differences in utilized methodologies to produce the assessment between Member States.

Clearly, in some cases the transition from one bioregion to another also marks a significant difference in landscape features and in the possibility for human settlement and agricultural exploitation. This is the case of the Alpine Bioregion, where chances for intensive agriculture are minimized by terrain morphology. In North-West Italy for example, the transition from the Alpine to the Continental regions coincide with the transition from mountainous, scarcely populated areas to the densely populated and intensively cultivated Po Plain. A similar pattern is visible in Austria. In the next section 2.3, more detailed analysis on conservation status at the bioregions level are presented.

The figure seems also to indicate that the conservation status of agricultural-related habitats is on average worse when compared to the whole set of assessed habitats. This is evident for example in Northern Spain, Germany and Continental France. In the following section we further investigate whether there is a significant difference in the conservation status of agricultural-related habitats and the totality of habitats, and whether this significantly differs across bioregions.

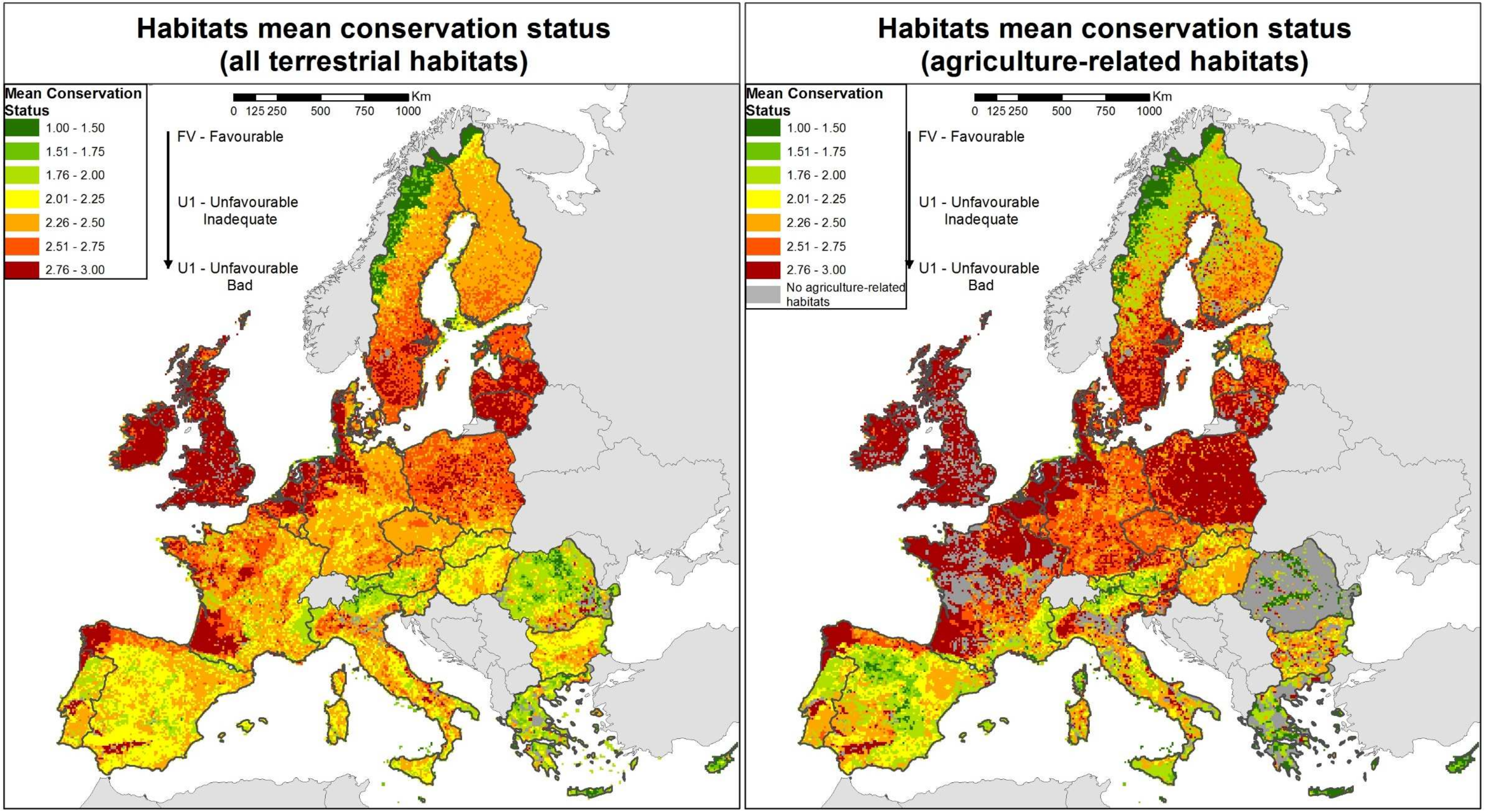


Figure 4: Mean conservation status of all terrestrial habitats (left) and agricultural-related habitats (right), by distribution on 10km cells

2.3 Difference in conservation status between agriculture-related habitats and others habitats

The source data of the analyses showed in this section is the full set of 3,117 habitats assessments provided by Members States and available on the EEA website[2]. Marine habitats assessments (5.2% of the total) were excluded from the analysis. Agriculture-related habitats assessment make up 35.9% of the total of non-marine habitats assessments. The three bar diagrams shown in Figure 5 displays, respectively, the distribution of conservation status of: all non-marine habitats (upper); agriculture-related habitats (middle) and non-agriculture related habitats (lower). It emerges that 21.1% of assessments for habitats depending on agriculture are 'favourable', whilst the figure for all terrestrial habitats is 25.4% and for the rest of habitats is 27.8%. Moreover, the relative majority of agriculture-related habitats are assessed as Unfavourable-bad (36.1%) whilst about 23.9% of the rest of habitats are classified as U2. Chi-square test were carried out to verify whether the distribution of agriculture-related habitats among the four classes is statistically different from that of the rest of non-agriculture related habitats and the totality of habitats. The table below (Table 3) shows the result of this test confirming that the difference is indeed statistically relevant in both cases. The same holds true if 'Unknown' conservation status are excluded from the statistics (not shown here).

Table 2: Difference between the conservation status of agriculture-related habitats and the totality of habitats

Conservation status of habitats depending on agricultural practice vs the totality of habitats			
	Frequencies		**Chi square Test**
Conservation Status	**observed**	**expected**	
FV	224	270	Degree of Freedom: 3 χ2 = 35,5 p < 0.01
U1	415	439	
U2	383	300	
XX	39	52	
Conservation status of habitats depending on agricultural practice vs the rest of habitats			
	Frequencies		**Chi square Test**
Conservation Status	**observed**	**expected**	
FV	224	295	Degree of Freedom: 3 χ2 = 93,9 p < 0.01
U1	415	453	
U2	383	253	
XX	39	59	

[2] http://www.eea.europa.eu/data-and-maps/data/article-17-database-habitats-directive-92-43-eec-1. Data shown here slightly differ from those reported in the EEA Technical report (EEA, 2015) because the latter does not include in the analysis data from Greece, as this country delivered its report in January 2015. Data presented in this section instead include also the Greek assessments.

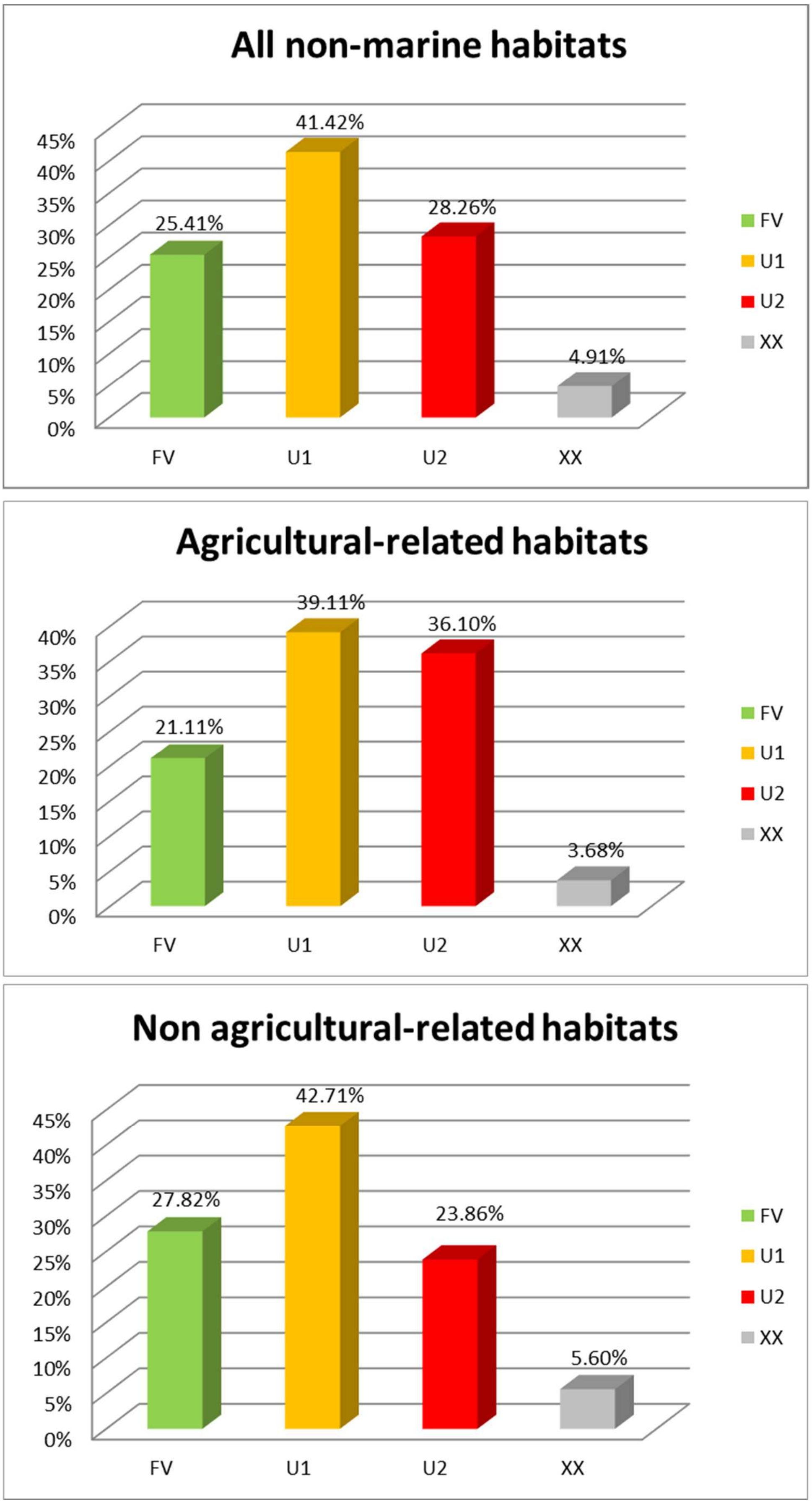


Figure 5: Conservation status of all non-marine habitats (up), agriculture-related habits (middle) and non-agriculture-related habitats in Europe based on Member States assessments.

The same analysis was carried out separately for the main biogeographical regions, to ascertain whether the worse conservation status of agricultural-related habitat identified at the continental level holds true also for geographical subsets. The following biogeographic regions were considered: Atlantic (ATL); Continental (CON); Alpine (ALP); Boreal (BOR); Mediterranean (MED) and Pannonian (PAN). These bioregions made up 90.3% of all the habitat assessment at the EU level. Other bioregions were excluded due to the paucity of assessments available to carry out the statistical test. For each bioregion, the distribution of agriculture-related habitats among the classes was compared with the distribution of the rest of the habitats. Results are reported in Table 4 and confirm the worse conservation status in the Alpine, Atlantic, Boreal and Continental bioregions. Conversely, in the Pannonian and Mediterranean Regions the distribution of the conservation status of agriculture-related habitats is not statistically different from that of the remaining habitats.

*Table 3: Results of the Chi-square test to determine whether conservation status of agriculture-related habitats is statistically different from the rest of habitats in different biogeographic regions. * Not significant*

Alpine Region (APL)				
Conservation Status	No. of assessments		Chi-square test (Degrees of freedom = 3)	
	Observed	Expected	χ2 value	p-value
FV	76	86	14.2	< 0.01
U1	80	81		
U2	42	25		
XX	8	13		
Atlantic Region (ATL)				
Conservation Status	No. of assessments		Chi-square test (Degrees of freedom = 3)	
	Observed	Expected	χ2 value	p-value
FV	18	18	24.3	< 0.01
U1	67	92		
U2	120	86		
XX	7	16		
Boreal Region (BOR)				
Conservation Status	No. of assessments		Chi-square test (Degrees of freedom = 3)	
	Observed	Expected	χ2 value	p-value
FV	17	30	20.7	< 0.01
U1	43	52		
U2	53	33		
XX	4	3		
Continental Region (CON)				
Conservation Status	No. of assessments		Chi-square test (Degrees of freedom = 3)	
	Observed	Expected	χ2 value	p-value
FV	38	60	30.5	< 0.01
U1	112	124		
U2	128	88		
XX	7	14		

Mediterranean Region (MED)				
Conservation Status	No. of assessments		Chi-square test (Degrees of freedom = 3)	
	Observed	Expected	χ2 value	p-value
FV	45	49	1.1	0.77*
U1	59	53		
U2	23	25		
XX	11	11		
Pannonian Region (PAN)				
Conservation Status	No. of assessments		Chi-square test	
	Observed	Expected	χ2 value	p-value
FV	15	18	3.4	0.33*
U1	30	31		
U2	15	10		
XX	1	2		

Finally, it is interesting to investigate whether a relation exists between habitat richness (i.e. no. of reported habitats within each cell) and their average conservation status. Figure 6 shows the average conservation status of habitats present in 10 km cells, by grouping the latter according to the number of habitats present therein. Although differences are not so pronounced, the overall average conservation status improves as the number of habitats increases, particularly for very rich (≥ 20 habitats) areas, when all terrestrial habitats are considered (left diagram). The same however is not true when only agriculture-related habitats are examined: in this case, no significant correlation emerges between habitat abundance and conservation status (right diagram).

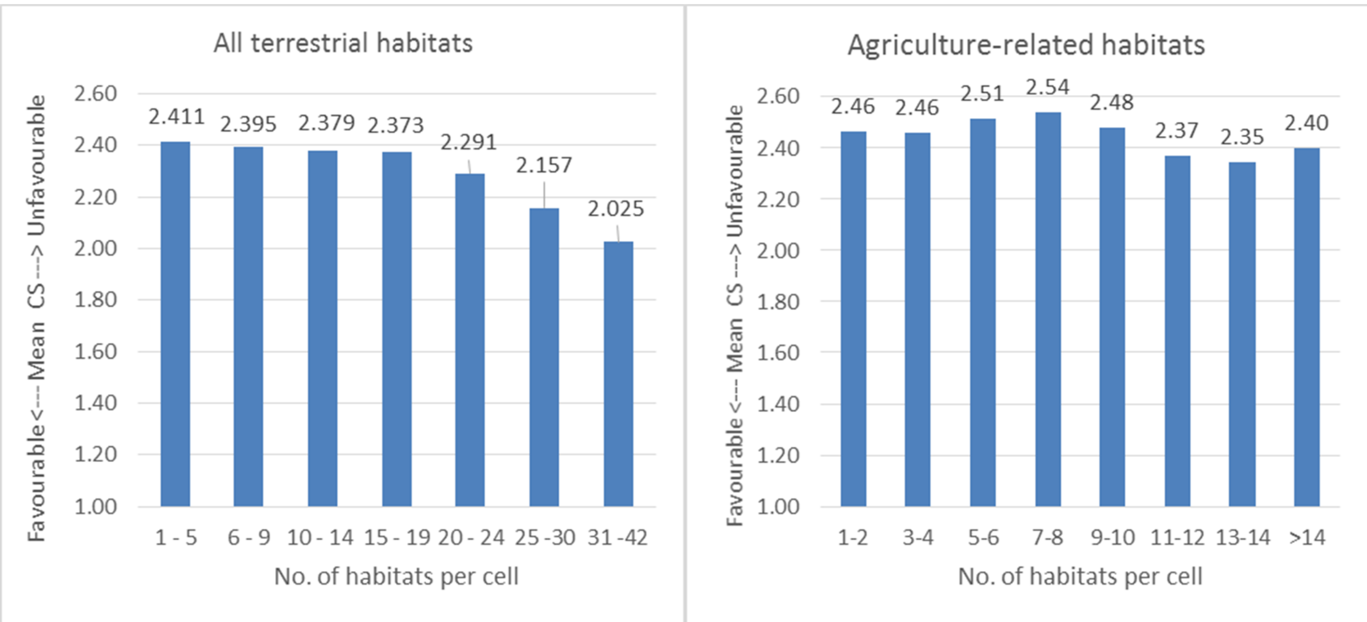


Figure 6: Average conservation status of habitats per cell grouped according to habitats richness. Left: all terrestrial habitats; right: agriculture-related habitats

The same analysis was carried out for the biogeographic regions. A statistically significant correlation was found too in this case, although differences are not so pronounced between habitat richness of a certain biogeographical region and their average conservation status.

Overall, these results confirm that agriculture-related habitats have, on average, a worse conservation status when compared to other habitats, and that those within the Continental, Atlantic, Alpine and Pannonian Regions have a significantly worse conservation status than the Mediterranean and Boreal habitats. Furthermore, areas with a relative higher habitats abundance feature a better average habitats conservation status as a general trend.

2.4 Relations between conservation status, pressures and threats in agriculture-related habitats

Given the relatively worse trend of conservation status for agriculture-related habitats, shown in the previous section, a further look to potential drivers is provided below. While removing marine regions, we added the remaining terrestrial domains to the analysis: Black Sea (BLS), Macaronesian (MAC), and Steppic (STE) bioregions.

In order to understand if a general trend related to pressures is present, the number of pressures recorded within each status class has been analysed. It should be stressed that the results presented have been generalized and no conclusions should be drawn at the level of the habitat or the location. At such scale of detail in fact, each pressure could have a particular behaviour depending on the context. Figure 7 shows the number of habitats (and their conservation status) grouped by the number of reported pressures acting on them.

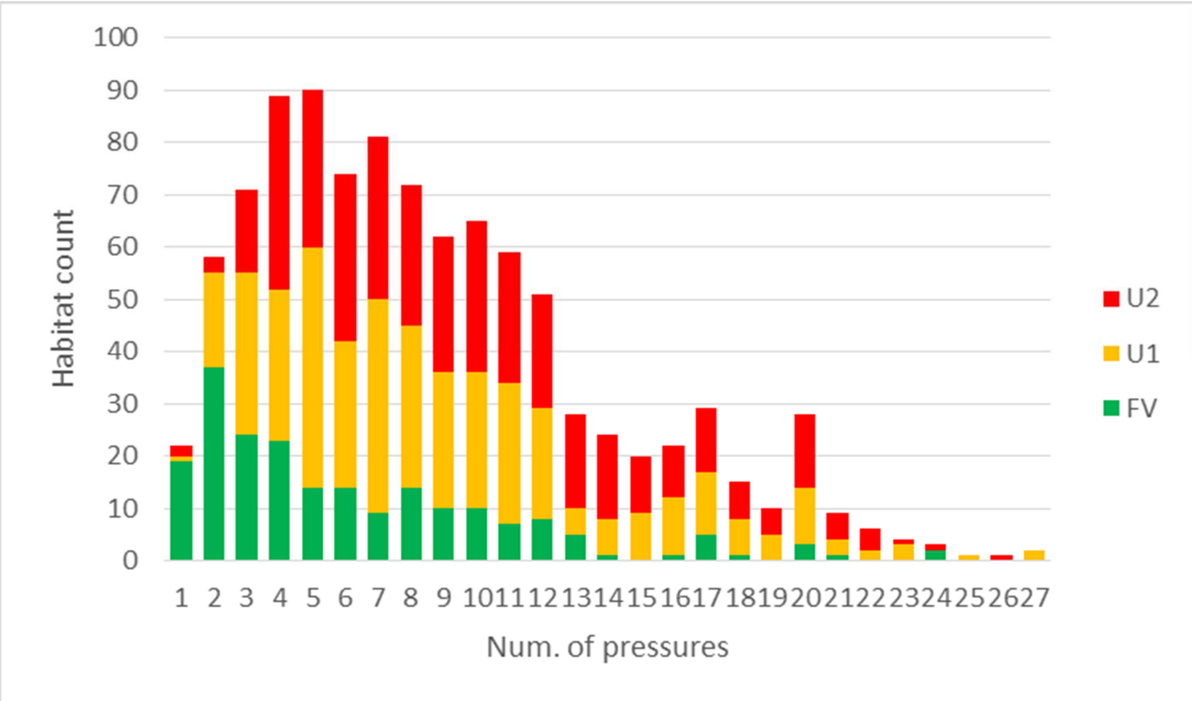


Figure 7: Relation between number of reported pressures and conservation status of agriculture-related habitats

The histogram suggests a slightly different skewedness for the three classes, so they are first compared two by two fitting a generalised linear model, with errors following a Poisson distribution. Here, the habitat counts are the response variable, depending on the conservation status (implemented as a two factors variable). The p-value shows the differences between the groups, by testing the slope of conservation status (Table 4).

Table 4: Habitat counts depending on conservation status.

FV vs U1

	Estimate	Std. Error	z value	p-value
(Intercept)	2.04	0.07	29.45	≈ 0
U1:U2	0.66	0.09	7.75	≈ 0

FV vs U2

	Estimate	Std. Error	z value	p-value
(Intercept)	2.04	0.07	29.45	≈ 0
U1:U2	0.62	0.09	7.16	≈ 0

U1 vs U2

	Estimate	Std. Error	z value	p-value
(Intercept)	2.70	0.05	54.26	≈ 0
U1:U2	-0.05	0.07	-0.64	n.s.

While there is generally less incidence of pressures on habitats with favourable assessment, no differences are found between the two degrees of unfavourable statuses. This is shown clearly by fitting a model to each of the classes, accordingly to a Poisson distribution (Figure 8).

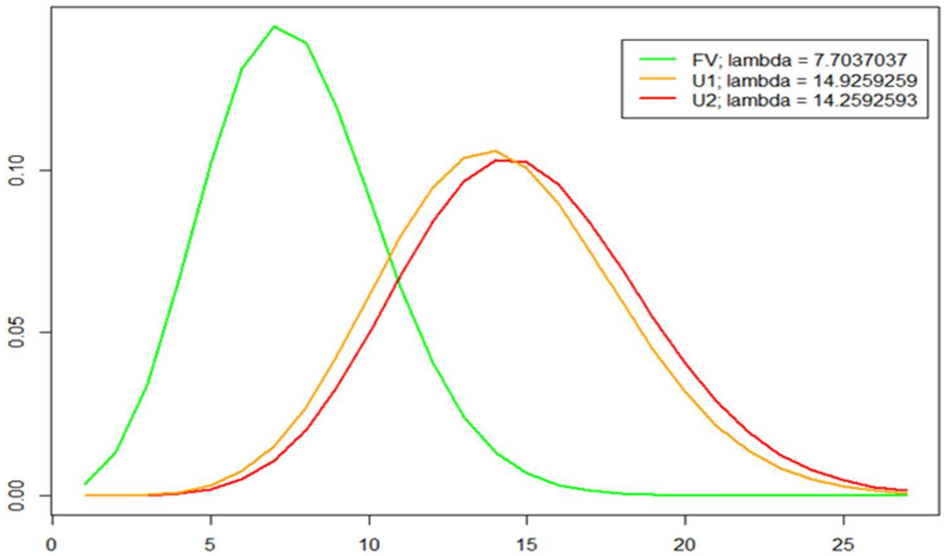


Figure 8: Probability of the presence of a certain number of pressures in the three classes of habitat conservation status, modelled according to a Poisson distribution. X-axis shows no. of pressures, Y-axis shows the probability density.

It follows that, at EU level, the number of pressures are not equally distributed among conservation statuses assessments, but rather they are more abundant in habitats with unfavourable status. Splitting the data by biogeographical regions and aggregating the habitats shows a more complex picture and the observed trend is less clear (Figure 9).

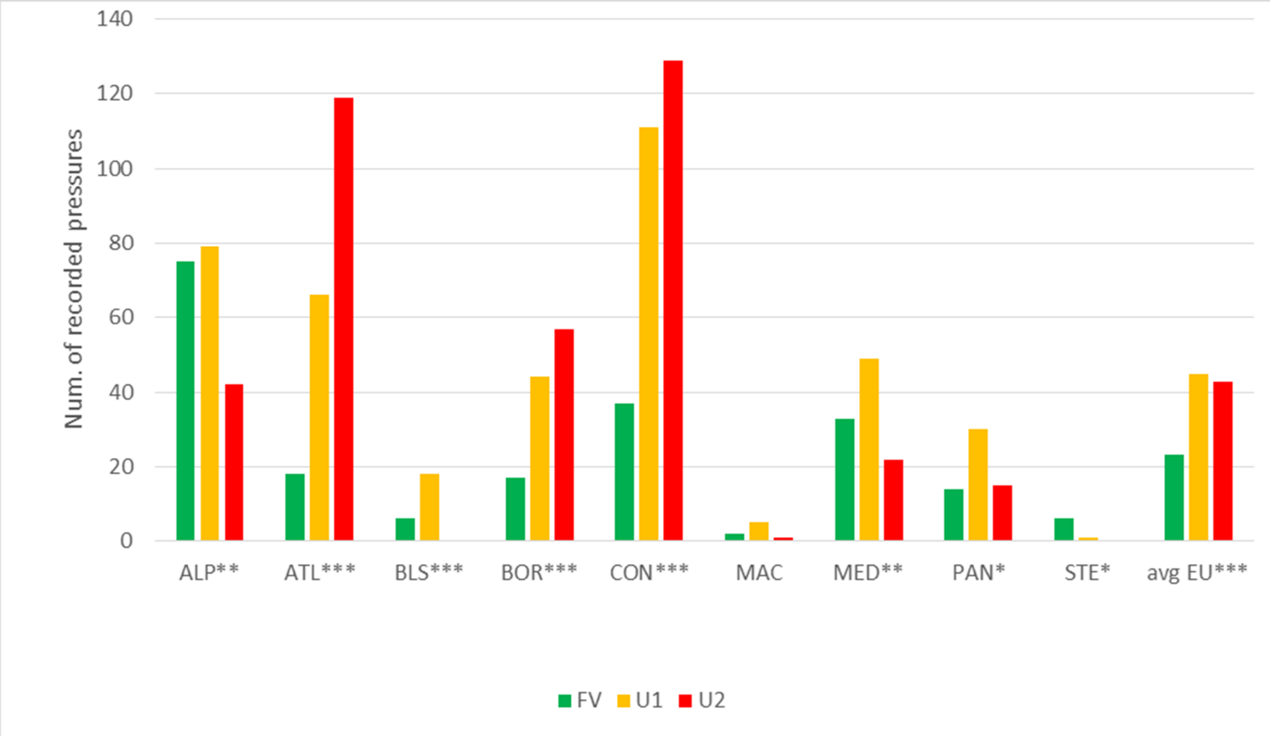


*Figure 9: No. of recorded pressure per habitat conservation status in different bioregions (*p<0.05; **p<0.01;***p<0.001)*

Here, a Chi-square statistic is used to assess the overall significance of differences between the conservation status and the number of pressures in each region. As one would expect, a higher incidence of pressures correlates with a worse conservation status for three of the broadest regions (Continental, Atlantic, Boreal), which partly explains the previous results at EU level, but this is not common to all regions. Among the others, Macaronesia alone doesn't show any significant difference with any of the three status classes, most likely because of the small number of habitats assessed; the others prove always significant at least at $p<0.05$ level between at least two status classes, but without an obvious common trend.

Another approach is to assign a score to each conservation status (FV=1; U1=2; U2=3, as in section 3.1) and test it against the aggregated number of pressures (Figure 10). A linear model is applied at biogeographic region scale (a) and the slope is tested against the null hypothesis of being not significantly different from zero. The ANOVA shows a significant trend at $p<0.05$ (upper diagram). However, sourcing from the disaggregated dataset provided by Member States at finer resolution (middle diagram), the same test fails. Similarly at habitat level no significant trends are detected (lower diagram).

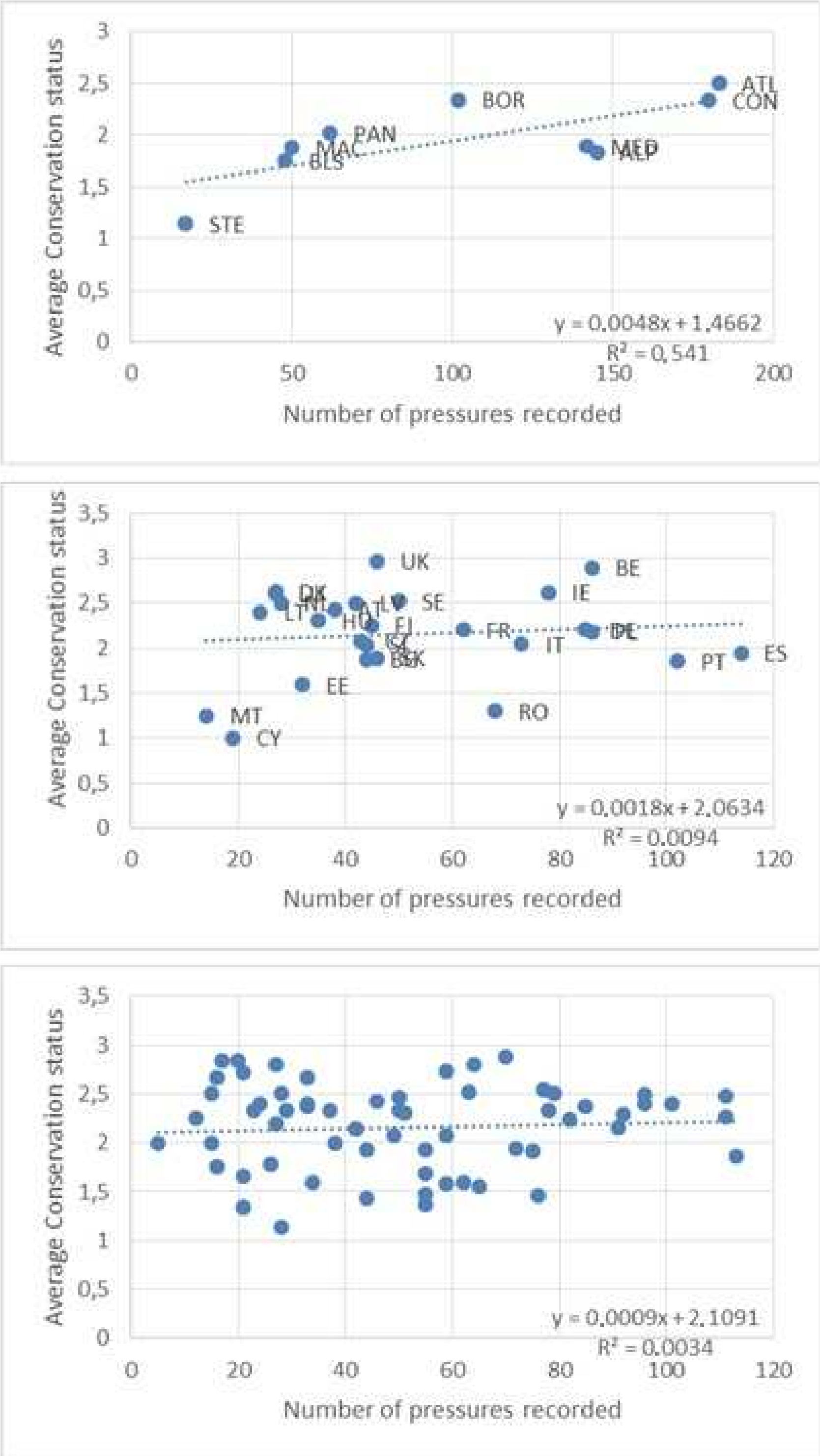


Figure 10: Correlation between no. of pressures and habitats average conservation status aggregated for biogeographic regions (up); Members States (middle) and habitat types (low)

Finally, setting up a multinomial logistic regression helps to prove if a trend of conservation status likelihood depends on increasing number of pressures, but again model coefficients tested using Wald statistic (z test) showed no significance at 0.05 level.

The overall conclusion is that the simple number of pressures is a rather weak indicator of status for agricultural related habitats as a whole. Assigning weights, for instance based on the number of habitats assessed or area of regions, may give clearer results, but would imply hazardous assumptions about both methods and data. However, taking into account single habitats, a higher incidence of pressures in habitats assessed as unfavourable is confirmed.

If on the one hand the presence of pressures is expected to affect the conservation status, on the other it is arguable whether all pressures are equally important. From this perspective, it is worth to hypothesize that some pressures impact the status more than others, on average. Pressures with a low frequency cannot be analysed, as statistical tests tend to be rather weak. A cross-comparison among pressures may therefore help to highlight the prominent ones and find out correlations. This argument is first analysed by modelling the relations between the three possible conservation statuses and presence/absence of pressures, using a multinomial logistic regression model. Starting from the full model including all pressures, a step-wise selective removal was done, looking at the increment of AIC (Akaike's information criterion) in the new model compared to the optimal one. The increment can be measured through deviance and a Chi square statistic can serve to state if the increment is significant or not. The bigger it is, the heavier is the variable in determining the conservation status response.

To take the analysis further, each recorded pressure is isolated from the others and conservation status is modelled as a function of it, again by means of a multinomial logistic regression. The latter provides the probabilities of having a certain status assessment in presence or absence of the pressure, given known statuses from multiple habitats. These probabilities are then compared against each other to test if they differ significantly. In fact, if statuses change in presence or absence of a certain pressure, the latter is more likely to be relevant for the habitats where it occurs. Significance is assessed through an exact multinomial test, comparing frequencies of status classes when the pressure is present against frequencies when the same is absent. The bar plots of Figure 11 show the ten most frequent pressures at EU level with a significant change of conservation status ($p<0.001$) whether they are present or not.

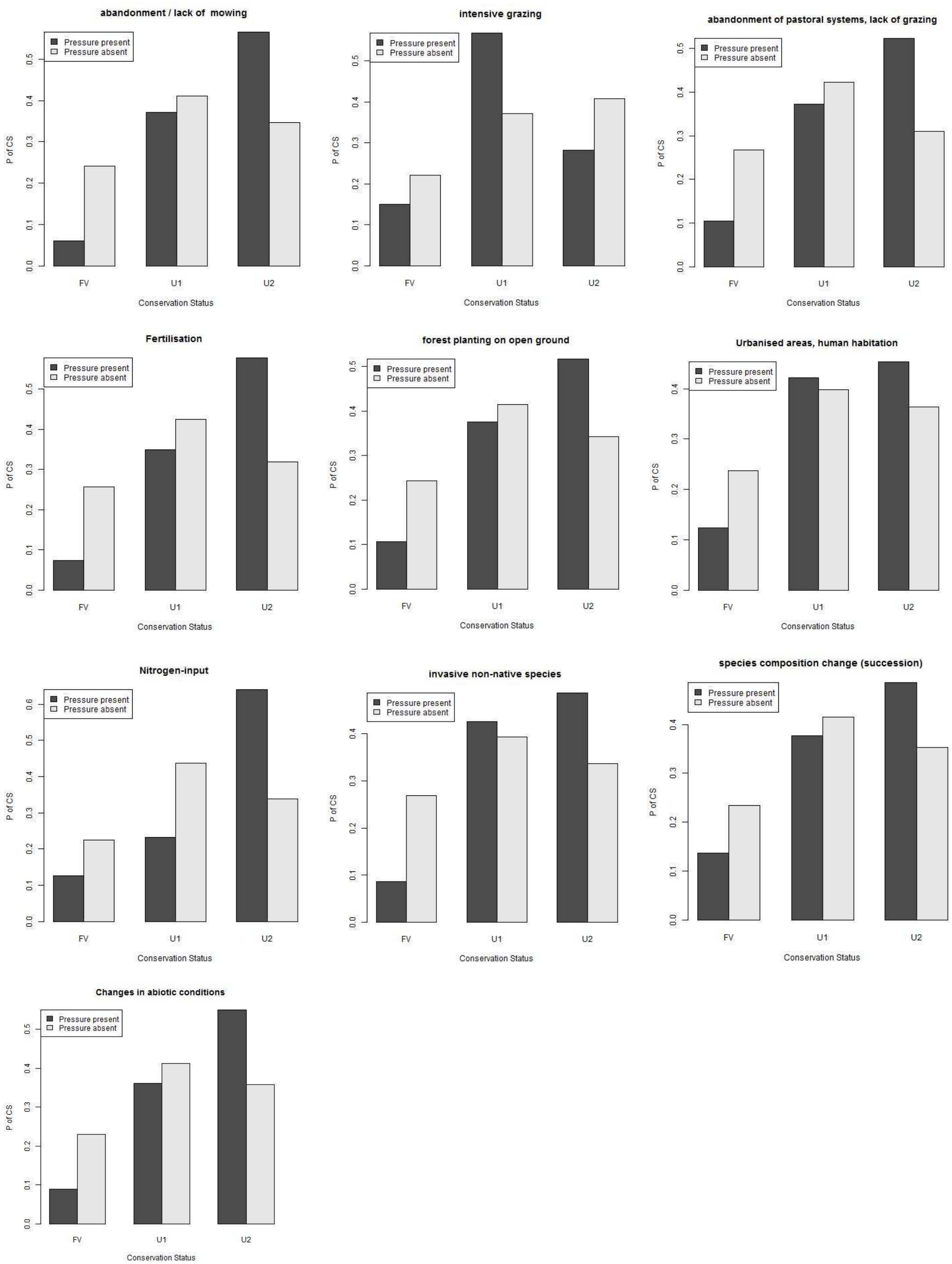


Figure 11: Frequency of conservation status classes and presence/absence of the 10 most frequent pressures at the EU level

During the previous step, all pressures likely to have a shallow average effect on conservation status were filtered out. Among the remaining pressures, the great majority fell within habitats whose conditions are reported to be worse than in their absence; interestingly, a few did not show the same trend (Figure 12). The explanation may be related to the wider context where the pressure was recorded: wild and pristine areas in fact attract tourists and encourage outdoor activities as those indicated as pressures, which consequently may be inherently associated to certain habitats.

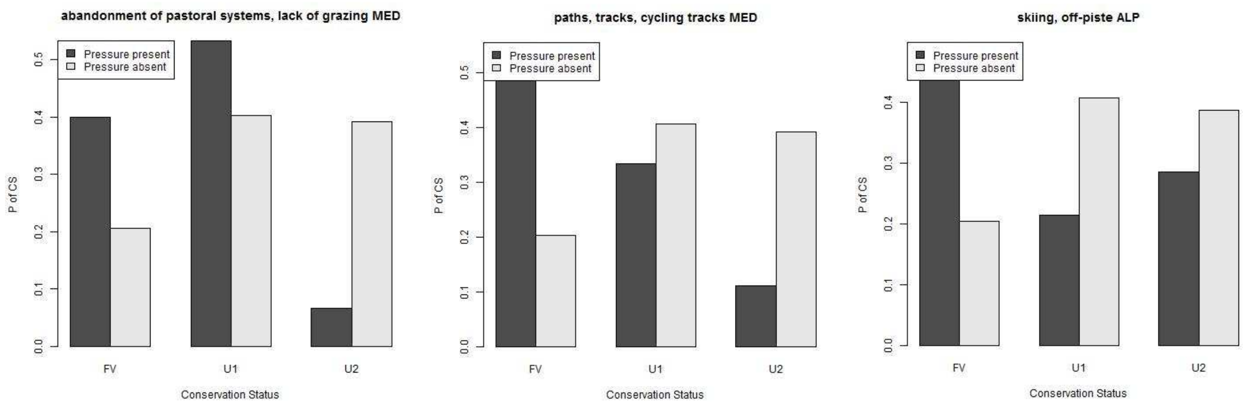


Figure 12: Pressures showing a positive impact on conservation status

In case of frequent co-occurrence of certain pressures, those would appear as equally important in relation to conservation status and it may not be possible to do any distinction while keeping the analysis limited to the Article 17 data. Ordination methods have proven to be useful to identify bundles of pressures, if any, and to collocate them in a space of relative similarity. A non-metric multidimensional scaling ordination is therefore performed (as a robust alternative to unconstrained correspondence analysis for zero-inflated data) and the results are given in Figure 13. The full list of pressure codes and their description in provided in the table in Annex 1

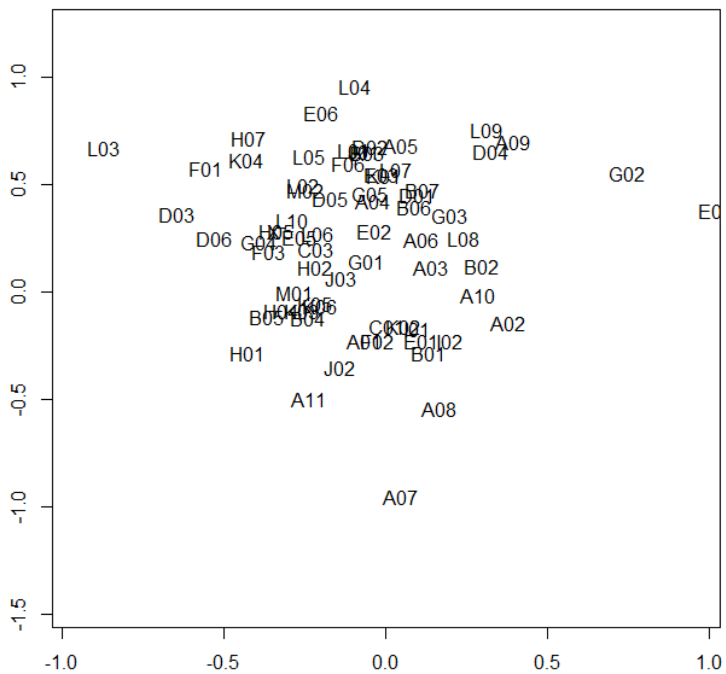


Figure 13: Two-dimensional scatterplot of the relative distance between pressures. Codes represent pressures described in the Table in Annex 1. For visualization purposes, only broader classes of pressures are plotted.

If on one side some clusters do not seem to be attributable to an identifiable driver typology, this is in some case possible, i.e. the lower cluster including B01 and I02 is related to pressures deriving from land uses (cultivation, urbanized areas, forest planation etc.). Similarly, grouping habitats based on pressures is helpful to identify those groups that may require similar intervention or mitigation on pressures (Figure 14).

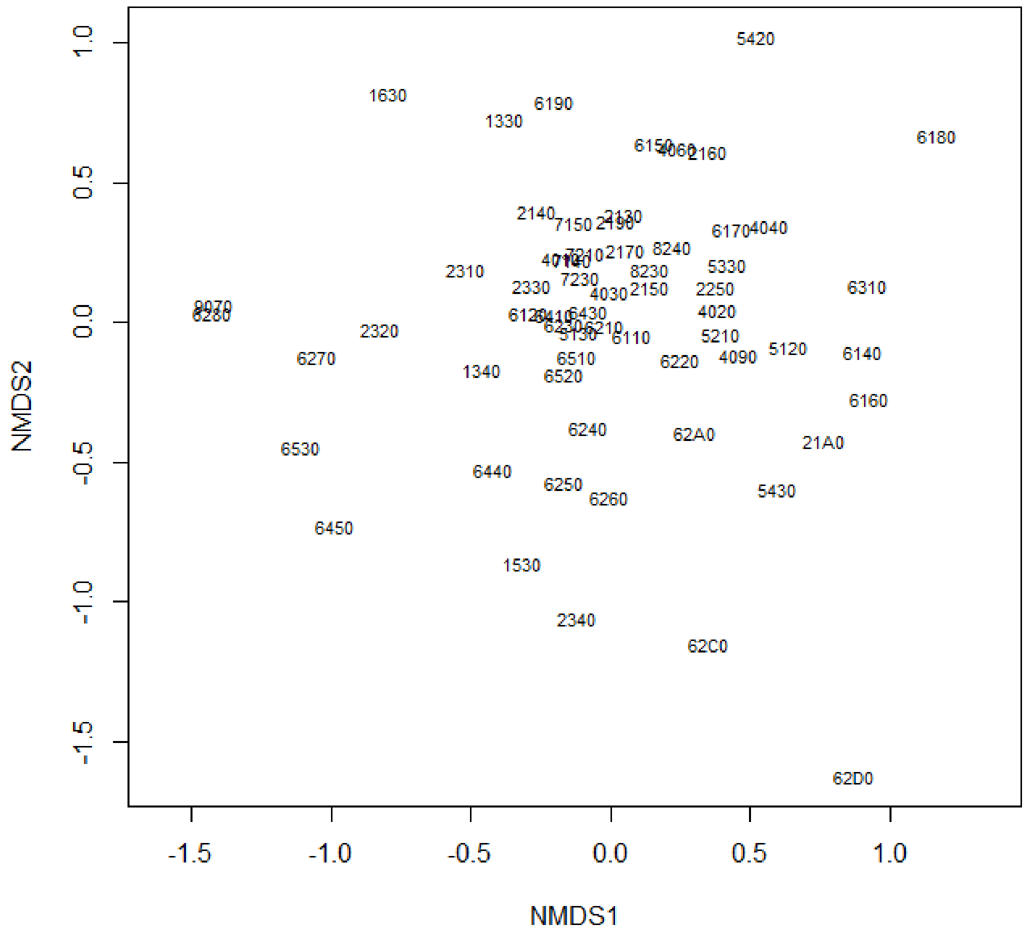


Figure 14: Two-dimensional scatterplot of the relative distance between habitats. Habitats descriptions are provided in Table 2

As no immediate patterns of association emerge from the plot, a hierarchical clustering is shown in Figure 15 to highlight degrees of similarity more explicitly.

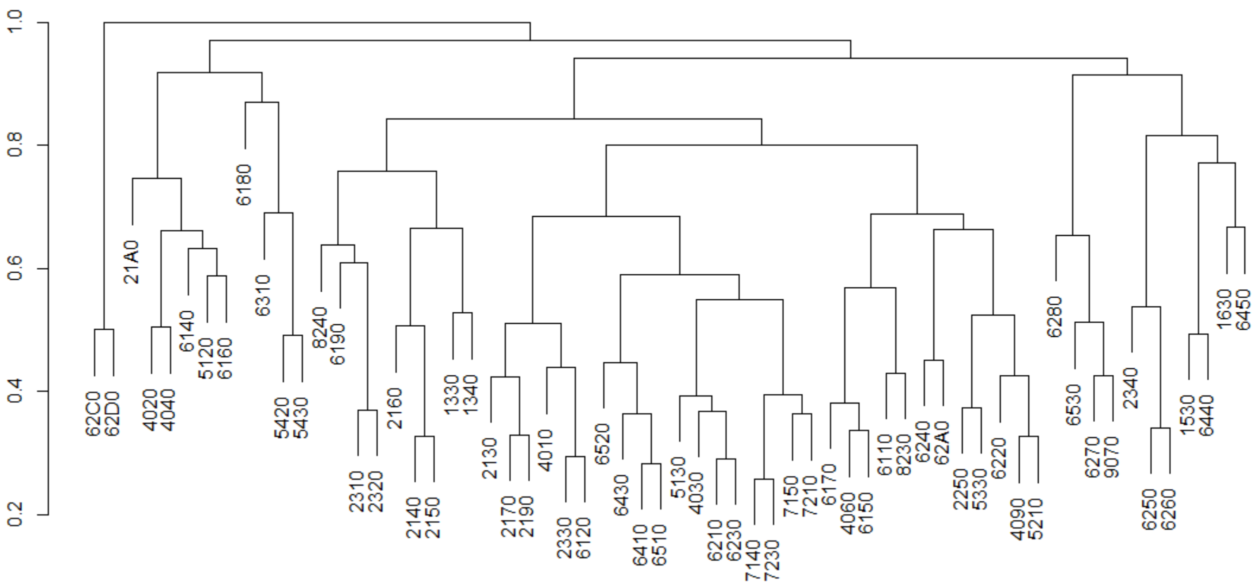


Figure 15: Hierarchical clustering of habitats based on pressures acting on them (y axis represents dissimilarity)

As expected, habitats belonging to the same biogeographical region are often grouped together, meaning that they are subject to similar pressures.

Finally, a further ordination can be performed by Member State, to highlight those countries where similar pressures have been recorded. Figure 16 displays such ordination as well the results obtained using the ordination at the biogeographic level.

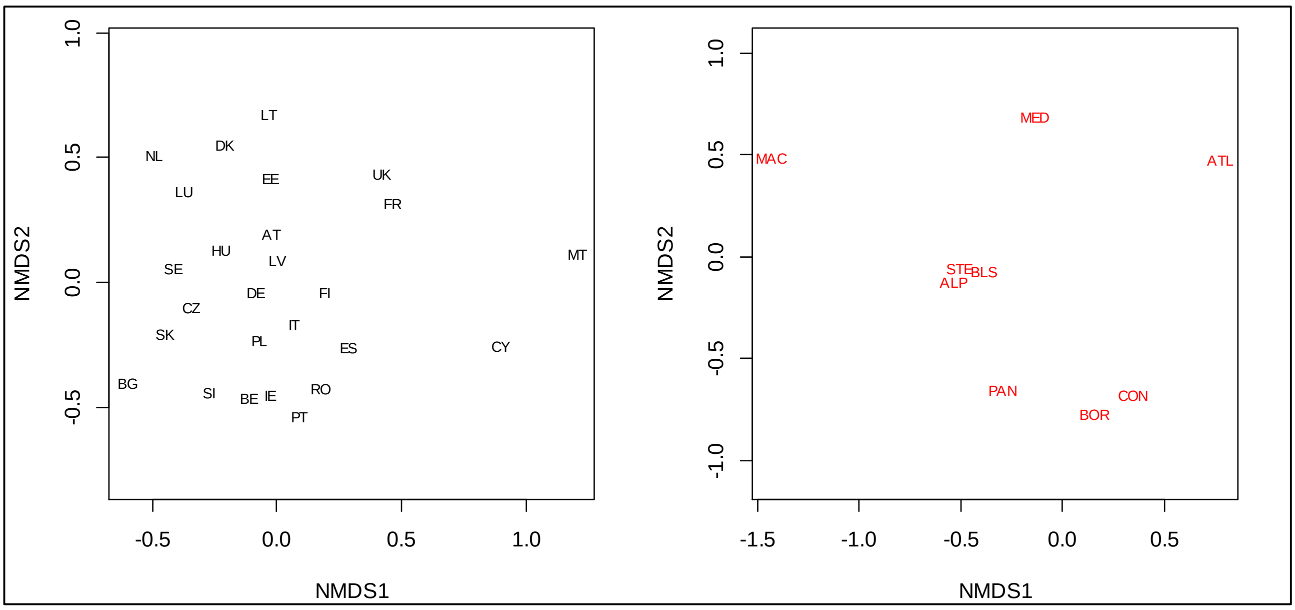


Figure 16: Ordination of Pressures by Member States (left) and Biogeographic regions (right)

Relevant pressures diverge especially when considering different geographical subsets, suggesting that impact of pressures may change depending on broader geographical features, rather than state level differences.

To sum-up, the trend that a higher incidence of pressures impacts on habitat status is confirmed. The pressure typologies that mostly impact on farmland habitats can be

grouped in abandonment, intensification, land cover change and invasive alien species. Among the considered pressures, regardless of their absolute frequency, some show a significant difference of occurrence across conservation statuses, suggesting these have an impact on it, mostly negative. This is true on average at the EU level, while at geographical subsets things may diverge. However, some others do not appear to influence in any direction the conservation status, even if locally or at single habitat level they may have an important impact. These conclusions are confirmed when picking each pressure individually and checking their presence or absence in all the habitats, where important pressures show a very different CS pattern when present compared to the pattern when absent.

3. Analyses based on IUCN data on species

3.1 Overview of IUCN data, characteristics and limitations

IUCN data provide an evaluation of species' risk of extinction based on past, present and projected threats, through a standardized methodology using the IUCN Red List Categories and Criteria (IUCN, 2012). Five main criteria have been established: a) Declining population; b) Geographic range size and fragmentation, decline or fluctuations; c) Small population size and fragmentation, decline, or fluctuations; d) Very small population or very restricted distribution; e) Quantitative analysis of extinction risk, defined as any form of analysis which estimates the extinction probability of a taxon based on known life history, habitat requirements, threats and any specified management options.

Based on these criteria, each examined taxon is qualified in one of the following categories:

•**Extinct (EX)** no reasonable doubt that the last individual has died.

•Extinct in the wild (EW): individuals are known only to survive in cultivation, in captivity or as a naturalized population well outside the past range.

•**Critically endangered (CR)** extremely high risk of extinction in the wild. A species is classified as such if its population has declined more than 90% in the past 10 years (or over a 3 generation period if longer than 10 years), or if the extent of occurrence is less than 100 km2or there are less than 250 mature individuals.

•**Endangered (EN)** very high risk of extinction in the wild. A species is classified as such if its population has declined more than 70% in the past 10 years/3 generations, or if the extent of occurrence is less than 5000 km2, or there are less than 2,500 mature individuals.

•**Vulnerable (VU)**: high risk of extinction on the wild. A species is classified as such if its population has declined more than 50% in the past 10 years/3 generations, or if the extent of occurrence is less than 20,000 km2, or there are less than 10,000 mature individuals.

•**Near Threatened (NT)**: a taxon is classified as such when does not qualify for the previous classes now, but is close to qualifying for or is likely to qualify for a threatened category in the near future.

•**Least Concern (LC)**: the taxon does not qualify for any of the previous categories. Widespread and abundant taxa are included in this category.

•**Data Deficient (DD)**: there is inadequate information to make a direct, or indirect, assessment of its risk of extinction based on its distribution and/or population status.

As mentioned in the introduction, the Red List Index is now widely used worldwide not only as a mere indicator of extinction risk, but more broadly – and in conjunction with other dataset - as an indicator for the state of the environment and for policymaking (Maes et al., 2015). Under this perspective, we explored some aspects of IUCN data, which could be relevant in the European context. Scientific literature contains a few papers making use of IUCN data at EU level (see e.g. Ballantyne and Pickering, 2013 and Wuczyński et al, 2014). However, there is a great potential underneath the dataset, which still has to be exploited properly, from both a research point of view and a policy one.

The base for this work is the IUCN spatial dataset of species, fitting all species distributions to a 10 km by 10 km resolution grid for the whole EU28 territory (the same grid used for the analysis of habitats conservation status shown in sections 2 and 3), which was the selected extent of the analysis. IUCN data show a good consistency across Europe, making it a good candidate for species and biodiversity analyses at EU level.

This section of the report based on IUCN data is structured in four main sub-sections beyond this introductory one: sub-section 3.2 aims at quantifying the importance of species based on their distribution and number per location (occupancy analysis); sub-section 3.3 makes use of the threat status assessments, as defined by IUCN (IUCN, 2012), to analyse the spatial distribution of species under threat; finally, in sub-section 3.4 a method for a balanced analysis of performance and comparison of biodiversity across EU, by means of species richness is presented.

It should be noted that the method used avoids referring to any potential/theoretical state of biodiversity in conditions different from the actual. Therefore, this approach may be particularly useful for policy and conservation, providing a picture of regions performing well and those needing improvement, based on an empirical and realistic baseline of species richness.

The scheme in Figure 17 describes the steps in the proposed approach. While species distribution and threat status can build on a consolidated set of literature and indicators, species richness requires more effort to avoid misleading mapping outputs. In fact, regions may host more or less species depending both on anthropogenic factors and natural processes, the former being under human control to a certain degree, the latter much less so at the same scale. This distinction may be very relevant in a policy context, where monitoring and restoration actions are required, thus should be based on a correct assessment of the "natural" baseline.

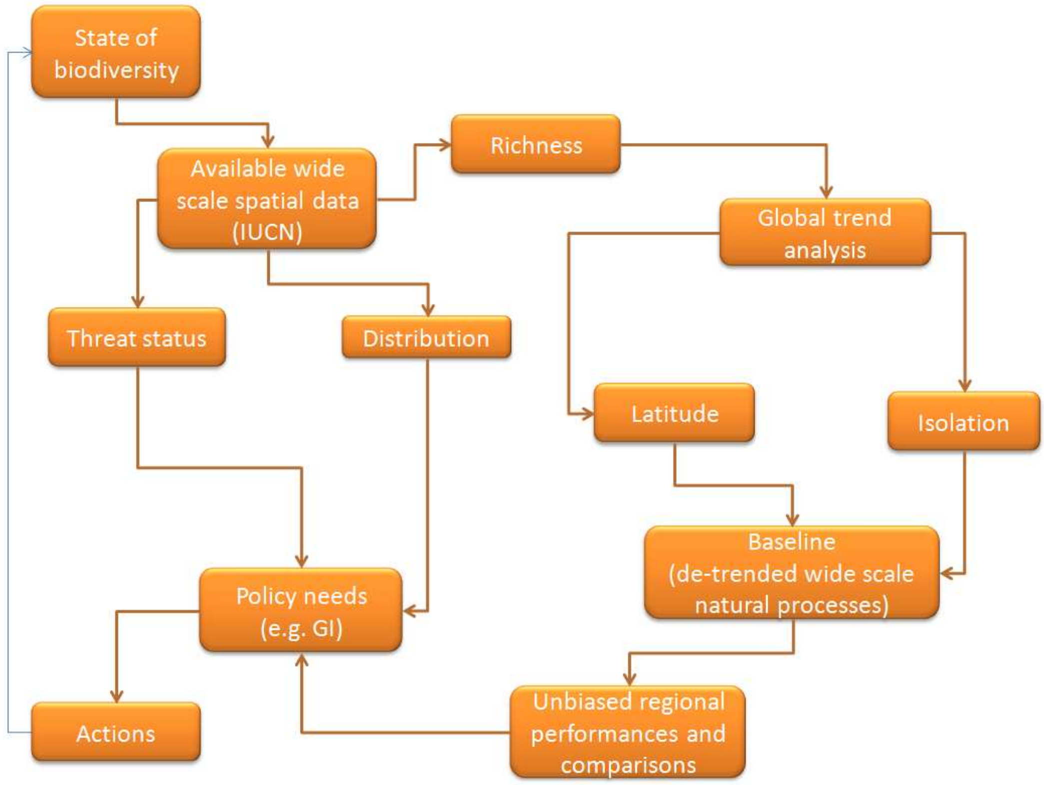


Figure 17: Schematization of the developed approach to IUCN data analysis for policy and conservation measures in the EU

The same reasoning – human versus natural processes – could be applied to both threat status and distribution of species, but, in those cases, decades of conservation efforts worldwide have shown that species under threat or with a narrow distribution, whether for natural reasons (e.g. evolutionary history) or human impact, are eligible for a special status of protection. The choice about what factors to take into account in species richness analysis, as proxies for wide scale natural processes, is explained in the coming sections.

Based on species incidence (i.e. presence), IUCN threat status and spatial partitioning, several measures were computed and mapped, which can be broadly resumed as follows:

- **Species richness**, as a count of species per cell.
- **Red List Index**: an average of species threat statuses per cell.
- Other **measures based on IUCN threat status**, such as ratio of critically endangered species versus least concern, etc. (by 10 km cell).

- Several **occupancy** measures, such as summary statistics per cell of the ratio of species distributions versus the whole EU28 extent, and related measures (including some weighted by threat status).

Some shortcomings of the source dataset, mainly concerning spatial accuracy, shall be pointed out.

Species ranges and species presence for spatial analyses.

Most of the species statistics presented here have been derived from the web services of the Digital Observatory for Protected Areas version 1.0 (Dubois et al., 2013, 2015) in particular from its service eSpecies (Cottam et al., 2013). These services are based on the IUCN distribution maps from the Red List of Threatened Species (August 2014, version 2) that have been rasterized on a 1 km grid at the global scale. The original species ranges are mapped as generalized polygons which often include areas of unsuitable habitat, and therefore species may not occur in all of the areas where they are mapped. In general, for range-restricted taxa, ranges are mapped with a higher degree of accuracy, sometimes down to the level of individual subpopulations, compared with more widely distributed species (Hoffmann, 2014). As a result of such process, the level of misclassification can be high. Typically, expert based country-classification schemes are more accurate than those obtained from the geometric overlay of all species range maps. We argue however that, considering the large number of species involved in the forthcoming analysis and the higher knowledge about European species which leads to lower uncertainties in the range maps of the European species, the results of the proposed analysed can certainly be improved but the overall trends are most likely to remain unaffected by our approximations which are justified by the significant computational efforts underpinning these analyses.

Latitudinal and areal de-trending for regional comparison of biodiversity measures across EU.

National borders have corresponding cells that often show an anomalous pattern, appearing more species rich; this does not reflect any real richness pattern, but instead relates to a double-counting issue. It happens for instance when one species distribution is drawn once for each neighbouring country: at the border, due to the relatively coarse resolution of raster cells, the two distributions may overlap, thus generating a double counting of the same species. Such cases were identified and removed before the analysis, and replaced afterwards by interpolated values, for mapping purposes. For Central-Eastern Europe, where the issue is more evident, any of the several interpolation methods gave robust and reliable results. However, islands need a dedicated procedure, especially those more distant from mainland, because extrapolation may occur instead of interpolation and results would not be reliable if not treated properly.

Coasts shape was also evaluated in advance to avoid artificial patterns or data misplacements. The problem in this case is the co-occurrence of terrestrial and open-water marine species in the same cell and the solutions appear to be less clear. We made the choice of including marine species in those cells which contain both land and sea, aiming for map completeness to policy oriented readers, but more attention should be paid if ecological analysis was to be performed. Therefore, the inclusion or exclusion of these cells or of marine species should be evaluated from the perspective of analysis and mapping purposes within this report.

At 10 km resolution, cells touching any national borders or coast lines make up to 20% of the total number of cells, so they might not affect the overall analysis at EU scale, but should not be ignored either, in particular if results are going to be evaluated at regional scale. For this reason, in addition to the full grid of almost 50.000 cells at 10 km grid resolution, a second grid was produced by deleting cells belonging to the two categories above (borders and coasts). Some were excluded because they contained clear biases related to the intersection of different spatial datasets, the EU28 territory converted to the 10 km grid and the IUCN spatial dataset. The latter in fact, in some regions, ignored small islands or sections of coasts, because of its coarser resolution, and consequently very low richness level were erroneously assigned to those areas. This is the case, for instance, of the islands in front of the Croatian coast or within the Aegean Sea.

This analysis focuses on distribution of species as a whole. As said, the grid resolution used is 10 km by 10 km, but, originally, the actual resolution of the data used to draw the distributions may vary from species to species. This implies a certain degree of uncertainty, because rare species and very common species tend to be overestimated or underestimated in function of the scale (Gaston & He, 2011). At coarse grain, rare species tend to appear more widely spread, while at finer scales, occurrence of common and abundant species is undervalued. Finally, our work is based on the global assessment of species, which puts Europe in the global perspective, in line with target 6 of the Biodiversity Strategy. Using the European assessments would be advisable if the analysis focuses strictly on EU or its sub-regions (more on this in section 3.3).

3.2 Occupancy analysis

Occupancy is defined as the degree of presence of a species within an extent (Gaston & He 2011). The rationale behind our analysis was to identify those areas where, for any reasons, species had a more restricted (or wider) distribution across the Union. The next map (Figure 18) presents the average of ratios between the distribution areas of each species within EU 28 (area of occupancy) and the total EU 28 area. The index ranges from 0 to 1 and the actual mapped values are adjusted to be equal to one minus the calculated average, so that the higher the index, the narrower the distribution. Widespread species have lower values (if a species covers the whole EU28, its value equals zero). The map displays the density of species with restricted (or wide) distribution within EU28, at a 10 km by 10 km grid resolution. In red areas, the species present therein have a (relatively) narrow distribution. A small species distribution means a higher level of endemicity or uniqueness within the extent of analysis.

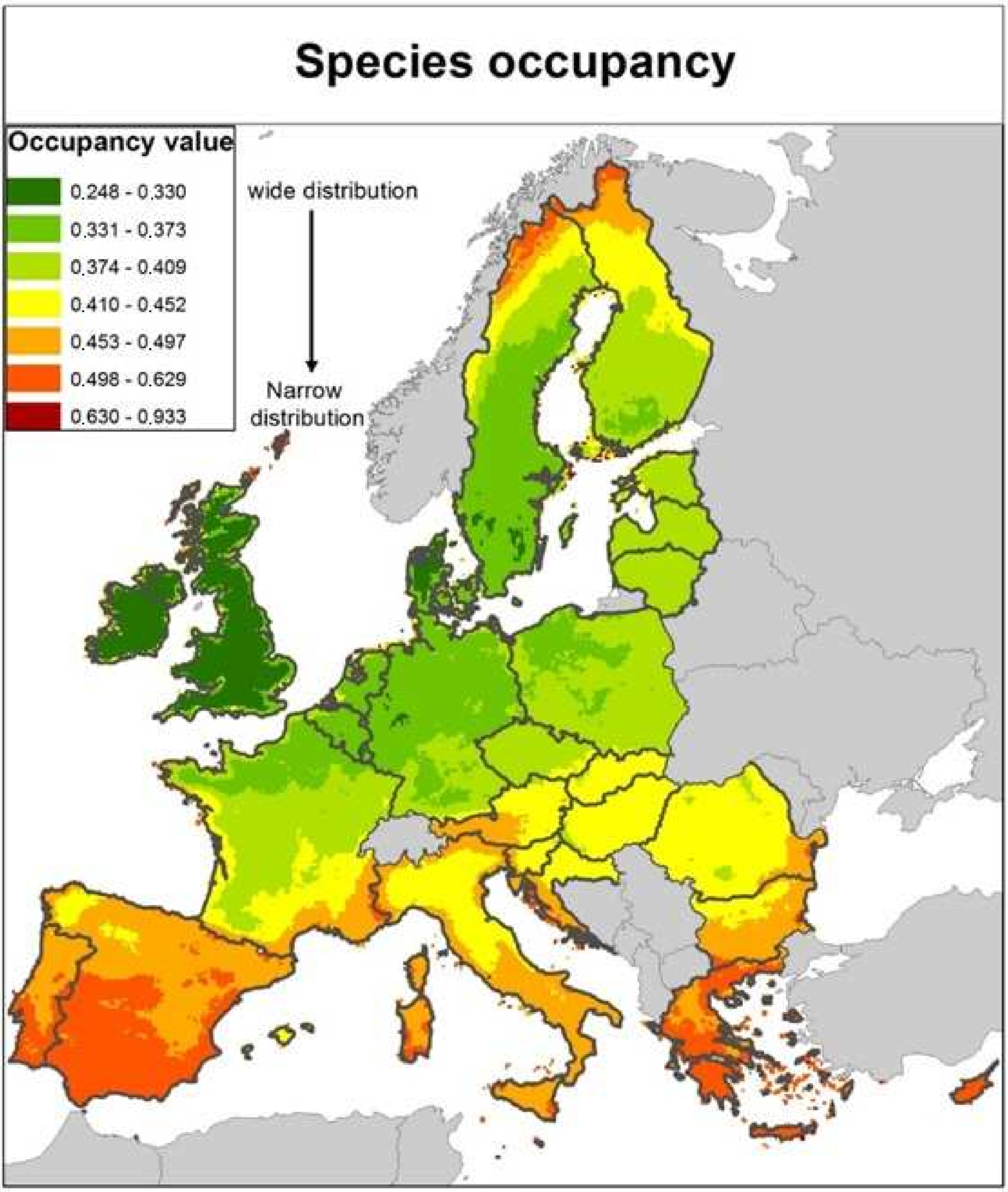


Figure 18: Average species occupancy in Europe in 10 km cells. A higher value means a high presence of species with narrow distribution in the examined cell

From a very general point of view, the species with a more restricted distribution should attract more attention, because they are more prone to significant habitat loss in case of disturbance and their populations tend to be smaller. However, this general statement can be questioned in several ways and it is worth to specify limitations. For instance, some species may have a wide but very fragmented distribution and a map at a relative coarse resolution would not allow detecting high levels of fragmentation, thus displaying an overestimation of their distribution. On the other hand, endemic species may have good viable populations, even if restricted distributions. Moreover, taxa behave very differently: dispersal or recovery capacity may be more important than distribution itself for the conservation of species, or the same area may host abundant populations for some of them and less than sufficient for some others.

The IUCN assessments and scientific literature (IUCN, 2014 and references therein) can provide very useful information to evaluate these and other arguments, before drawing conclusions on species or groups of species. However, at EU scale the map still succeeds to represent regions where high density of species with restricted distribution live, whether because of human induced reduction or evolutionary/bio-geographical history.

The ratios used to calculate the synthetic index from each taxon are relative to the extension considered, that is the EU28 territory. Then, one very important consequence to consider is that even species with a wide global or continental distribution, but still a narrow distribution within the EU28 borders, will have a high score, i.e. just like strict endemic species. This somehow arbitrary choice may not have a proper ecological meaning, but was considered as policy relevant. In fact, even if their distribution outside EU is wide, only the populations present within the EU28 borders are subject to the main EU conservation policies. Therefore, the lack of control over the whole distribution area may justify the choice to highlight them, just as other species with a true narrow distribution. At the same time, any ecological statement drawn on this theme must be cautious and take into account the previous considerations.

With further species-specific analysis, such as excluding the species present at the EU28 borders only and those whose distribution was severely reduced by human disturbance, the map should highlight the regions with the highest density of endemics as well.

A more sophisticated analysis of partitioning and fragmentation of species ranges would be certainly of great interest, but would also involve several other factors which were not analysed here (e.g. phylogenetic diversity). First, a detailed evaluation of data quality would be indispensable, since distance based spatial analyses are sensitive to resolution issues (Magurran and McGill, 2011); then, for the same reason, a comprehensive analysis across scales and their effect should be carried out. Finally, most likely it would be necessary to divide the taxa into groups and introducing some other covariates, in order to draw results of higher ecological meaning. A single index or weighing factor as presented here implies that measures applicable to one taxon are good for all the other taxa (i.e. measures concerning beetles are comparable to those for migrating birds). For a wider discussion on area of occupancy see Gaston & He (2011) and Jiménez-Alfaro et al. (2012).

It shall be noted that being an average of ratios calculated for each species, the mean occupancy score per cell may overlook the species with an extremely narrow distribution (ex. strict endemics) or within a region rich of species with a wide distribution. A more appropriate index to describe those phenomena is the minimum value of calculated ratios per cell. Figure 19 below displays this index; the map shows for each cell the occupancy of species with the most restricted distribution, regardless of the other species. Red areas in the map can be interpreted as regions of presence of at least one endemic species or a species whose distribution is particularly small. Towards green are those areas where all species recorded have a progressively wider distribution.

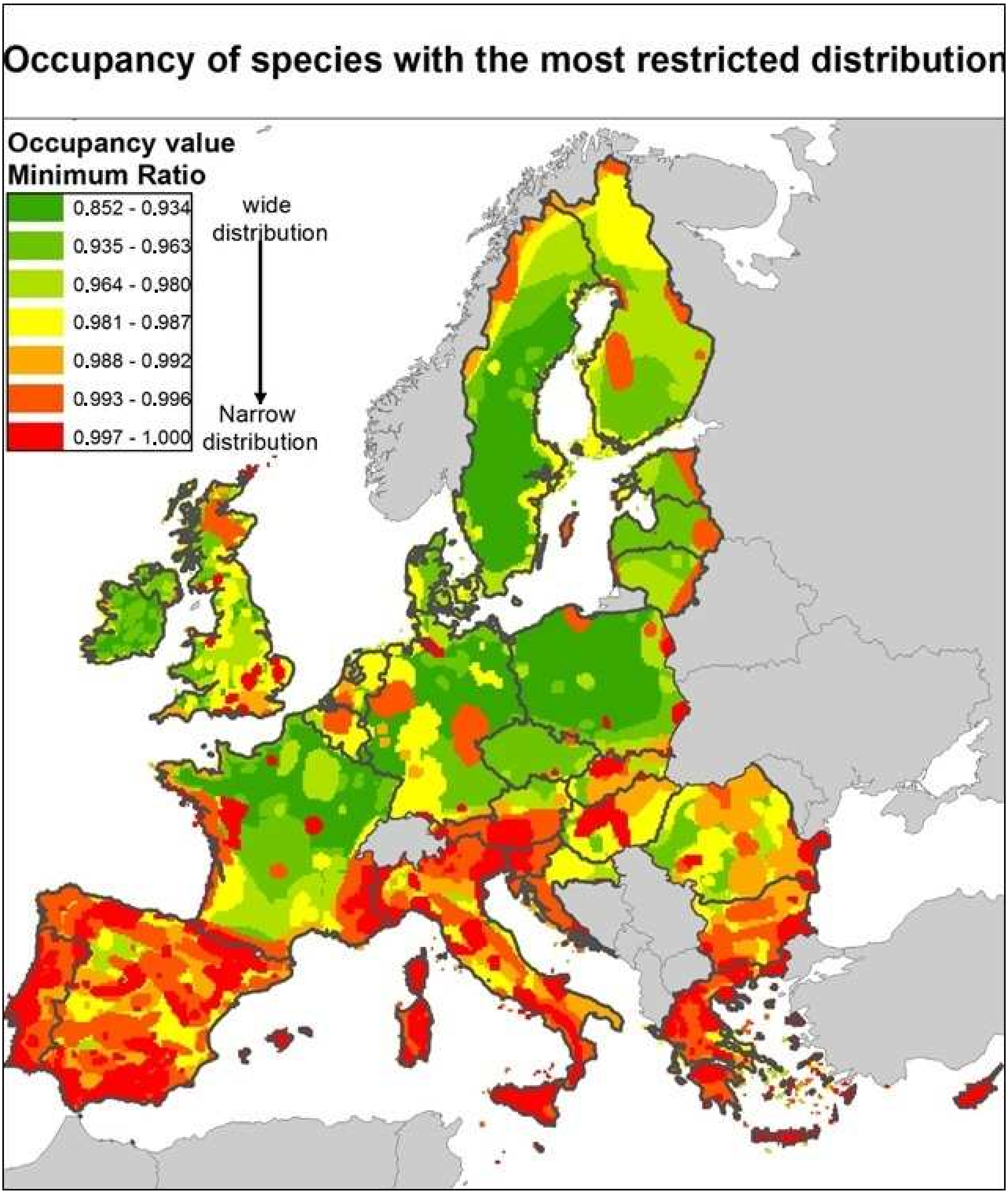


Figure 19: Minimum species' occupancy value in each 10 km cell

3.3 Threat status of IUCN species – The Red List Index

The Red List Index (RLI) is basically the mean value of species' threat status on a scale ranging from 0 to 1 in a determined extent: the lower the value, the worse the overall threat status of taxa within the geographical subset considered. A score of zero means that all species are extinct in that cell, a score of one that all taxa included in the analysis are classified as of Least Concern (Butchart et al., 2007). Figure 20 below is the map of calculated RLI, based on published IUCN species distributions and their global threat status assessments, at 10 by 10 km grid resolution.

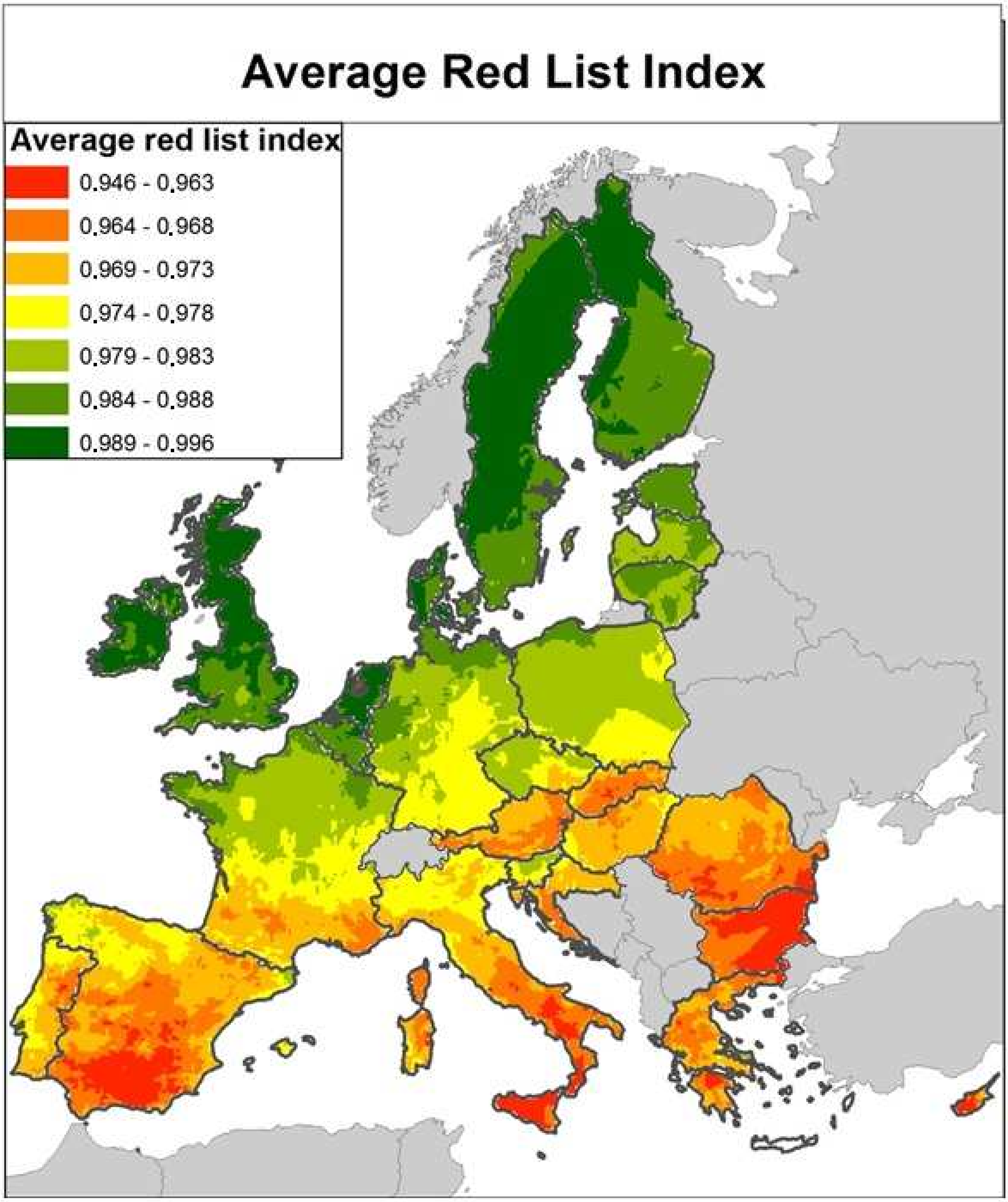


Figure 20: Average Red List Index values per 10 km cell. The higher the value, the better the species' average conservation status in the cell, according to their global assessment

This map shows the average IUCN threat status of species across EU28, according to their global assessment. Red areas contain a higher density of species with a worse threat status (i.e. more threatened species; extinct species were not considered). It is important to point out that average threat status score depends on species richness (shown in figure 24 pag. 42): in areas with a high number of species of least concern, species critically endangered may not show up on the map. On the other hand, in areas with a relatively low richness, a single seriously endangered species may bias the map downwards to a worse average threat status. If emphasis is given to more seriously threatened species, a possible solution is either to exclude the species of least concern (which are the great majority) or to select another measure for the assessment, for example only the worst threat status assessment among species found in each cell, or the ratio of endangered versus the others (see below).

Although the formal grid resolution is 10 by 10 km, actual resolution may vary from species to species: some species (i.e. many mammals) have very detailed distribution data, while others less studied may have much coarser spatial data, or simply may be the result of different mapping protocols (see IUCN documentation, IUCN 2014). Therefore, data extraction from small regional subsets should be done carefully, possibly checking the metadata on distribution of species involved.

The IUCN global assessment reflects the threat status at global scale. If referred to other geographical subsets, assessments conclusions may be different. For instance, some species may be not endangered at the global scale, while being so at local level. Assessments at different scale, in particular at EU level, are available (IUCN & EEA 2012), so which geographical subset choosing will depend on the scope of the analysis, not only from the spatial scale of interest. The map showed here uses global assessments, putting the IUCN species present in EU on a global conservation perspective. However, it is worth to do the same analyses using the regional/local assessments too.

Coasts in general show a different pattern from adjacent mainland; that is mostly related to the marine species that were assessed on adjacent seas. Mapping such species on the coast was the only way to give those species some consideration, in particular to highlight their relation with the terrestrial assessments and possibly the influence of mainland. In addition, coasts are of great importance for some species generally considered as marine species (i.e. sea mammals). However, a detailed selection of these could be a useful improvement for the map.

Conclusions drawn from the map should be evaluated carefully: greenish areas might be the result of successful policies of conservation - at the same scale of the IUCN assessments, global in this case - resulting in many species of least concerns, but also the result of multiple regional extinctions in pre-history and historical times, that left only the least sensitive species, or areas of relatively low conservation interest. Vice-versa, red areas might indicate a poor implementation of conservation strategies, but also stories of successful protection of rare, endemic or long time endangered species, suggesting spots of biodiversity of primary importance.

Koyanagi (2013) reports an interesting study on how the RLI can be used for the assessment of processes such as land abandonment and could be an interesting reference for further development.
To obtain a deeper understanding on the spatial distribution of threatened species across the

EU, other indexes have been calculated and mapped out starting from the original dataset, namely:

- *All_vs_LC* : ratio (by cell) of the number of species in all threat status but "Least Concern" versus the number of species with "Least Concern" status. It highlights the weight of "Least Concern" assessments on the total assessment
- *notLCvsTOT* : similar to the previous: ratio (by cell) of the number of species in all threat status but "Least Concern" versus the total number of species with any threat status (Figure 21 left).
- *ENCRvs_Tot*: ratio (by cell) of the number of species in "Endangered" or "Critically endangered" threat status versus the total number of species with any threat status. It highlights areas with the highest density of the most threatened species (Figure 21 right)
- *RLIwoutLC*: Red List index calculated after excluding species of "Least Concern". The map shows more clearly the score of taxa with a worse threat status (Figure 22).

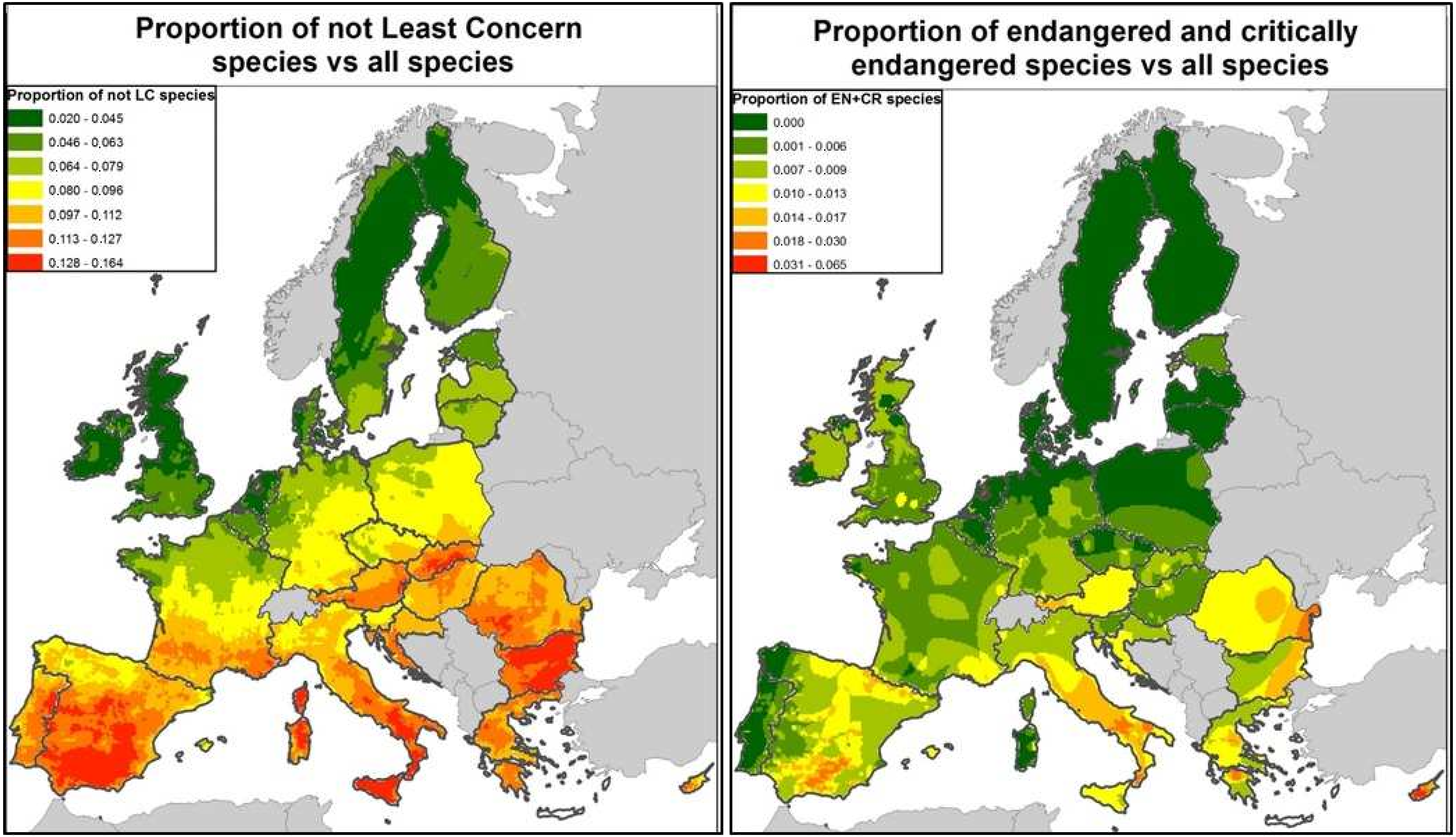


Figure 21: Left: Proportion of not Least Concern species per cell; right: Proportion of endangered plus critically endangered species per cell

As expected, the average RLI value and the share of not Least Concern species (Figures 20 and 21 left) show a similar pattern, since clearly the higher the relative abundance of endangered species, the lower the average index. In both cases, a spatial pattern emerges, with a gradient from North-West to South-East Europe emerging along which the Red List Index value decreases and the proportion of not Least Concern Species increases. This broad trend at the continental scale is further investigated in Annex 2. Figure 21 right instead shows the relative weight, in each cell, of the most threatened species (critically endangered and endangered). The previous pattern is much less identifiable, but still shows that, with very few exceptions, areas with a higher relative shares of seriously endangered species are to be found in Southern and South-Eastern Europe.

A further map shows the Average Red List Index excluding Least Concern species from the computation (Figure 22). As this category accounts for the majority of assessed species (but as seen, with a decreasing proportion from NW to SE), this map is intended to provide a better visualisation of the average conservation status of species that are threatened to some extent or Near Threatened.

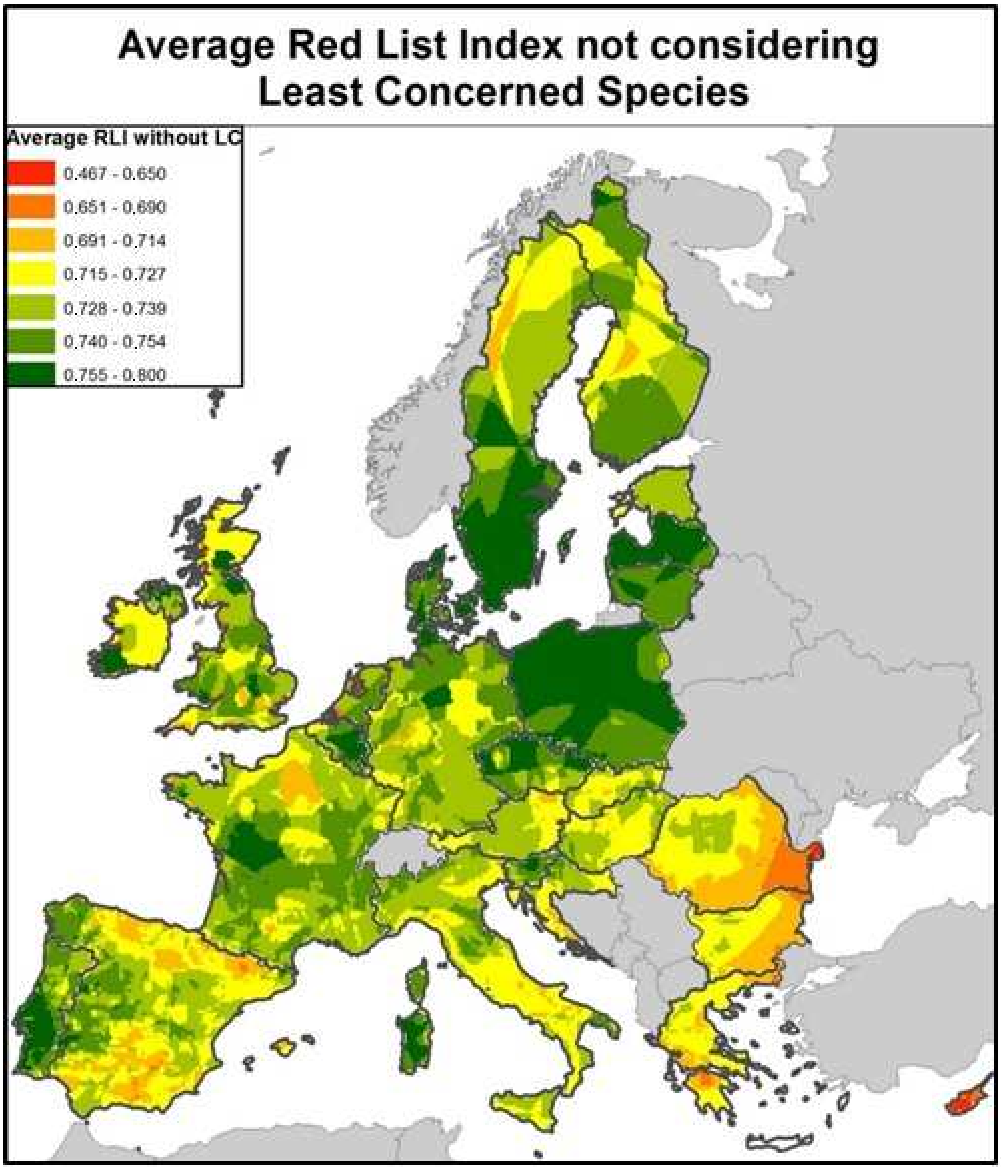


Figure 22: Average Red List Index calculated excluding Least Concern *species*

In fact, in areas with a high number of species of least concern, endangered species may not appear if the average value is displayed. In this new map, areas with relatively low values of the RLI index now show up also in Northern and Atlantic Europe, though there is still a prevalence of low values in already identified areas in Southern and South Eastern-Europe.

3.4 Species Richness

Species Richness is simply defined as the total number of species recorded in each cell. Figure 23 below displays the number of IUCN species across EU28, at the usual 10 by 10 km grid resolution

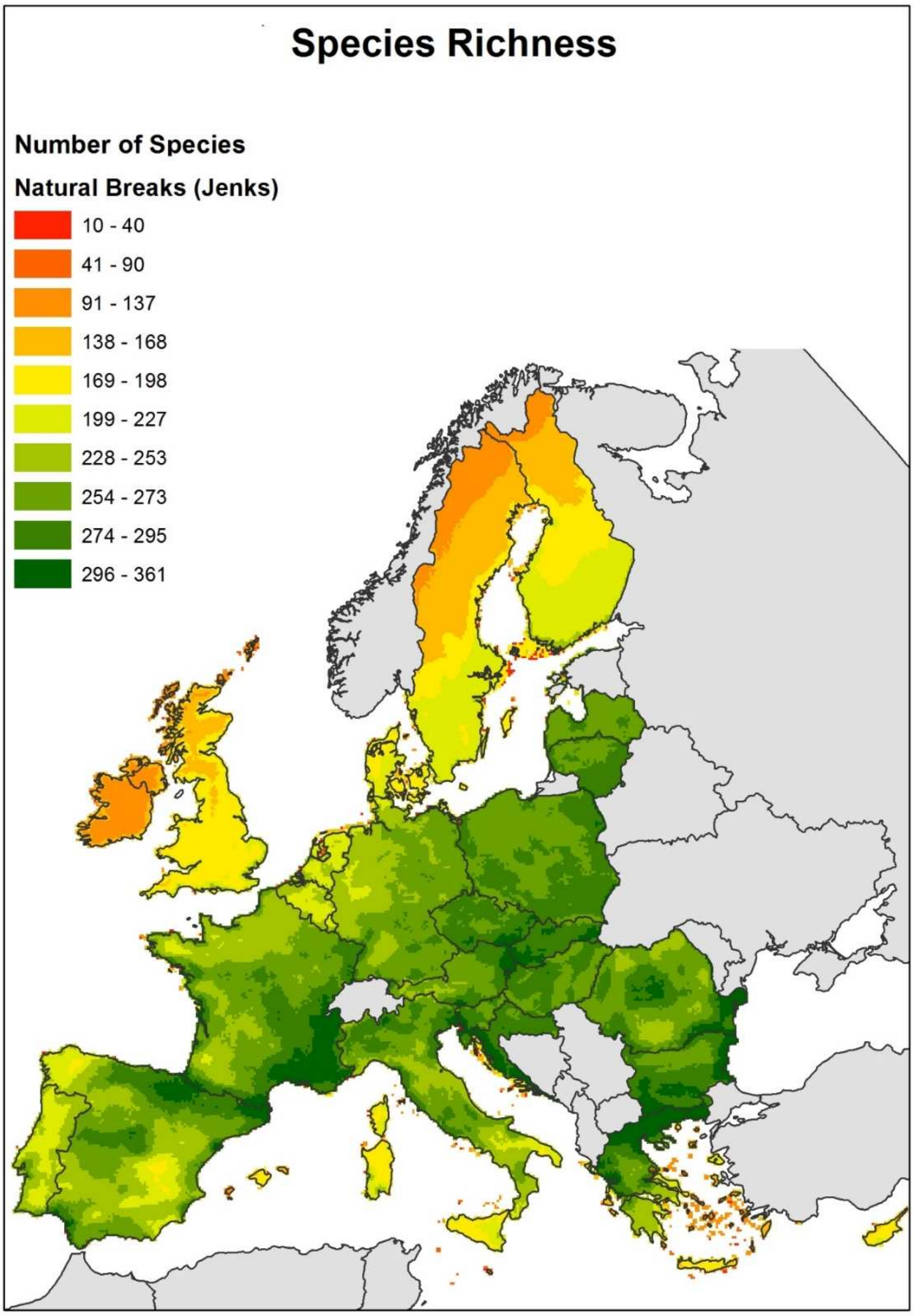


Figure 23: Species Richness - No. of species in each 10 km cell

Species richness is the simplest and perhaps the most popular biodiversity index worldwide. However, if the scope of the analysis goes beyond the analysis of richness itself, conclusions based on raw richness only may be controversial. For instance, concerning Europe, it appears that certain geographical regions on average perform worse than others. It is not possible to demonstrate from the map itself if this is the consequence of poor conservation strategies. Anthropic influence likely plays a role, but if the influence of humans on biodiversity is discarded, geographical patterns seem a more reliable explanation for the spatial pattern distribution, in particular latitude and isolation and perhaps morphology of terrain. If so, evaluating the effect of human impact or conservation actions becomes tricky, as any of those non-human driven factors may bias the conclusions.

In order to smooth down these differences and focus on events which act at finer scale, or to compare richness between regions for policy assessments, a method is needed to account for natural processes that influence richness. This would then allow separation and identification of most of the variability related to the other factors, such as anthropogenic pressure. However, given the complexity of such processes and the wide scale of our interest, it might be sufficient to focus only on main wide trends at such scale. This possibility has been explored and discussed in detail in Annex 2 of this report. We will therefore provide hereafter the main findings.

The aim of the analysis was to identify some general trends of species richness linked to major geographical patterns identifiable at continental level, and de-trend the data, in order to enhance in the index the component linked to other factors that can influence species richness, and on which policy can have an impact. Furthermore, after de-trending, the index can be more easily compared across countries, which is not possible using the original index since it is not correct to impute the lower number of species e.g. in Scandinavia compared to the Mediterranean to any human-related factor.

The three main geographical factors that have been identified and modelled are: latitude, longitude and isolation. The "Latitudinal diversity gradient" is one of the main observed ecological patterns, according to which the number of species increases from the poles towards the equator. Isolation is defined as the total amount of land area surrounding a cell within a certain radius and it relates to the Species-Area Relationship (SAR); this is another well-established ecological law according to which the number of species found within a certain region increases as its area increases, following a mathematical relation. We developed five different models with increasing degree of complexity to take into account such factors and derive observed species richness only from macro-geographic features. The predictive power of the models proved good, with R^2 values around 0.75-0.77, meaning that they are able to explain up to 75-77% of the observed variation of Species Richness in Europe.

Residuals of the models, e.g. the difference between the predicted and the observed richness, can subsequently be used as an indicator of the *relative richness* and be compared across different locations to identify "hotspots and coldspots ", e.g. areas where observed richness is significantly higher or lower than expected if only geographic factors determined it. Results indicate that regardless of the chosen model, hotspots and coldspots are found in the same areas. This is illustrated in Figure 24 with two examples taken from Annex 2. By applying this method, it will then possible to investigate whether variations of the relative richness correlate with other factors, e.g. related to human activity.

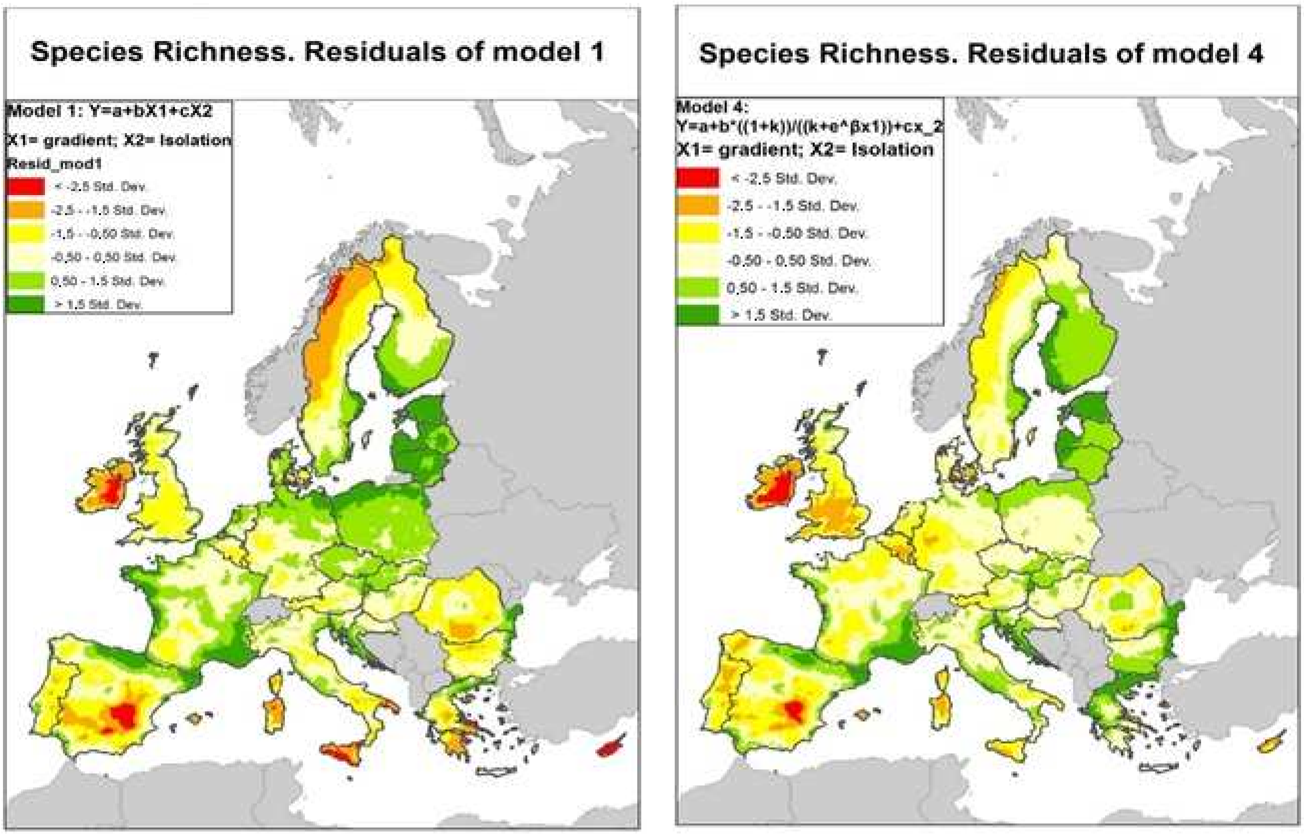


Figure 24: Example of spatial variations of an indicators related to species richness as derived from the two models reported in the legends. More details about these results are provided in Annex 2

Further analyses showed that the large scale trends in species richness are most likely also affected by anthropic pressures, agricultural management and so on but more research is needed to specify the individual contribution of each factor.

We also showed that not only species richness, but also their status in terms of distance from the risk of extinction are strongly affected at the continental scale by the geographical gradient (see Annex 2, Section A2.5) . However, if no straightforward interpretation could be given, we provided in Annex 2 a few research directions and further stressed the need to reiterate such exercise using the European species assessment from the IUCN instead of the global data used in this study.

In the next section, we will conclude this report by providing a couple of examples of applications combining both information obtained from the Art. 17 data on habitat assessment and the indicators on species richness and conservation status derived from the IUCN Red List of Threatened Species data.

4. Integrating Art. 17 and IUCN data

As shown in the previous sections, both art. 17 and IUCN data represent two comprehensive and powerful datasets providing valuable information at a continental scale. In this section, we provide some examples of how they can be conjointly used to derive information and inform policy-making.

4.1 Habitat Conservation Status and species richness

Using the usual 10 km reference grid, we first combined data on habitats mean conservation status, obtained by elaborating on the assessments provided by Member States pursuant art. 17 (see section 2.2, Figure 4) with IUCN-derived data on species richness. We considered the *relative richness*, i.e. not the total number of species recorded per cell, but the "de-trended" value, i.e. the residuals from the models (figure 25 section 3.4 and Annex 2), to account for the identified geographical trends. Both the mean cell's habitat conservation status and the relative richness were subdivided in three descriptive classes, as shown in Table 5 below:

Table 5: classification of 10 km cells according to their mean habitat conservation status and their relative species richness

Conservation status value (mean of all habitats assessments in each cell, where FV =1, U1=2 and U2=3)	Conservation status Class
≥1 and <2	"Good"
≥2 and < 2.5	"Average"
≥ 2.5	"Bad"
Relative richness values (residuals from models)	Relative richness class
1st tertile	"Low"
2nd tertile	"Medium"
3rd tertile	"High"

Therefore, each cell of the grid belongs to 1 of the 9 categories derived by the combination of the 3 x 3 categories defined above. Figure 25 below shows as an example the spatial representation of this cross-tabulation, using the residuals from model 2 (see previous section) to determine the relative richness, and the mean conservation status of all terrestrial habitats based on art. 17 assessments.

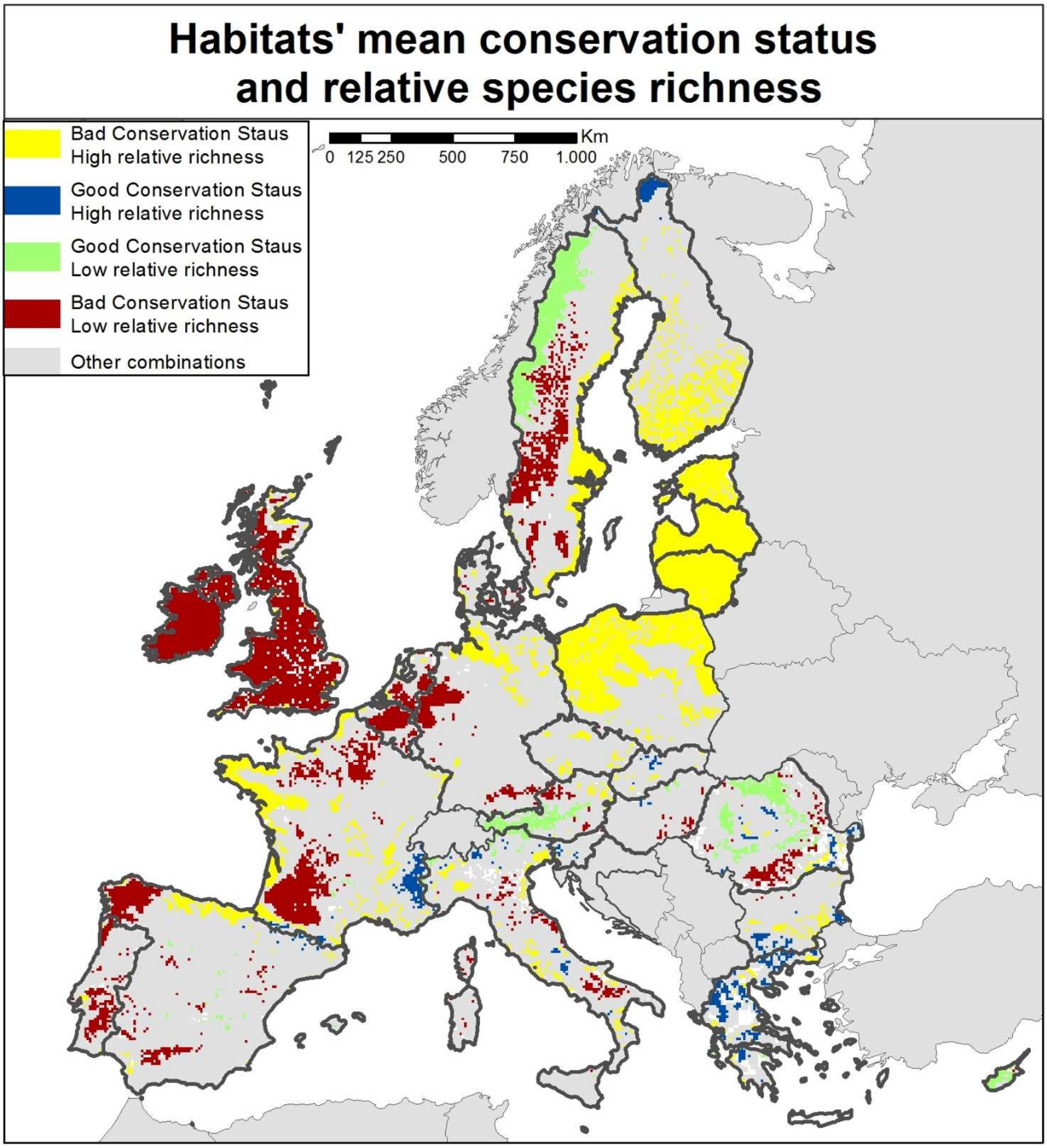


Figure 25: Spatial representation of habitats mean conservation status according Art. 17 assessments and relative species richness

To obtain a clear and straightforward visual representation, we highlighted in the map only the 4 most "extreme" combinations of habitats conservation status and species richness. Therefore, cells with an average/medium value either of conservation status or relative richness do not show up on the map. Blue areas in the map represent the best possible combination of good conservation status and relative high species richness; conversely, red areas may be considered the most problematic ones in terms of the Biodiversity Strategy's objectives, as they feature both a poor habitat conservation status and relative lower values of species richness (i.e. lower than expected even considering geographic trends). Yellow areas are relatively rich in biodiversity as far as species are concerned, but have a bad habitats conservation status, so they may identified as target for specific restoration measures aimed at improving habitats. Green areas feature a good conservation status but a relatively low richness: in such cases, other geographical factors may be important such altitude or asperity as they are all located in mountains areas.

4.2 Habitat Conservation Status and Red List Index

Similarly to what was done in the previous sub-section, we cross-tabulated for each cell the mean habitat conservation status and the mean Red List Index. Again, three classes for each indexes were defined; respectively labelled as "good", "average" and "bad". As regards the Red List Index, the values of the first and second tertiles were considered. As concerns the habitats status, the same values reported in Table 5 were used. For each 10 x 10 km cell, 9 combinations of habitats status and threat status (expressed through the Red List Index) are thus possible. In the following map (Figure 26) the four most interesting combination are showed.

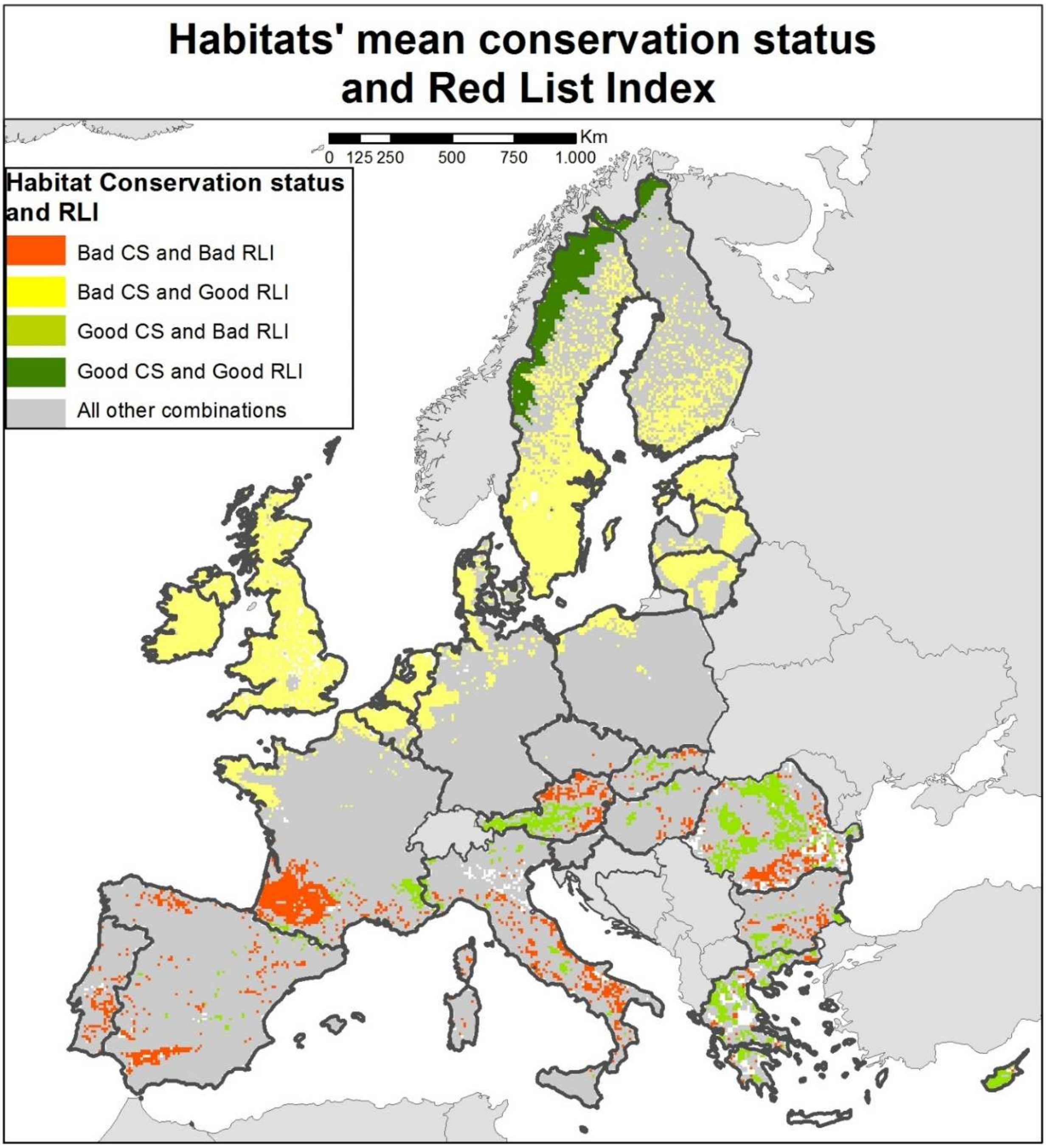


Figure 26: Spatial representation of habitats mean conservation status according to art. 17 assessments and Red List Index

The following contingency table provides possible interpretations of the four combination displayed in the previous Figure.

Table 6: Possible interpretations of different combination of species threaten status expressed through the Red List index and Habitat Conservation Status (per cell).

Average species conservation status (Red List Index	habitat conservation status	Possible interpretations
Good	Good	Successful policies of conservation, low anthropic pressure.
Bad	Good	Stories of successful protection of rare, endemic or long time endangered species, spots of biodiversity of primary importance to be preserved.
Bad	Bad	High anthropic pressure, poor implementation of conservation strategies
Good	Bad	High anthropic pressure, low richness with a majority of common and generalist/tolerant species, sensitive species proportionally less represented or extinct in historical times

Again, and keeping in mind the Red List Index trend along the NNW-SSE gradient (see section 3.3 and Annex 2), the spatially explicit representation allows identifying some wide geographic trends useful to target policy interventions. At a first glance, it can be noted that only the most remote areas in Europe in the Scandinavian Mountains feature a good conservation status and a good Red List Index. Clearly, very low anthropic pressure is a key factor here, but such areas may also be taken as positive examples of successful conservation policies – most areas belongs to Nationally designated Areas and/or the Natura 2000 network. Therefore, in these cases policy measures may be limited to the maintenance of the current status of such areas.

A combination of good Red List Index and poor conservation status, which may reflect low richness with a majority of common and generalist/tolerant species, with sensitive species less represented or extinct, is found in the British Islands and in North Atlantic/Boreal regions (in yellow in the previous map). Such areas can thus be the target of measures aimed at improving the ecological equipment (e.g. the green infrastructure)

Areas with good habitat status but bad Red List Index are found predominantly in mountain areas in the Alpine and Mediterranean Bioregions. The low value of the Red List Index is not necessary an indicator of ineffective conservation measures, on the contrary such areas may represent stories of successful protection of rare, endemic or long time endangered species. Overall, they can be identified as spots of biodiversity of primary importance to be preserved and, if possible, enhanced.

Areas with "bad" values of both the Red List Index and habitat conservation status are the most problematic ones: they are scattered across central and Southern Europe and are likely to suffer from high anthropic pressure (intensive agriculture, urbanization) and/or represent cases of poor implementation of conservation strategy. They can thus be the target of restoration and renaturalisation measures, but also of broader policies aimed at decreasing the anthropic pressures on ecosystems.

5. Conclusions and ways forward

Biodiversity loss and habitats degradation are among the most critical environmental problems Europe and the world are called to address in the next years. The European Union has established a set of ambitious but attainable conservation objectives within its Biodiversity Strategy for 2020, notably including halting the loss of biodiversity and ecosystem service degradation of ecosystem services by 2020, establishing a Europe-wide green infrastructure and restoring 15% of degraded ecosystems. These objectives are in turn translated into specific and measurable actions that the EU and individual Member States at different level have to implement. Such efforts must rely on affordable and informative data on habitats and species status to target policies, identify priority areas for intervention, and monitor progress towards the achievement of stated objectives. Research is thus needed on each of these aspects to provide policy-makers with accurate and useful information.

In this study we carried out some elaborations on the aforementioned issues by exploiting two essential datasets: 1) habitats conservation status assessments used in the third European Report on the status of habitat pursuant Art. 17 of the Habitats Directive for the 2007-2012 period; 2) IUCN Red List of Threatened Species data on (global) species threat status. A spatially explicit evaluation of conservation status of all terrestrial habitats in Europe was performed, allowing to visualize the mean habitat conservation status at the EU level on a 10 km x 10 km resolution grid. Agriculture-related habitats were identified and assessed against the other habitats, results indicating that on average the former have a comparative worse conservation status. Statistical analyses were also performed to identify threats and pressures having most influenced the status of the agriculture-related habitats.

IUCN data on species richness and threat status were used to produce spatially explicit representations of species distribution, status and richness across the EU 28. A first major result ensuing from this exercise is the identification of wide geographic variables linked to ecological theory that explain to a large extent the continental trend in species richness. These variables are related in particular to the latitudinal gradient (which in Europe was identified as a lati-longitudinal gradient) and the species-area relationship. Empirical models were consequently developed to remove these trends, allowing us to better reveal the locations with highest and lowest biodiversity.

Finally, we provided an example of how the two exploited datasets can be jointly used by cross-tabulating data on habitat assessments and species threat status in a spatially explicit way at 10 km resolution, aiming at identifying different situations were different types of policy measures could be implemented.

Beyond the specific analyses made in support of Art.17 assessment, much research has been conducted to explore the potential use of the global Red List of Threatened Species to produce in-depth knowledge on biodiversity at the EU level. These efforts demonstrated that even when using relatively simple data and indicators, results may show complex patterns, especially if the spatial dimension is explicitly taken into account.

Policy objectives are to be formulated in a clear, straightforward and possibly measurable way, as it is case for the EU Biodiversity Strategy. Accordingly, research shall strive to provide clear and usable outputs to effectively support the design, implementation and monitoring of the policies. This study, however, highlighted the complexity of underlying processes and the fact that having access to better data not necessarily provides all the answers, but rather opens possibilities for new research.

Potential developments and analysis options stemming from the present study are manifold. As regards the elaborations based on Art. 17 assessments, the conservation status of agricultural-related habitats, which was shown to be on average worse compared to the other habitats, could be put in relation with some spatially explicit indicators on farming intensity and livestock (Robinson et al. 2014) to derive information on whether, how and where management practices influence habitats status.

The analyses on pressures and threats can be further deepened by considering geographical subsets to see if pressures' impact on habitats changes in space depending on broader geographical features.

As already pointed out, in this study we used the global IUCN Red List of Threatened Species. The same analysis shall be carried out using the European database to look for possible differences and matches with Art. 17 data. Results showed that also the Red List Index is strongly correlated to the identified lati-longitudinal gradient, but detrending was not carried out because it was not straightforward to disentangle "geographic" factors from anthropic ones. This point thus deserves further research and opens the way to new developments. The same applies to occupancy analysis.

More broadly, further research can build upon the developed empirical models to add other environmental variables (e.g. energy, soils, water, morphology of terrain) and/or the other ones accounting for human pressure and dynamic phenomena to develop comprehensive multivariate models. Further extending the above to functional and ecological traits and/or selection of taxa/sub-groups/sub-regions, one will find a great potential for development towards both theoretical ecology and environmental assessments. Other possibilities include a systematic and complete analysis of the SAR models and parameters across geographical/environmental gradients with a consistent dataset.

The analyses presented are multi scale, the methodology can therefore be re-applied at much finer scales, provided the underlying data set can match such resolution. This would allow us to distinguish nested models in the spatial correlation and decompose the factors affecting microscale and macroscale variations. All such elaborations can feed policy oriented analysis, with comparison and assessment of different policy scenarios and regional differentiations.

From the modelling point of view, we have resorted to empirical, low-degree polynomial models but more advanced methods could be used such as geostatistical methods that can take the spatial correlation and geometrical anisotropies explicitly into account and can further benefit from the use of additional information in a multivariable framework (see e.g. Goovaerts, 1997; Fortin and Dale, 2005). As for the statistical analyses, we employed in this study maximum likelihood estimates for model parameters and tests, but different approaches can be pursued. For instance, Bayesian techniques represent a very interesting alternative, specifically developed to deal with uncertainty and complex relationships among variables.

As for data requirements and needs, quality issues shall not be underestimated. Art. 17 assessments and reports have strongly improved compared to the previous period but it is inherently still difficult to avoid differences in data collection accuracy and a certain degree of subjectivity between Member States. For what concerns the Red List of Threatened Species, the limitations due to the non-homogeneous species distributions of species occurrences within the geometries defined by the theoretical ranges are obvious. Ecological information available in the right format for systematic and automatic analysis is also still lacking, although abundantly present as plain text in the scientific literature and within the reports published by IUCN itself. This includes information on functional traits, trophic roles, sensitivity, morphology, population ecology, habitat requirements, etc. As underlined in the Global Biodiversity Informatics Outlook (Hobern et al., 2013), translating this wealth of information in a synthetic and consistent way, such as a tabular format, would have a major impact on conservation and biodiversity analyses, leading to many applications and theoretical ecology developments.

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ANNEX 1

List of pressures on habitats used by Member States under art. 17 assessment.

Pressure code	Description	Analysis code
A01	Cultivation	1
A02	modification of cultivation practices	2
A02.01	agricultural intensification	3
A02.02	crop change	4
A02.03	grassland removal for arable land	5
A03	mowing / cutting of grassland	6
A03.01	intensive mowing or intensification	7
A03.02	non intensive mowing	8
A03.03	abandonment / lack of mowing	9
A04	grazing	10
A04.01	intensive grazing	11
A04.01.01	intensive cattle grazing	12
A04.01.02	intensive sheep grazing	13
A04.01.03	intensive horse grazing	14
A04.01.04	intensive goat grazing	15
A04.01.05	intensive mixed animal grazing	16
A04.02	non intensive grazing	17
A04.02.01	non intensive cattle grazing	18
A04.02.02	non intensive sheep grazing	19
A04.02.03	non intensive horse grazing	20
A04.02.04	non intensive goat grazing	21
A04.02.05	non intensive mixed animal grazing	22

ANNEX 2

Use of the IUCN Red List of Threatened Species data for assessing Species Richness

A2.1 Species Richness

Species Richness is simply defined as the total number of species recorded in each cell. Figure 27 below displays the number of IUCN species across EU28, at the usual 10 by 10 km grid resolution

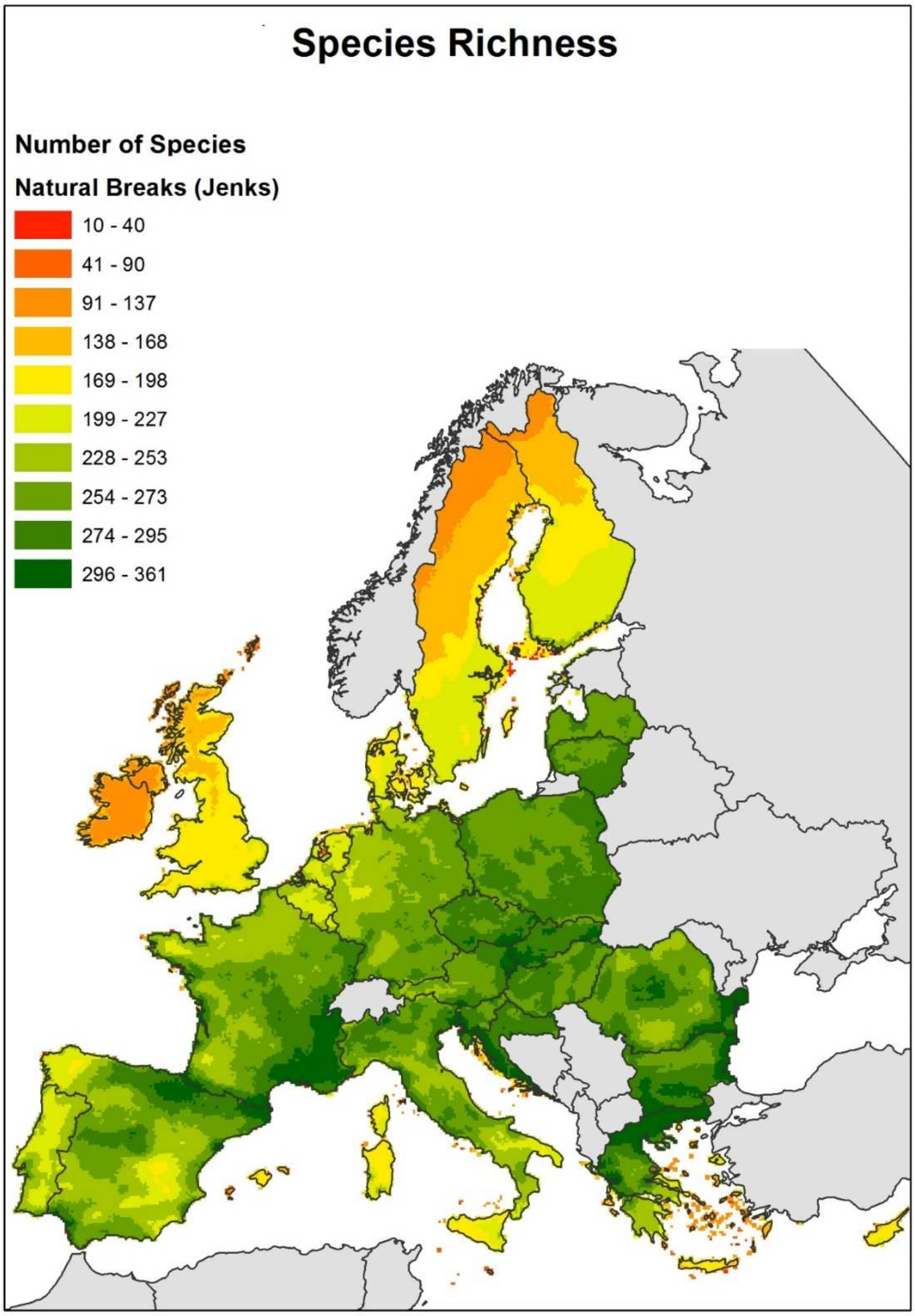


Figure 27: Species Richness - No. of species in each 10 km cell

Species richness is the simplest and perhaps the most popular biodiversity index worldwide. However, if the scope of the analysis goes beyond the analysis of richness itself, conclusions based on raw richness only may be controversial. For instance, concerning Europe, it appears that certain geographical regions on average perform worse than others. It is not possible to demonstrate from the map itself if this is the consequence of poor conservation strategies. Anthropic influence likely plays a role, but if the influence of humans on biodiversity is discarded, geographical patterns seem a more reliable explanation for the spatial pattern distribution, in particular latitude and isolation and perhaps morphology of terrain. If so, evaluating the effect of human impact or conservation actions becomes tricky, as any of those non-human driven factors may bias the conclusions.

In order to smooth down these differences and focus on events which act at finer scale, or to compare richness between regions for policy assessments, a method is needed to account for natural processes that influence richness. This would then allow separation and identification of most of the variability related to the other factors, such as anthropogenic pressure. However, given the complexity of such processes and the wide scale of our interest, it might be sufficient to focus only on main wide trends at such scale. We explored this possibility in the following sub-section.

A2.2 Identification of macro-geographic trends of species richness in Europe: the role of latitude and longitude

The first and most obvious pattern emerging from Figure I above is the reduction of richness at increasing latitude. The "Latitudinal diversity gradient" has been known for a long time (e.g. Forster 1778, Fisher 1960) and analysed for many taxonomic groups, usually showing a linear trend of decreasing richness towards the Poles (notable exceptions are reviewed in Storch et al, 2007). However, a definitive causal-effect link for it has not been established yet (Willig et al., 2003, Magurran and McGill, 2011), making it one of the most active fields of bio-geographical research.

Hawkins et al., (2004) blames the fact of calling such gradient "latitudinal" because this implies only one dimension, while it should be intended as a component of a wider set of "geographical" gradients, including longitude and altitude for example. This hypothetical set of geographical variables could be even ignored, in favour of the direct analysis of explanatory variables related to the ecosystems and species, such as climate or soil type. In fact, today such information are readily available as spatial dataset, while in the past their absence justified the introduction of latitude as a proxy variable. However, for simplicity we decided to keep the latitudinal perspective of richness, as a shortcut, because the aim of the work was not to determine the causes of geographical gradients, but simply to extract a spatial pattern, an approach that Hawkins (2004) himself admits. Also, given the extent considered, it works well for Europe.

For global analyses, other options should be considered, even for a comprehensive spatial pattern analysis (see Field et al, 2009 for an extensive meta-analysis of gradients of richness and in Storch et al, 2007 for a wider dissertation on geographical patterns of biodiversity). As suggested, the latitudinal gradient relates to several factors (Turner, 2004). Among those one in particular, accordingly to Hawkins et al., (2003): climate, which at last brings to energy and water availability. Where both energy and water are available and abundant, higher levels of richness are found, and vice-versa. For Europe in particular, energy is a very relevant factor (Fig. 1 in

Hawkins et al., 2003) and relates directly to latitude, given that solar radiation reaching the ground decreases towards the Poles.

An approach which tries to identify general latitudinal trends was applied to the data for exploration purposes, in order to verify if any significant trend was present. Capturing the wide scale trends would allow us to analyse differences in species richness across regions by just weighting those trends or de-trending the data.

The blue dots in Figure 28 show the species richness on vertical axis for each cell, projected on latitude. The lighter blue line is a fitted polynomial model showing the general trend of richness as a function of latitude. Looking at the same model applied to the whole dataset from another perspective (Figure 29), it is possible to visualize together the richness trends for both Longitude and Latitude (green line and blue line respectively). The light blue cloud represents cells' richness values, on the vertical axis, against latitude and longitude.

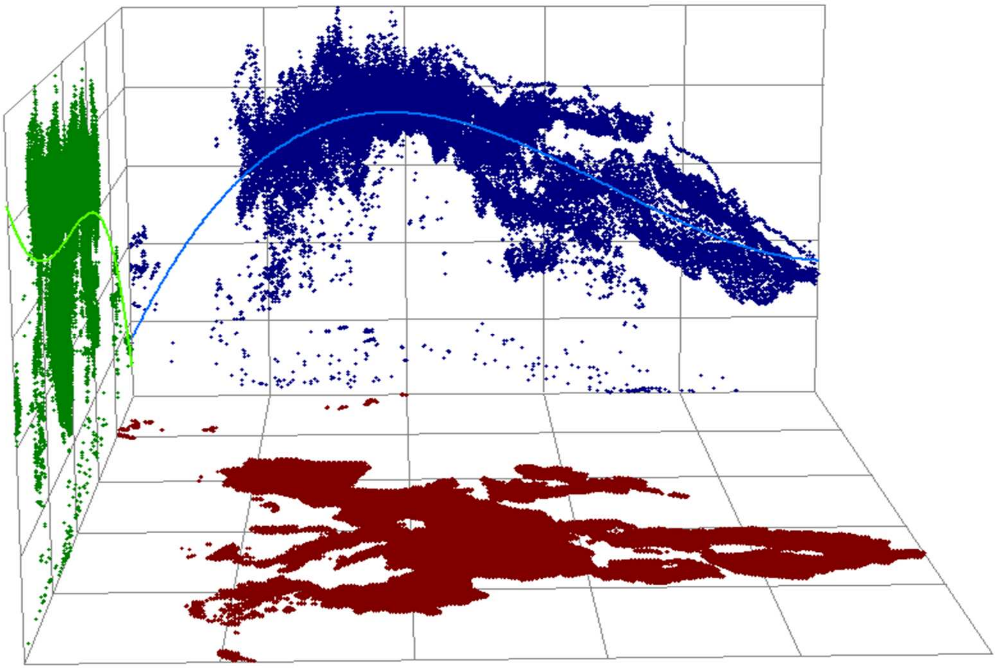


Figure 28: Species richness in Europe projected on latitude

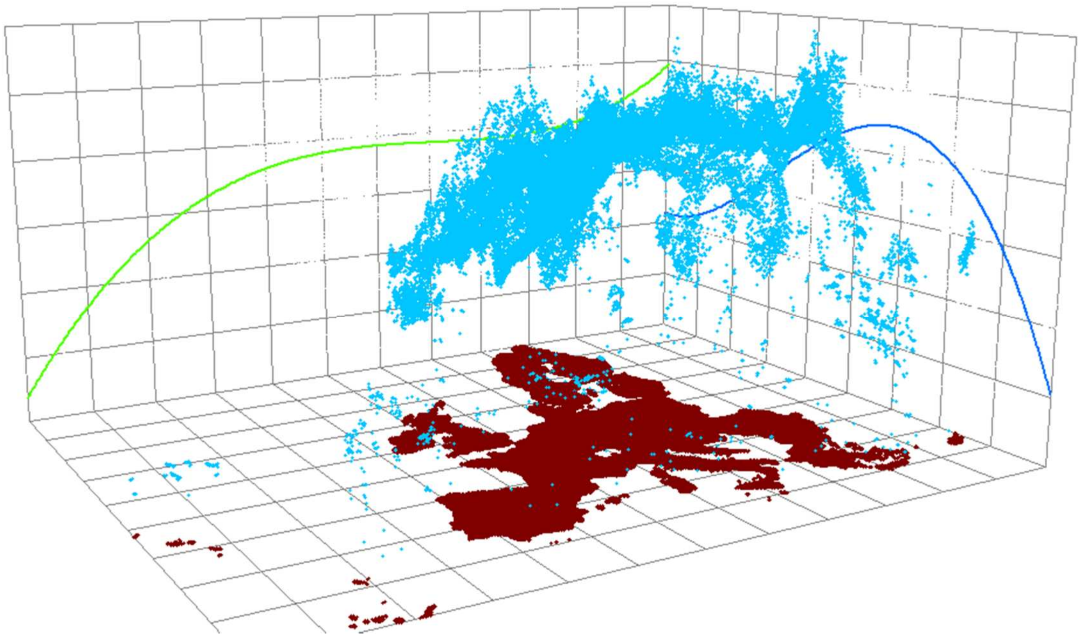


Figure 29: Species richness in Europe projected on latitude and longitude

Changing the orientation of the horizontal axis makes it possible to fit the model in any direction. Figure 30 for example shows an extremely consistent trend, which goes from North-West to South-East of Europe and may well be considered the "true" geographical gradient of richness across Europe (small islands and national borders were removed to avoid some data issues illustrated before). This appears to be the same gradient identified for the Red List Index (Figure 20). Such a trend is likely to be related to a combination of latitudinal (i.e. climatic) and biogeographic factors, as it is also discussed later. However, a specific reference was not found and this pattern may deserve further investigation (but see Coope et al.,1998; Hortal et al., 2011, Field et al., 2009 and Svenning and Skov 2007). Two comprehensive analysis of patterns of richness are found in Storch et al, (2007) and Gaston (2003).

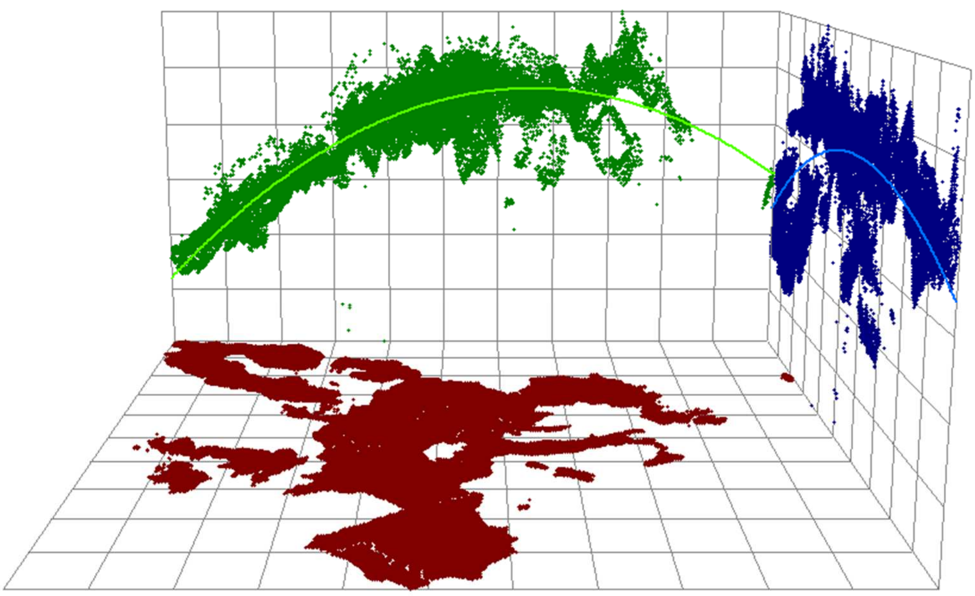


Figure 30: Species richness projected along a North-West South-East gradient

Despite the big deviations of points from the modelled lines, especially in Figures 28 and 29, the images suggest that some general trends of species richness across Europe actually exist. At a first glance, they appear to be linked to latitude and longitude. Besides that, common knowledge in macro-ecology suggests that another geographic factor having a role is **isolation**, intended, *sensu lato*, not only as the distance of islands or peninsulas from the main continent, but also as the incremental amount of land available at increasing distance. Therefore, in the following, we analyse IUCN data accordingly to those geographical wide-scale trends, in an incremental way, firstly looking more in detail to latitude and longitude, then adding isolation as a further explanatory variable.

The aim is to develop a general empirical model able to describe species richness in Europe taking into account wide geographic trends; once they are sufficiently isolated from the other factors influencing richness at local scale, it should be possible to smooth down or delete their effect, or on the other hand to focus at best the attention on them. Although de-trending was recently discouraged for specific inference and modelling purposes (Beale et al., 2010), it was still applied in this analysis to account for wide scale components influencing richness. In addition, the work presented here is aimed at exploratory purposes, rather than inferential or hypothesis testing.

The adopted empirical approach consists in using global regression (also known as polynomial regression), a method suited to describe non-linear relationships, where multiple interacting factors cause complex patterns of the dependent variables, species richness in this case. Its features free the analysts from making any assumption about the data and the causal relationships among variables, because it is based on empirical data (Fortin et al., 2005). In GIS science, it is often used for interpolation purposes. Unlike smoothers or other empirical techniques, polynomials' curves are influenced by the data as a whole, while are relatively less sensitive to local variation of data as long as the polynomial order remains low. It is thus well suited to describe wide scale trends.

A polynomial model assumes the following general form:

$$Y = a_0 + a_1X + a_2X^2 \dots + a_nX^n + e \qquad (1)$$

Where X is latitude and Y is species richness. This approach not only prevents us from generating separate models for each trend, but also has the advantage of being quick, simple and not sensitive to local scale events.

This modelling exercise is applied first to a single dimension, aggregating all cells from the same latitude and using as reference the average richness calculated for each latitudinal slice (dots of Figure 31). Different orders of polynomial were applied to the data and are showed as lines in the same plot. The orders of polynomial showed were selected based on their significant improvement in respect to the preceding order (analysis not shown).

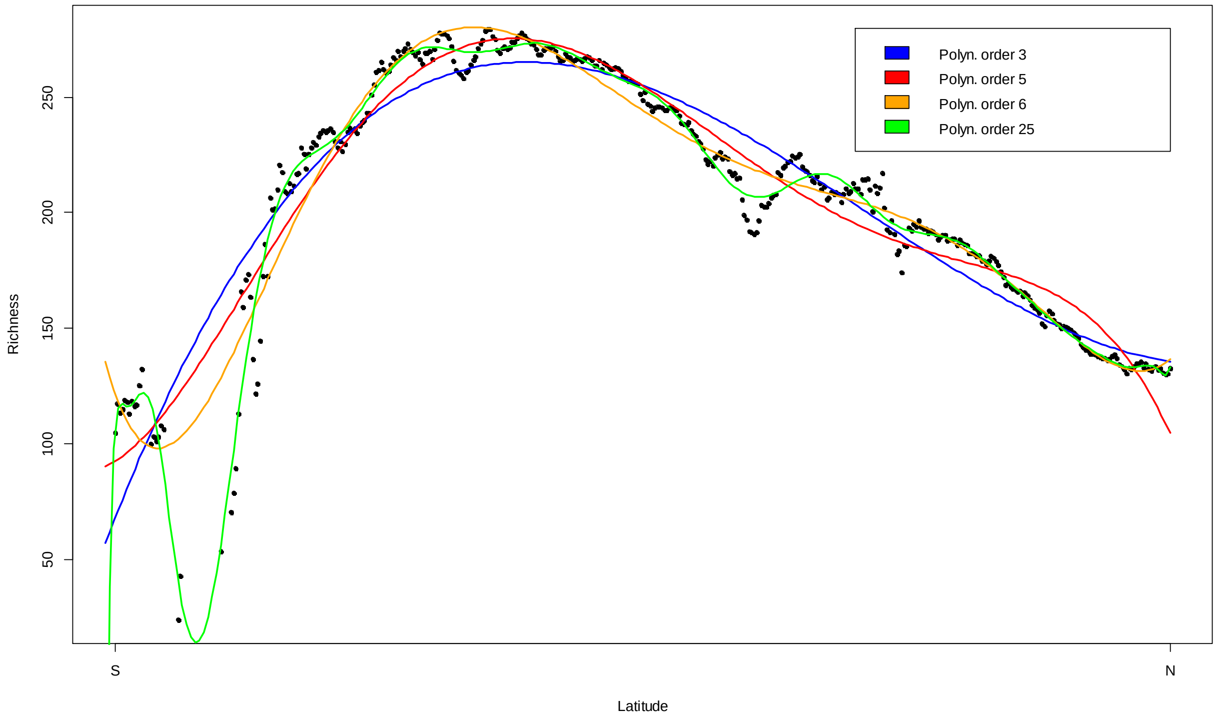


Figure 31: Fitting of 4 different polynomial models to average species richness per latitudinal slice

As shown in Figure 31, models of different order have different shapes, leading the same latitude slices to be identified sometimes as hot-spots of richness, sometimes as highly species deficient. The reasons are multiple: the order, the choice of variable, the aggregation and distribution of data. Statistical techniques allow choosing the "best" model, in the sense of best mathematical fit to the data, but its true meaning is hard to defend when compared with other very similar models giving opposite results.

Plotting the residuals of three polynomials (Figure 32) pictures again the different fit of models, but in addition shows a clear non-random pattern distribution of dots, suggesting further inspection of data, first of all to account for spatial auto-correlation. A useful dissertation on these modelling methods and issues is found in Zuur et al., (2009) and Beale et al., (2010). High deviations from the model were expected anyway; otherwise, it would imply either that the model filtered away all the variability within the data (as might happen in case of over-fitting), or that no other events are determining species richness, apart from latitude.

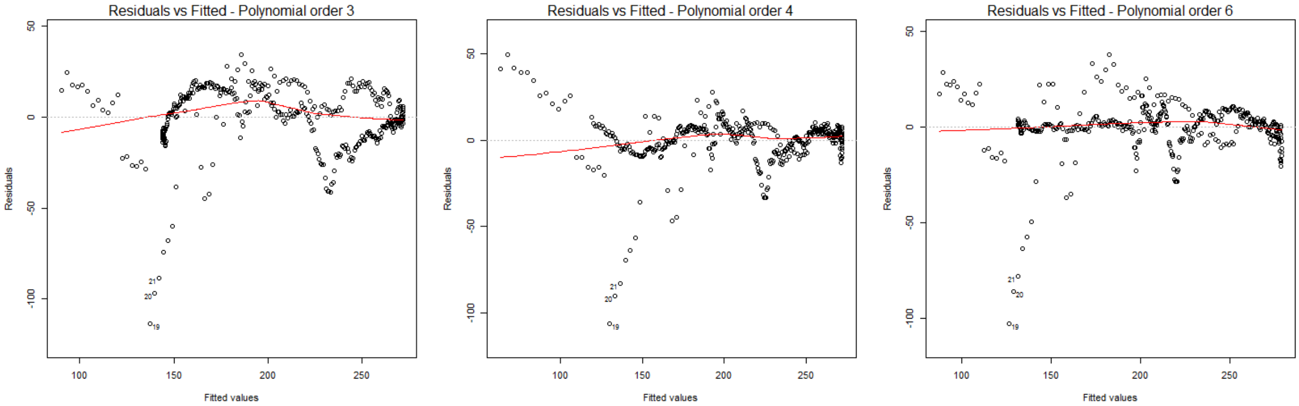


Figure 32: Residuals vs fitted values of species richness for the three polynomial models of order 3, 4 and 6

In Figure 33 below, as an example, the residuals of the sixth order polynomial model are mapped to give a rough idea of what could be expected from an agreed model acting as species richness baseline. The colours highlight those areas were species richness lays below or above the fitted model, supposedly in relation to other factors than latitude.

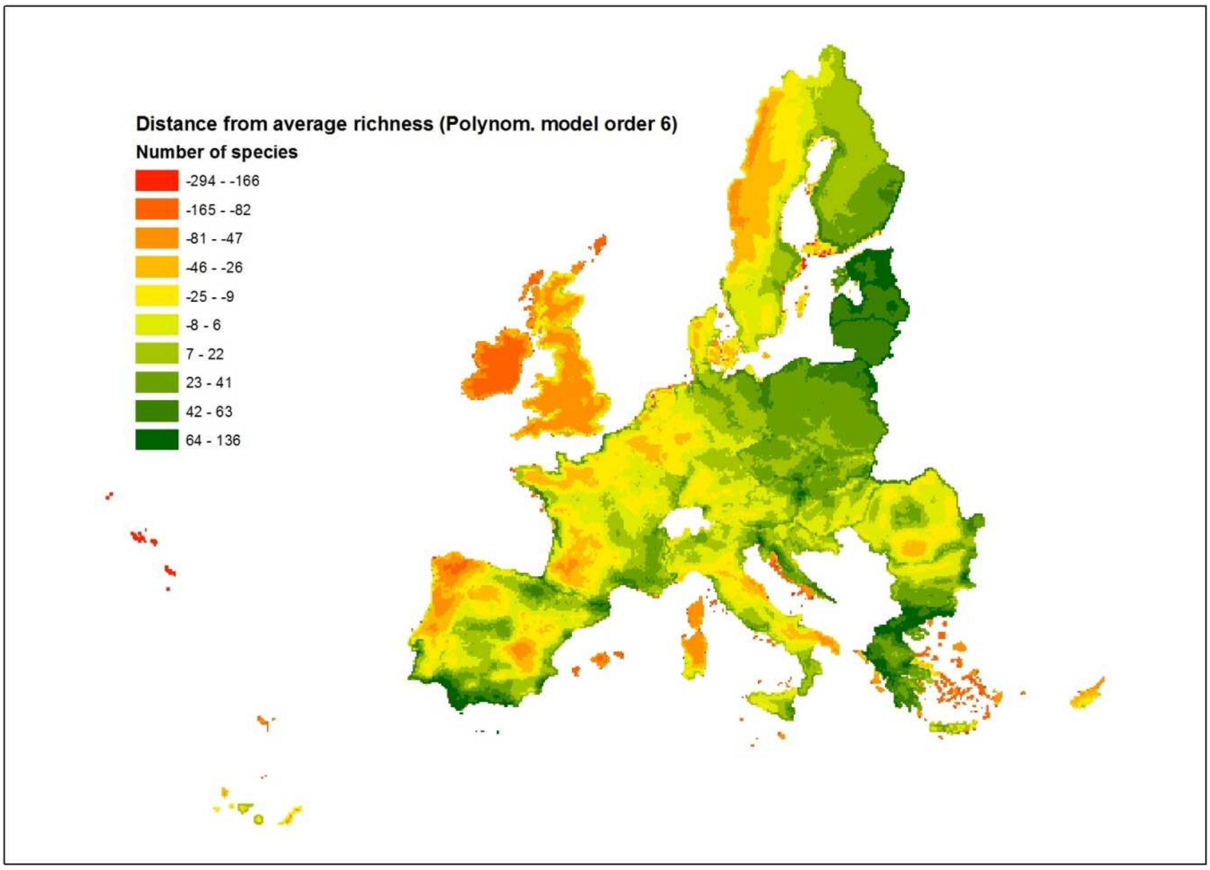


Figure 33: Distance from average richness – residuals of order 6 polynomial model accounting for latitude. Resolution: 10 km square cells

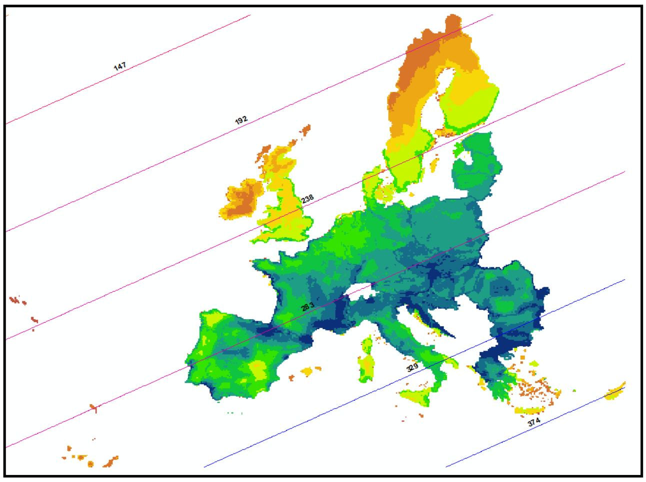
Latitude and Longitude

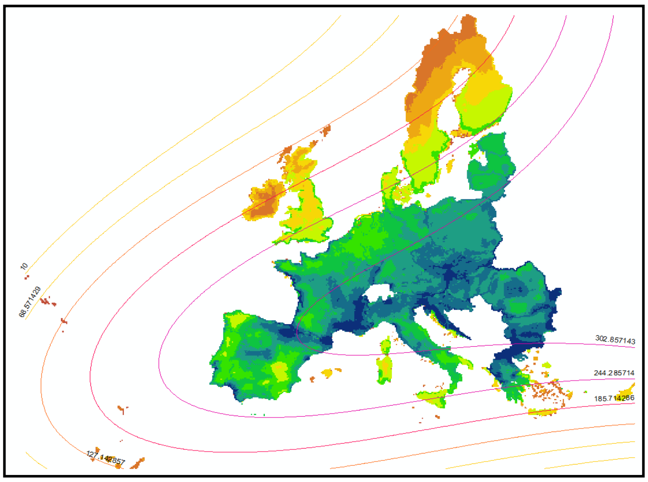
The next step in the modelling exercise is to consider both latitude and longitude, again using the polynomial approach. In this case, the polynomial assumes the following general form:

$$Z = a_0 + a_1X + b_1Y + a_2X^2 + b_2Y^2 + c_1XY \ldots + c_{n-1}X^{n-1}Y + c_nXY^{n-1} + a_nX^n + b_nY^n + e$$
(2)

where Z is species richness and X, Y are longitude and latitude respectively. Equation 2 represents a surface whose shape depends on the order of the polynomial.

Figure 34 below reports the initial map of richness superimposed by the contour lines from three trend surfaces modelled as explained; in particular, the upper map is a two dimensional linear model (= polynomial order 1), whilst contour lines in the middle and lower maps are polynomial of order 3 and 6 respectively). According to the different polynomials, it is possible to observe fitted wide-scale trends of species richness on map, through the use of contour lines.





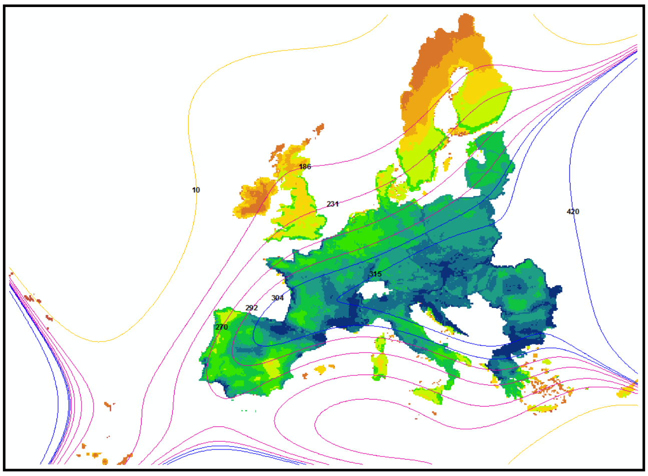


Figure 34: Contour lines of a three different polynomial models for species richness as a function of latitude and longitude. Upper-left: linear model; upper right: third grade polynomial; low-left: sixth grade polynomial. Number represent the expected richness values (decimal digits shall be ignored), the figure in the background displays actual species richness (red= low richness; blue = high richness: see also figure 24). Resolution: 10 km square cells.

Figure 35 below shows, for each of the three models, the plot of predicted vs measured richness (left) and the spatially explicit map of residuals (right).

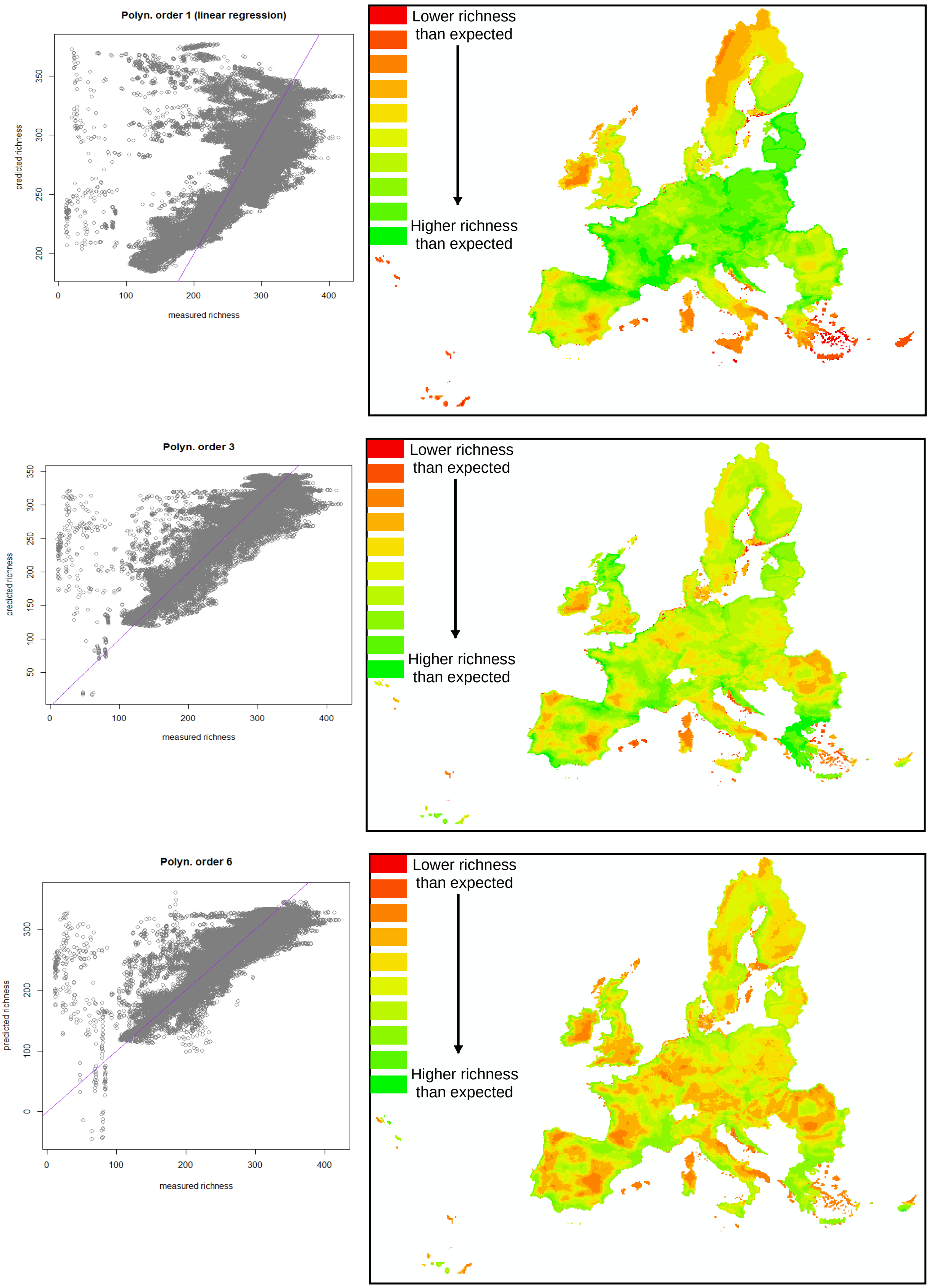


Figure 35: Predicted vs measures values of species richness in Europe (left) and map of residuals (right) for three different polynomial model: linear (upper); third order (middle) and sixth order (lower) polynomial models.

At first glance, the third order polynomial (upper-right) has a good fit to data, without being too oversimplified, as contrarily happens in the linear model (upper-left), whose contour values keep increasing southwards, even though the real mapped richness starts decreasing. On the other hand, the sixth order polynomial has obviously the best fit to the data, but more complex patterns emerge, which may be harder to explain relying on wide scale trends only. In addition, contour lines immediately outside land cells seem to present a highly distorted pattern. This suggests that the model could still be used on known data, but not applicable safely to any area without data (i.e. not to be used for interpolation).

A counter argument towards this approach may point out its over-simplification, due to the absence of potential significant explanatory variables, or the scarce fit between the ones we chose and the phenomena under observation. This argument may refer especially to habitat diversity, which has been pointed out as a main determinant of biodiversity at regional scale. However, Steinmann et al. (2011) found habitat diversity to be responsible only of 20 to 30% of plant species richness at regional scale, when compared to the overwhelming effect of area. Also other prominent scientists from the past put bio-geographical elements forward, as briefly resumed by Connor and McCoy (1979): "the "area-per se hypothesis" was developed by Preston (1960, 1962) and MacArthur and Wilson (1963, 1967) […] and deemphasizes the importance of habitat diversity and instead explains species number as a function of immigration and extinction rates (see Simberloff 1972)".

Moreover, in our case it would introduce a confusing element to the anthropogenic versus natural processes analysis, because habitat diversity could be strongly affected by human pressure in many densely populated areas of Europe, instead of being the result of natural processes only. Certainly, adding habitat diversity to the scheme of Figure 17 (section 3.1) would help to improve the understanding of species richness patterns, but would require a detailed pre-analysis as well, in order to distinguish mainly human driven contexts from mainly natural driven contexts.

Conversely, even a visual inspection of the residuals maps allow to identify some recurrent areas where species richness tends to be lower than expected: these mainly comprises islands (evident e.g. in Sardinia, Corsica, Ireland, the Aegean archipelago) but also "peripheral" mainland like Apulia (Southern Italy) or Northern Sweden. As already noted, this suggest that *isolation* is another macro-geographic trend acting at the continental scale that can be incorporated into the general model. To this we turn in the next sub-sections. In particular, in the next section A2.3, theoretical and modelling aspects of isolation are presented in discussed; subsequently, in section A2.4, a general empirical model of macro-geographical trend of species richness in Europe is presented and applied.

A2.3 Isolation

The Species-Area Relationship (SAR) is another established ecological theory. It is based on the "area-per se hypothesis", developed by Preston (1960, 1962) and MacArthur and Wilson (1963, 1967) and derived as a prediction of the equilibrium theory of island biogeography" (Connor and McCoy, 1979).

The SAR general model (known as power model) is described as

$$S= cA^{z} \qquad (3)$$

where S is species richness within a region of area A. This relation has been proved as such several decades ago (Arrhenius 1921, Preston 1960), but it still attracts a lot of interest and is an active branch of ecological research. The relationship works at all scales, from microbial communities within a handful of soil, to the distribution of phyla across continents (Rosindell and Cornell, 2007; Storch et al, 2007).

To look for any effects of area on richness in IUCN data, we started plotting richness values against the sum of land cells surrounding each cell for two given radius, 100 km and 200 km, which can be intended as measures of *local/regional* isolation. The radii we applied are arbitrary and possibly spatial analysis techniques can find more solid ones, but we thought it is quite reasonable to include home-ranges or whole populations for many species. To avoid biases given by changing latitude, the latter was incorporated subdividing the dataset into latitudinal slices 10 km thick and then calculating the mean terrestrial area surrounding cells within each slice and their mean species richness. In this case, isolation was assumed to be independent from latitude. Plotting the results displays a well-defined non-linear trend (Figure 36): while increasing the land surface around a cell, the number of species found there within increases, regardless of the latitude.

From a certain surrounding-area onwards, richness does not seem to increase anymore. This is obvious because any cell, even the most diverse, has a finite richness; however this limit may also suggest a threshold (i.e. a minimum area of neighbouring land) below which richness starts decreasing, or, on the other hand, above which land area (i.e. radius) is no more relevant for species richness. Consequently, isolation may be an implicit cause of lower richness, in cells surrounded by less than that critical area. Alternatively, isolation may be intended as a reference of expected richness in a cell.

Figure 37 shows on map the degree of isolation calculated as explained using 100 km (left) and 200 km (right) radius. Note that the *absolute* number of species observed in a cell is highly scale dependent and, all the rest being the same, vary with its area: the bigger the cell area, the more species are found, because of the same SA relationship. All along this report the reference units were cells of 10 by 10 km (100 km^2), so instead of the usual comparison of richness among extents of different areas found in textbooks, an incremental sum of cells of equal area was used.

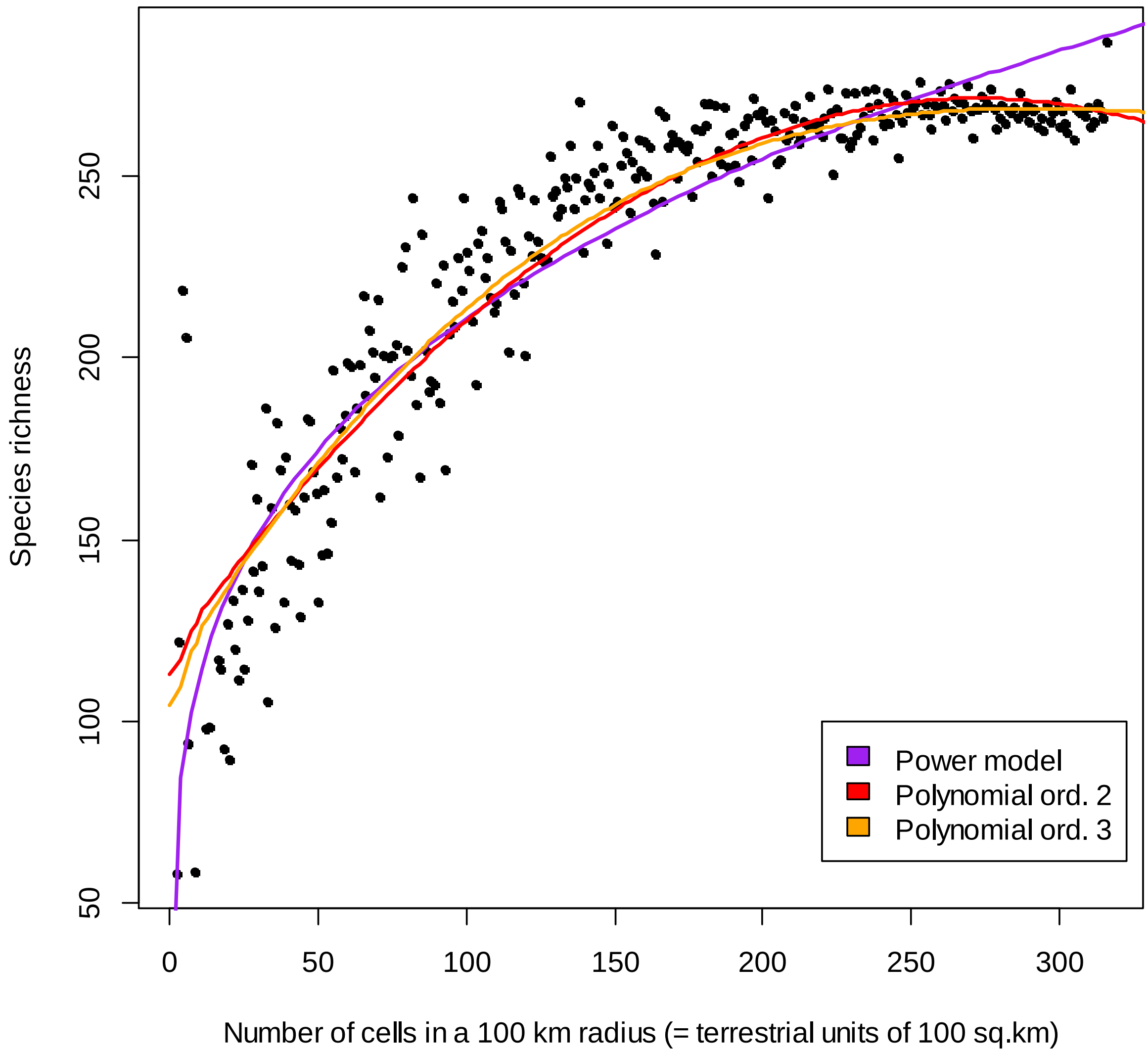
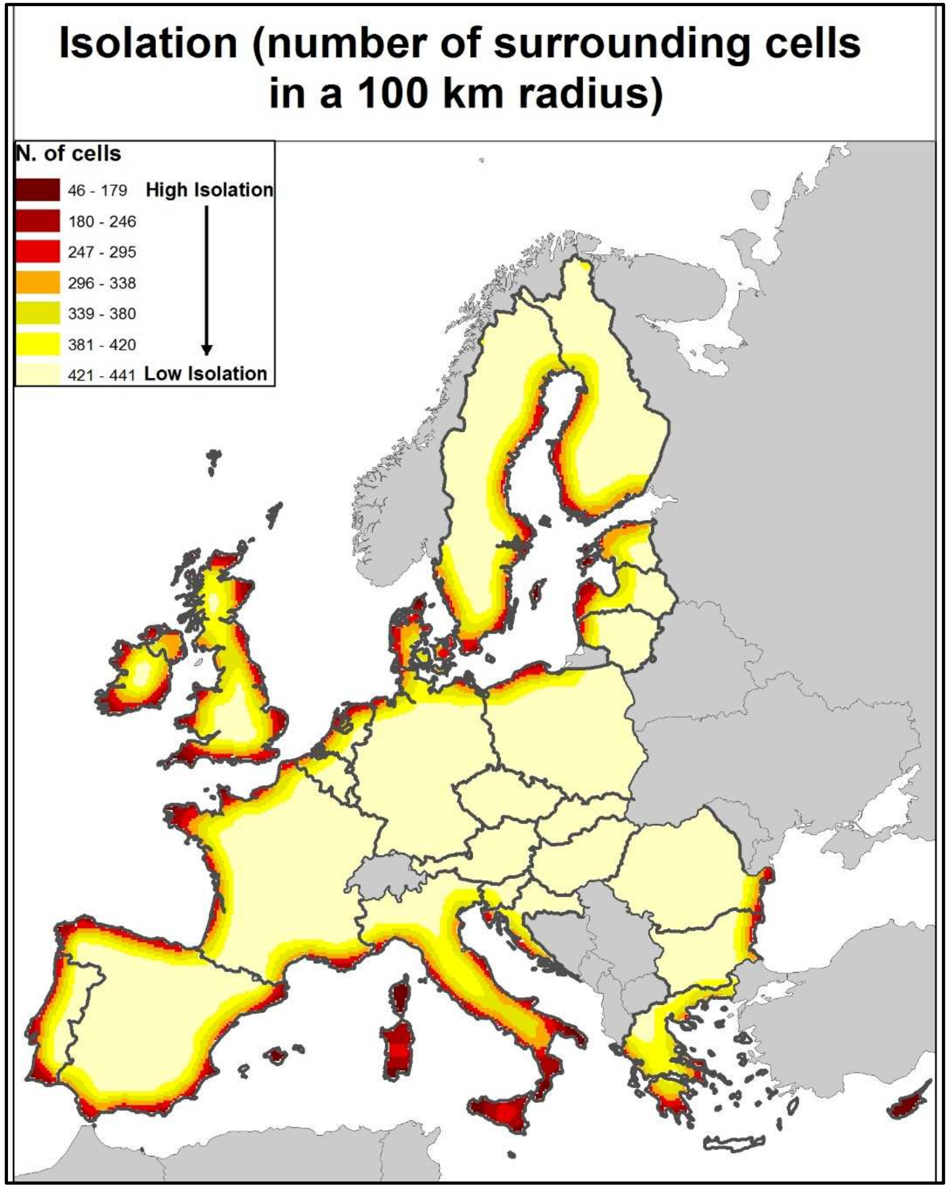


Figure 36: Relation between regional isolation and species richness, calculated as the number of (100 km radius). The three lines represents different models fitted to data.



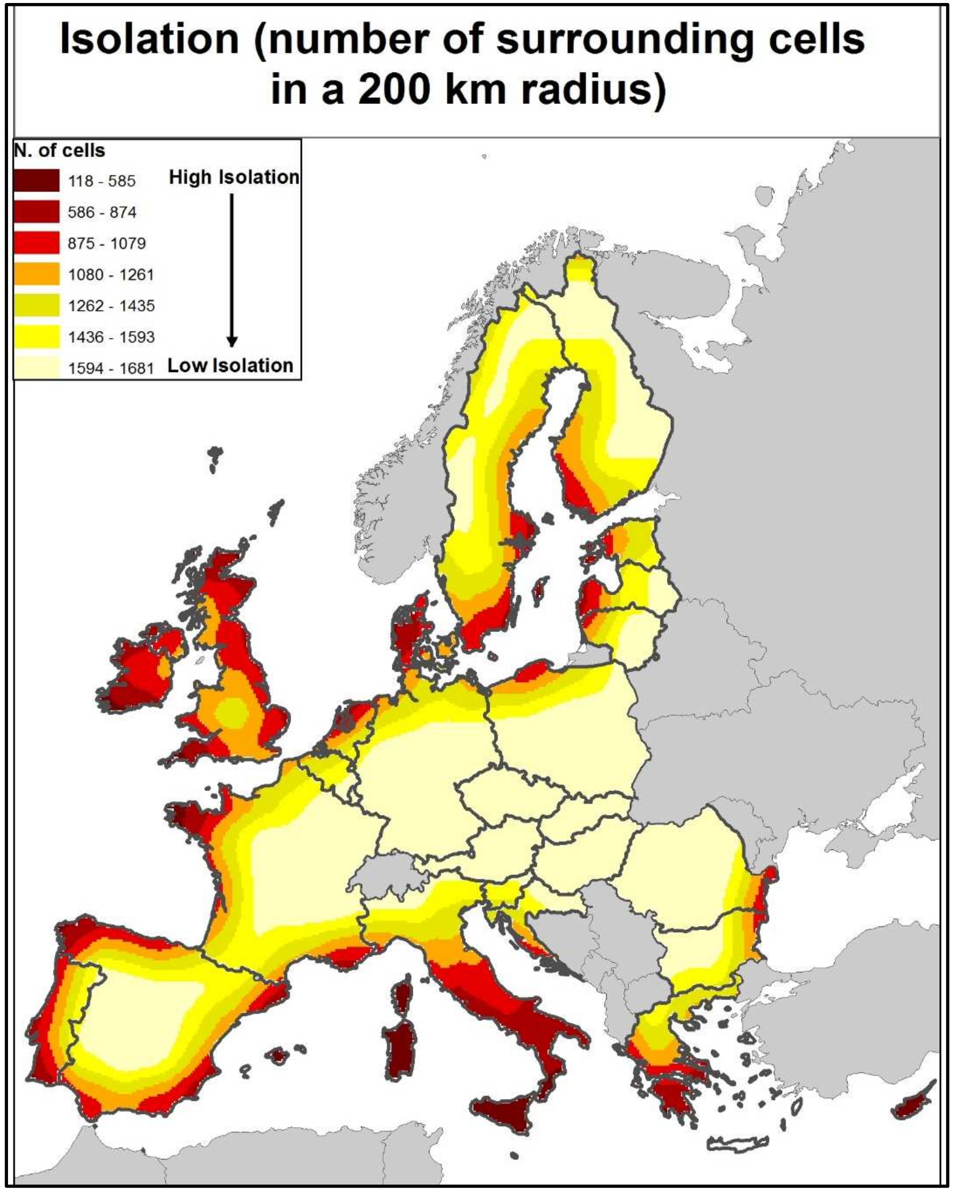


Figure 37: Regional Isolation calculated, for each cell, as the number of surrounding cells in a 100 km radius (left) and 200 km radius (right)

The SAR relationship has been widely studied and therefore many models have been proposed to describe it, but to date the most acknowledged is the power model (Arrhenius 1921, Triantis et al, 2012, Gerstner 2013). In fact, one of SARs main features is its non-linearity: the reasons for that are multiple and synthetic but comprehensive reviews are found in Drakare et al. (2006) and Magurran and McGill (2011). The latter also reviews the state of the art in quantifying the different aspects of biodiversity and it is a highly recommended reading (together with the review by Storch et al, 2007). For an extensive insight on early research on SAR, but not outdated, see Connor and McCoy, 1979.

For its wide acknowledgement, the power model was chosen for this step of IUCN data analysis. However, as far as a general agreement on SARs models is close but not yet reached (Magurran and McGill, 2011), while working with SARs it is advisable to test different models, trying to address at best the data under analysis. Most models are quite straightforward to implement in any scientific oriented programming language, but specific tools are already available for SARs: SAM (Rangel et al., 2010), EstimateS (Colwell 2013) and some R packages (e.g. mmSAR, Guilhaumon et al, 2010), among others.

The lines of Figure X are three models fitted to the data. The power model was expected to have the best fit, and indeed it has at lower x axis values, but it fails to identify the upper limit of richness, which is better modelled by two empirical polynomial regression models. At this regard, the choice of the model may be dictated also by the scope of analysis, whether it focuses on isolated areas or on core areas.

These differences, the scale dependency and the distribution of dots are worth further investigation because the curve may well approximate the general SAR for the whole study area. See Magurran and McGill (2011) and Storch et al, (2007) for a detailed review of recent developments in the field of SAR. It would be interesting to extend the same analysis on separated taxonomic or functional groups too, something that may truly give more appealing results overall. Similarly, geographical subset of ecological meaning (e.g. bio-geographical regions) may be used. However, a rigorous approach to define those groups/subsets would probably involve additional research and fairly challenging work.

Indeed, Gerstner et al., (2013) showed how biomes are better domains to estimate SAR model parameters for plants, in comparison with floristic reigns or land cover types. Still a general study across other taxa is missing and IUCN data are an excellent candidate for such study. Here, for simplicity, all taxa were kept aggregated and EU analysed as a whole. This fact may or may not affect conclusions, depending on the questions under study.

It is also possible to keep latitude as an external reference and build on top of that. For instance, it might be interesting to see if and how SAR changes from North to South. To do this we subdivided data cells into slices, 10 km and 210 km wide, and analysed each slice separately. The choice to subdivide this way was made in order to avoid partitioning of the dataset into objects of rather different characteristics and to ease the following steps. However, if investigation focuses specifically on theoretical aspects of SARs, it is very convenient, if not mandatory, to down-scale the analysis to bio-geographical subsets.

First, accumulation curves were built for each subset (whether latitudinal slice or band). This was achieved through a random sampling of 200 cells within each subset or as many as available below that threshold, then repeating the sampling 20 times. It was assessed empirically how such a relatively low number of repetitions, in conjunction with a sample of 200 cells, did not affect the representativeness of the curve, which also usually flattened enough to reveal some sort of asymptote (which is sometimes interpreted as the estimation of true species abundance, in specific contexts). This behaviour is easily understood, as not so many cells compose each subset; the curve may be drawn even from the whole subset (possibly obtaining the pattern observed in Figure 36).

At every repetition, the number of species for the first sampled cell were recorded, then the second cell was sampled and the species absent in the first cell were added to the overall count; so the third was compared with the growing species pool, to look for the unique species which were not found in the first two, and so on up to the 200th cell (Figure 38 and 39). If all the species were sampled before reaching the last cell, the accumulation curve reached a steady maximum. A systematic evaluation of the number of samples and number of repetition to build the accumulation curves should be done, but during analysis the selected method showed a consistent behaviour in the output curves' shape.

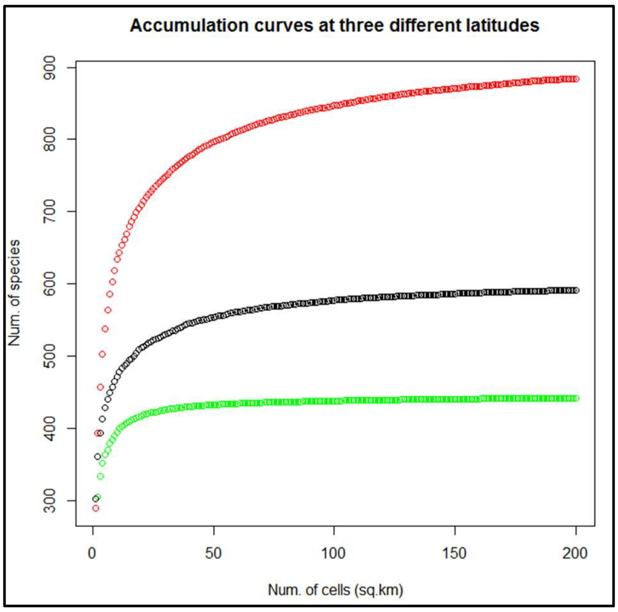


Figure 38: Accumulation curves of number of species and number of sourrounding at 3 different latitudes

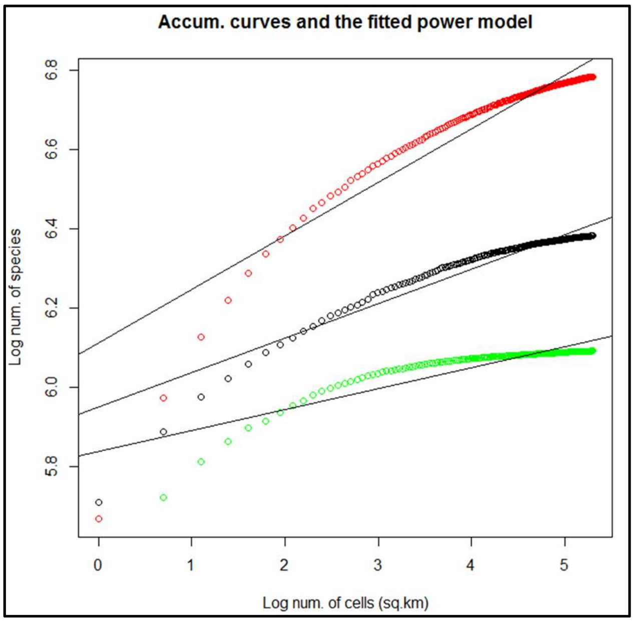


Figure 39: Accumulation curves of number of cells and no. of species in three different latitudinal slices - Log-transformed values and the fitted power model

Once the accumulation curves for each subset (whether latitudinal slice or band) were made, the modelling process began. After testing other options, the *rssoptim* function was used to fit SAR models to the curves (from the R package "mmSAR", Guilhaumon et al, 2010). This function allows an optimal selection of the model parameters, through information criteria (AIC or BIC). A module for multiple models comparison (e.g. beyond the power model) is available within the same package. The estimated parameters *c* and *z* were collected for each subset (model parameters have a great interest in ecology themselves, see for instance Gerstner et al, 2013). Then the species richness (*S*) was calculated using the estimated parameters and applied to each cell of the full extent of analysis (EU28), consisting of almost 50.000 squares grouped into 410 latitudinal slices or bands. As a consequence, there were 410 + 410 different parameter estimates for the whole extent of analysis (slices + bands).

To neutralize the effect of changing area on richness, a hypothetical richness was computed for each latitudinal subset, as if they all had the same area of 200 cells (i.e. 20.000 square km), using their correspondent power model parameters. The most obvious choice may seem to calculate the richness value for a single cell, therefore referring to the C parameter of the model directly. However, as the previous log-log plot from the three modelled SARs shows, the "raw" fitted models such as the power model have a worse performance when decreasing at small areas, while they improve at increasing areas.

To solve this issue and build reliable single cell richness estimates, specific methods have been developed (see Magurran and McGIll, 2011 and references therein for a review) and implemented in dedicated tools, such as EstimateS (Colwell 2013). One of such estimators was applied for our data that estimated the single cell richness baseline for each latitude subset (not shown, it follows Colwell et al, 2012). However, since no analysis at local scale was carried out and samples usually contained hundreds to thousands of cells, the simpler "raw" power model, applied to 200 cells, was preferred to extract SARs' parameters. It is important to underline that, without prior testing, by no mean 200 cells should be considered the best reference area, as it was chosen as an empirical value suited for this exercise. Inspecting the *rssoptim* function and the other models available within mmSAR package may give good insights on this, as models comparisons and confidence levels of the model fitting are computed as well.

When plotted against each other, z and C parameters show two main patterns (Figure 40). These should be due mainly to the latitudinal gradient and to a strong spatial autocorrelation effect, but specific insight was not carried out. Further work could shed a light on the various factors generating such pattern.

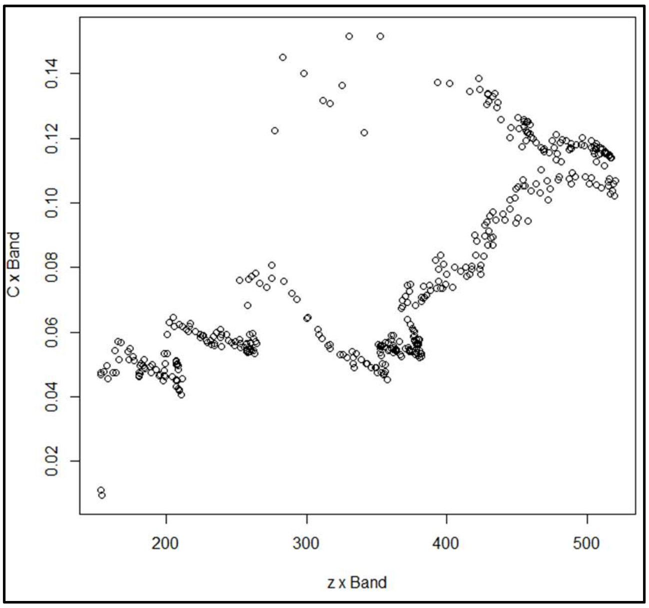


Figure 40: Plot of the estimated C and Z parameters of the Power model. Points represent latitudinal slices

When the model parameters are plotted against latitude, they show a clear trend in comparison with it, both in the slice subsets and the band subsets (Figures 41 and 42).

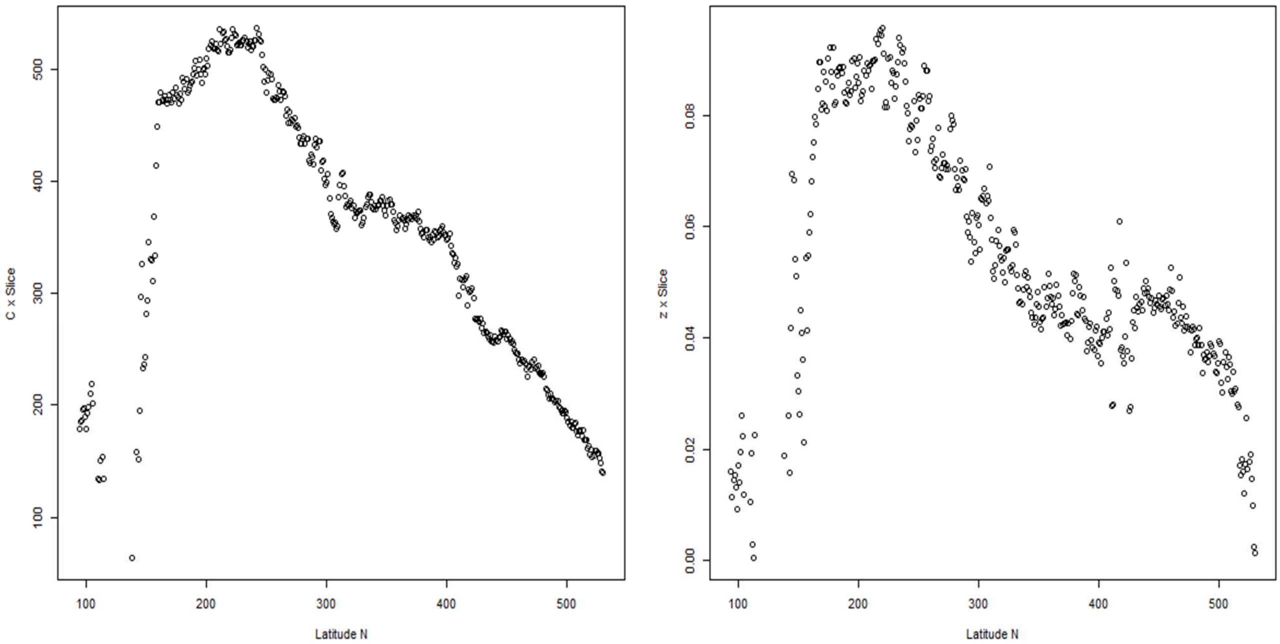


Figure 41: Estimated C and Z parameters of the richness Power Model plotted against Latitudinal slice

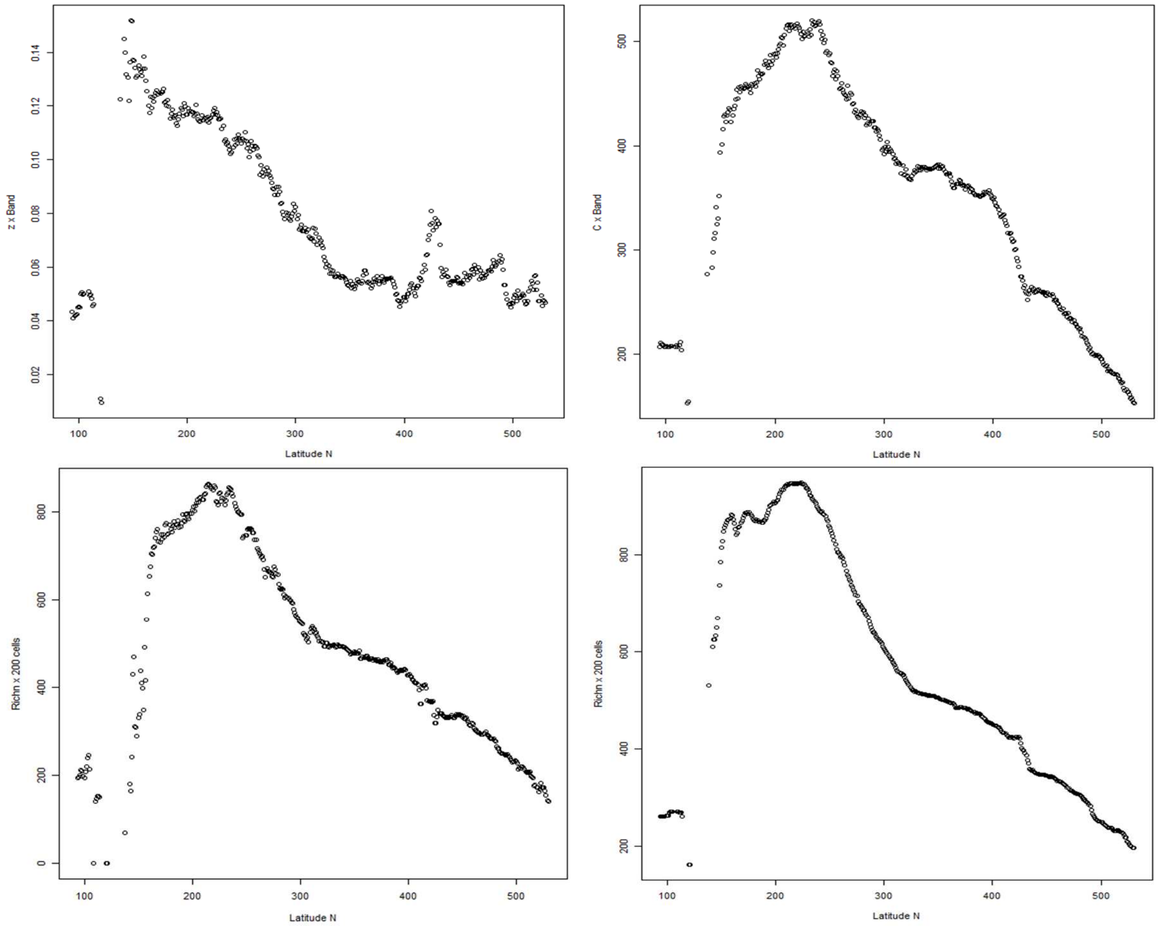


Figure 42: Upper: z and C estimated values per latitudinal band; lower: accumulated richness on 200 cells count per latitudinal band (left) and slice (right)

This explains at least partly the pattern of z and C in the former plot. In all plots Atlantic Islands, at least those located the lowest latitudes, behave quite differently (the others are "absorbed" into continental data at their latitude slice). See for instance upper left graph of Figure XVI, showing z parameter per latitudinal band. With further analysis, the patterns observed in the previous figures could unveil very interesting facts about C and z parameters for the study area.

A2.4 Towards a generalised empirical model of species richness in Europe

In the previous sub-sections, we have shown how two main geographical trends in Europe may affect the overall observed pattern of species richness at the continental scale: i) latitude (and, to a lesser extent, longitude); and ii) isolation. Each of them, if examined separately, partly explains the observed data, so in this section we try to develop a general model incorporating both aspects.

Again, it is worth stressing that the aim of this work is not to find an ultimate theoretic explanation to species richness across Europe, but to develop an empirical model able to capture wide scale trends so to de-trend observed richness and identify areas where lower/higher value are found, presumably due to other factors such as human pressure. Therefore, we resort again to polynomial models, this time including both latitude/longitude and isolation as explanatory variables of species richness.

When exploring the geographical gradient, a very consistent trend was found along a NNW-SSE gradient (figure 23 in section 3.4). As noted, this might well be considered the "true" latitude/longitudinal gradient acting in Europe, so we choose to use it as one of the main geographical variables together with isolation. Interestingly enough - but not entirely surprising given the partial dependence of the Red List Index on richness - a similar gradient was also observed as regards the average calculated values of the Red List index. The gradient is shown in Figure 43 below and its heading is 341° NNW. A value along the gradient is thus assigned to each 10 km x10 km cell considering the coordinates of the cell centre (values increase from SSE towards NNW).

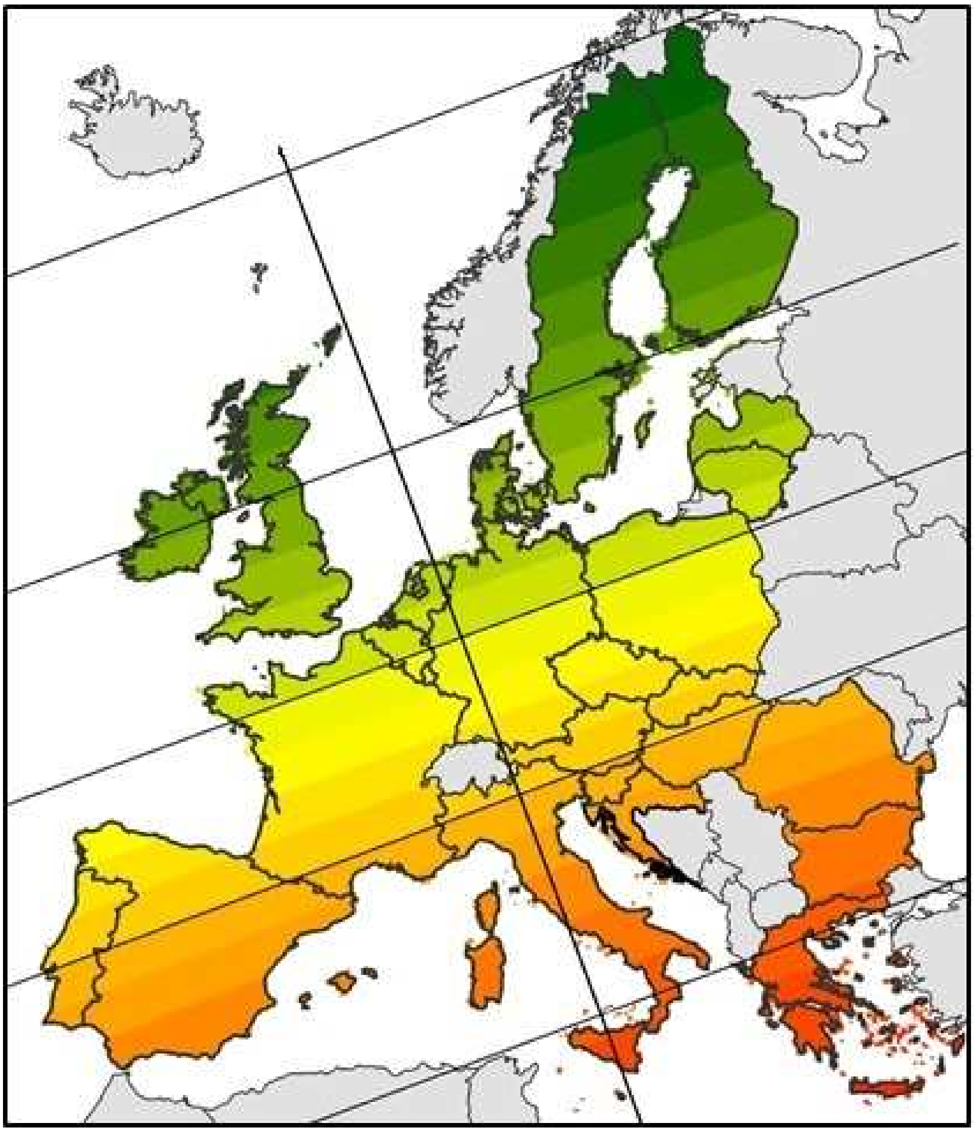


Figure 43: The identified NNW- SSE gradient of species richness in Europe. Parallel lines indicates a constant value along the gradient

Data preparation

Before proceeding with the modelling exercise, some preliminary data preparation work was done. Firstly, it was deemed necessary to separate the Atlantic islands from the rest of the dataset. In fact, the islands located well offshore from continental Europe show always a very different behaviour from the mainland. The green line in Figure 44 below shows the trend of richness in the East-West direction: richness drops dramatically in correspondence of the islands, while the rest of continental Europe overall shows a homogeneous trend, even though the remarkable differences within it. Some differences between the two geographical domains can be immediately pointed out.

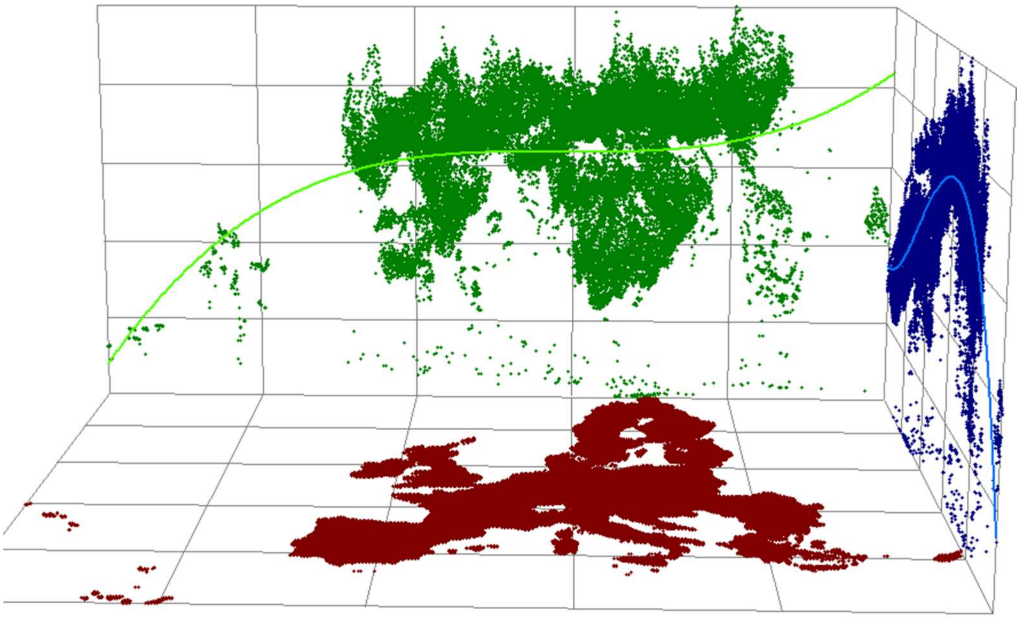


Figure 44: Variation of Species richness along longitude

First, half of the Atlantic islands are located at lower latitudes, where no other EU28 mainland territory is present, thus making integration in a single model a risky extrapolation exercise. Second, they are small, especially if compared to continental Europe, but would be analysed at the same scale of the latter and assuming that the same processes are acting. Third, they are distant from the continents, implying that several processes very peculiar to remote islands are ongoing, which are not adequately captured by the concept of local/regional isolation incorporated in the model, even when a 200 km radius is used to calculate isolation. A large amount of scientific literature was produced on this, from Darwin to MacArthur's Island Biogeographic Theory and there on (e.g. Triantis et al, 2012). Finally, problems of resolution may persist, or better an "edge effect", in that a significant percentage of the species on the islands may actually be marine species, artificially occurring on the islands because, at the grid resolution, islands coasts are included in the same cell together with inner land; terrestrial species may not even appear at all, because the smaller islands were not mapped within the IUCN dataset. To correct for this issue a careful review of the species assigned to the islands should be done. For all the reasons explained above, Atlantic Islands were discarded before modelling.

Furthermore, other cells were eliminated from the original dataset due to data quality issues discussed in section 3.1. Discarded cells belonged to two categories: some were excluded because contained clear biases related to the intersection of different spatial datasets, the EU28 territory converted to the 10 km grid and the IUCN spatial dataset. The latter in fact, in some regions, ignored small islands or sections of coasts because of a coarser resolution and consequently made the correspondent grid cells appear erroneously at a low richness level. This is the case, for instance, of the islands in front of the Croatian coast or within the Aegean Sea. The second category of excluded cells occurs on national borders that for some reason appear to be more species rich. That artificial pattern along borders does not reflect any real richness pattern and resembles very much to a double-counting issue. Overall, about 20% of the circa 48,300 original cells were discarded at this stage, leading to a final "clean" dataset of about 38,900 cells.

In the following, we present the results and performances of four different empirical additive polynomial where:

- *Y* (independent variable) = species richness, i.e. number of species observed in each cell of 10x10 km according to the IUCN dataset
- X_1 = position of the cell's centroid along the identified NNW-SSE gradient (values increase from SSE to NNW)
- X_2 = Isolation: for each cell defined as the number of (terrestrial) cells surrounding it in a given radius. This mean that the *higher* the numerical value, the *less* isolated the cell is. (see figure XI).

As for isolation, two radius values were considered, namely 100 km and 200 km. Results of the models' runs indicate that considering a 200 km radius yields better results in terms of goodness of fitness, other things being equal. Therefore, in the following we refer to isolation values calculated considering a 200 km radius.

For each model, the following descriptive statistics are presented:

- R^2= coefficient of determination
- SSE: The sum of squares of the errors (or residuals) of the model;
- MSE: The means of the squares of the errors (or residuals) of the model
- RMSE: The root mean squares of the errors (or residuals) of the model
- The correlation matrix of model's parameters (same for all models)
- The calculated values of model's parameter; the numeric value in itself doesn't have a specific ecological meaning, given how the numeric value of the variables is defined. They are however reported because it is interesting to see their sign to understand the function's shape.

Model 1

The starting model assumed as a benchmark for further comparison is a simple double linear regression between the explanatory variables and species richness, i.e. it assumes that richness increases along the gradient and decreases with isolation linearly. Recalling that gradient values increases from South to North and that the variable X_2 represents the number of surrounding cells in the search radius for each cell, it is expected that the coefficients *b* and *c* be negative and positive respectively.

$$y = a + bx_1 + cx_2$$

Table 7: correlation matrix of the variables considered in the models

Correlation matrix:			
Variables	X_1 Gradient	X_2 Isolation	SpRichn
X_1 Gradient	1.000	0.059	-0.736
X_2 Isolation	0.059	1.000	0.284
Y = Species Richness	-0.736	0.284	1.000

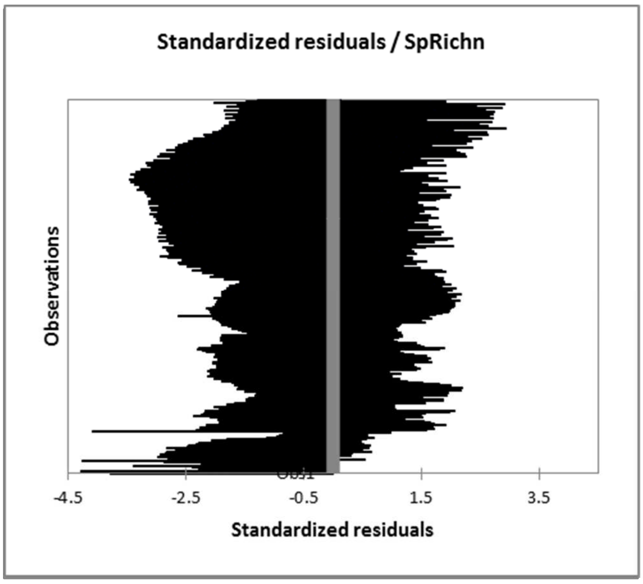
The correlation matrix (Table 7) shows that the covariance between the explanatory variables X_1 and X_2 is low (0.059) which allows to insert them in general additive models and to exclude interactions between them (i.e., the term X_1X_2 is not present in the equation). As expected, the matrix also shows a strong negative correlation between Species richness and the gradient and a less strong but still significant positive correlation with the inverse of isolation.

The goodness of the fit statistics and the calculated values of the parameters are summarized in the following table 8

Table 8: Descriptive statistics of Model 1 and parameters' estimated values

Descriptive statistics		Parameters' estimated values	
R^2	0.649	a	263.917
MSE	795.018	b	-0.4394
RMSE	28.196	c	0.0507

This simple model, which has also a clear and understandable ecological meaning, has already a fair prediction power, with R^2= 0.649 meaning that it succeeds in explaining almost 65% of observed variation in species richness across Europe. Model's residuals and predicted vs actual values of species richness are shown in Figure 45 below.



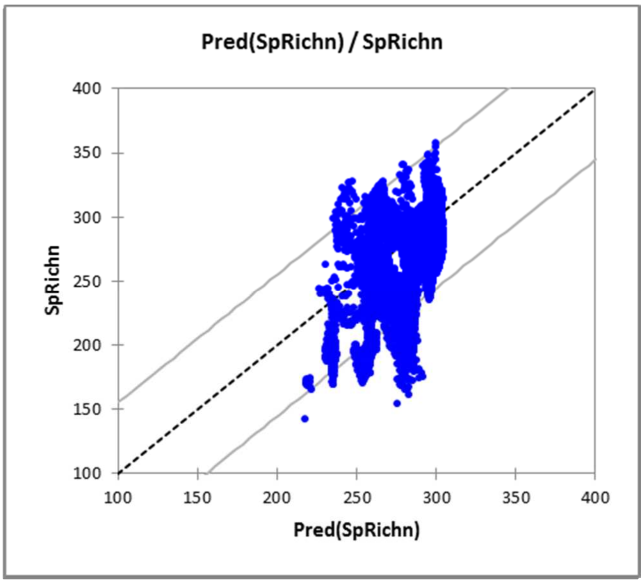


Figure 45: Residuals of model 1 (left) and plot of predicted vs observed values of species richness (right)

Model 2

The second model increases the complexity by assuming a non-linear relation between species richness and the position along the gradient through a second-degree polynomial, whilst maintaining the dependence with isolation linear. The resulting equation is:

$$y = a + bx_1 + cx_1^2 + dx_2$$

Table 9: Descriptive statistics of Model 2 and parameters' estimated values

Descriptive statistics		Parameters' estimated values	
R^2	0.742	a	185.732
MSE	585.367	b	0.4703
RMSE	24.194	c	-0.0019
		d	0.0399

As shown by the matrix (Table 9), the goodness of the fitness of this models is significantly improved with respect to the previous one. (R^2= 0.742). Figure 46 below show the residuals plot and predicted vs actual values of species richness.

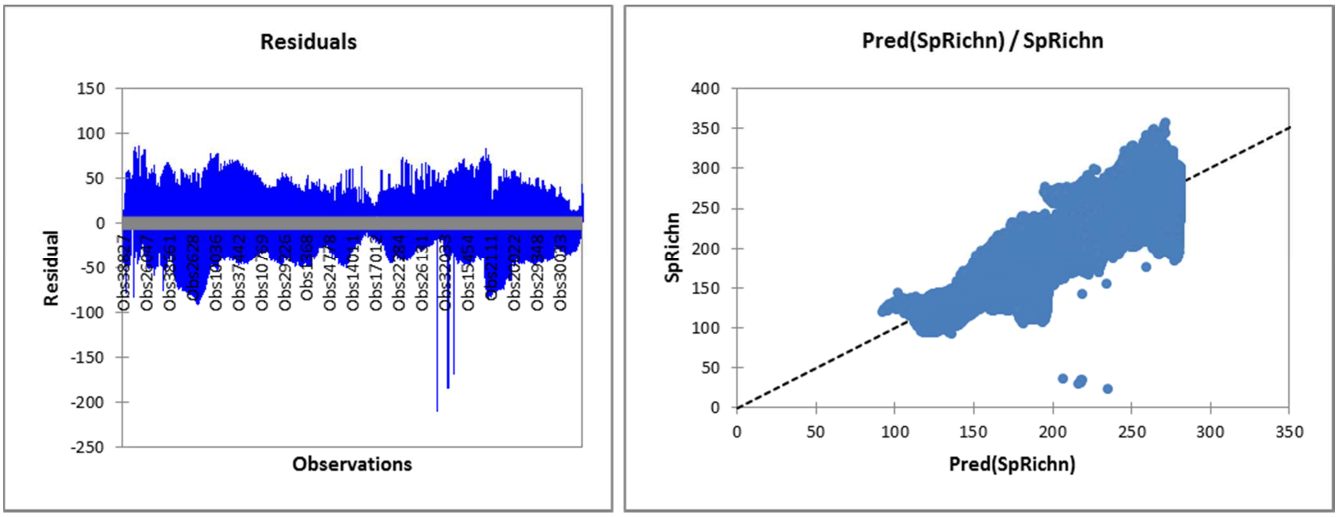


Figure 46: Residuals of model 2 (left) and plot of predicted vs observed values of species richness (right)

Model 3

In this model, the dependence of richness from both the gradient and isolation is no longer linear but follows a second degree polynomial. The resulting equation therefore is:

$$y = a + bx_1 + cx_1^2 + dx_2 + ex_2^2$$

Table 10: Descriptive statistics of Model 3 and parameters' estimated values

Parameter	Value	Descriptive statistics	
a	136.6	R^2	0.750
b	0.41744	SSE	21997395
c	-0.00185	MSE	566.097
d	0.13864	RMSE	23.793
e	-0.00004		

This complexification of the model, which might be not easy to explain in ecological terms, increases the fit goodness only to a limited extent compared to the previous models (R^2=0.75). Figure 47 below show the residuals plot and predicted vs actual values of species richness.

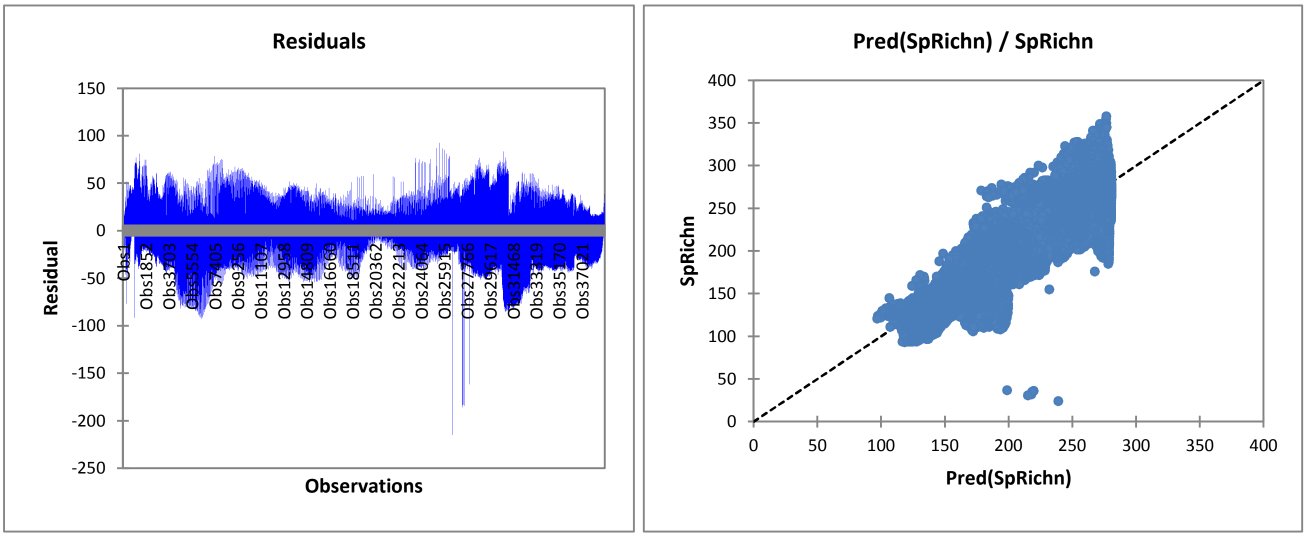


Figure 47 Residuals of model 3 (left) and plot of predicted vs observed values of species richness (right)

Model 4

This model hypothesizes that species richness monotonically increases along the gradient, but not linearly, following instead a sigmoid (inverse logistic) curve with minimum at NNW and an asymptotic maximum towards SSE. This may have a clearer ecological meaning compared to the previous model if, as hypothesized in section 4.4.1, one of the explanation of the general latitudinal gradient is linked to the availability of solar energy, which increases not linearly from the poles to the equator. The resulting equation is:

$$y = a + b\frac{(1+k)}{(k+e^{\beta x1})} + cx_2$$

Table 11: Descriptive statistics of Model 4 and parameters' estimated values

Descriptive statistics		Parameters' estimated values	
R^2	0.741	a	75.254
MSE	586.455	b	135.967
RMSE	24.217	k	14783.692
		β	0.031
		c	0.039

Overall, the goodness of fit statistics of this model is comparable to the one of models 2 and 3 (R^2 = 0.741). Model's residuals and predicted vs actual values of species richness are shown in Figure 48 below.

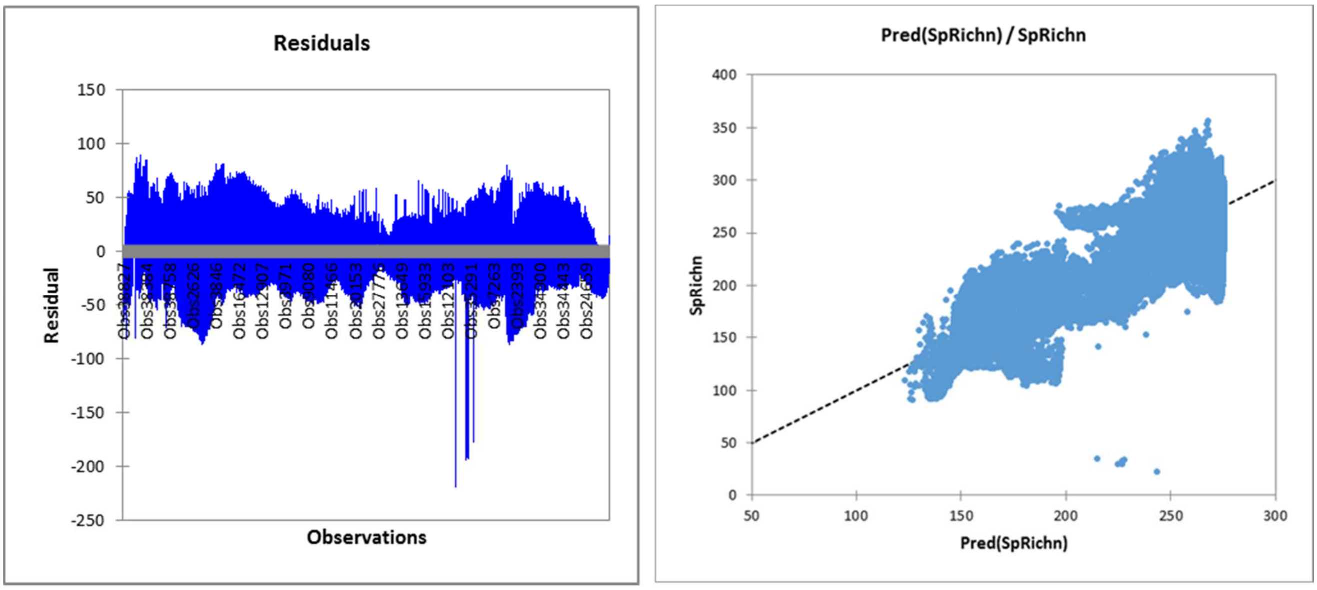


Figure 48: Residuals of model 4 (left) and plot of predicted vs observed values of species richness (right)

Model 5

This non-linear additive model hypothesizes species richness as the combination of isolation and geographical positioning, which are assumed to be independent. The first term of the equation is given by isolation (X_3), through a non-linear power model; the second is determined by latitude (X_1), accordingly to a simple linear model. An additional term, a polynomial model of degree 2 depending on longitude (x_2), is added mainly to correct for data shortcomings at the longitudinal extremes of the dataset, allowing for straighter residuals without overfitting.

The resulting equation is:

$$y = Cx_3^z - (\alpha + \beta x_1) + (a + bx_2 + cx_2^2)$$

Table 12: Descriptive statistics of Model 5 and parameters' estimated values

Descriptive statistics		Parameters' estimated values	
R^2	0.774	C = 3850.207	a =291.3156
MSE		Z= -0.530362	b = -0.0001643036
RMSE	26.919	α = -120.523	c =2.163976e-11
		β = 3.945621e-05	

Overall, the goodness of fit statistics of this model is good (R^2 = 0.774). Model's residuals and predicted vs actual values of species richness are shown in Figure 49 below

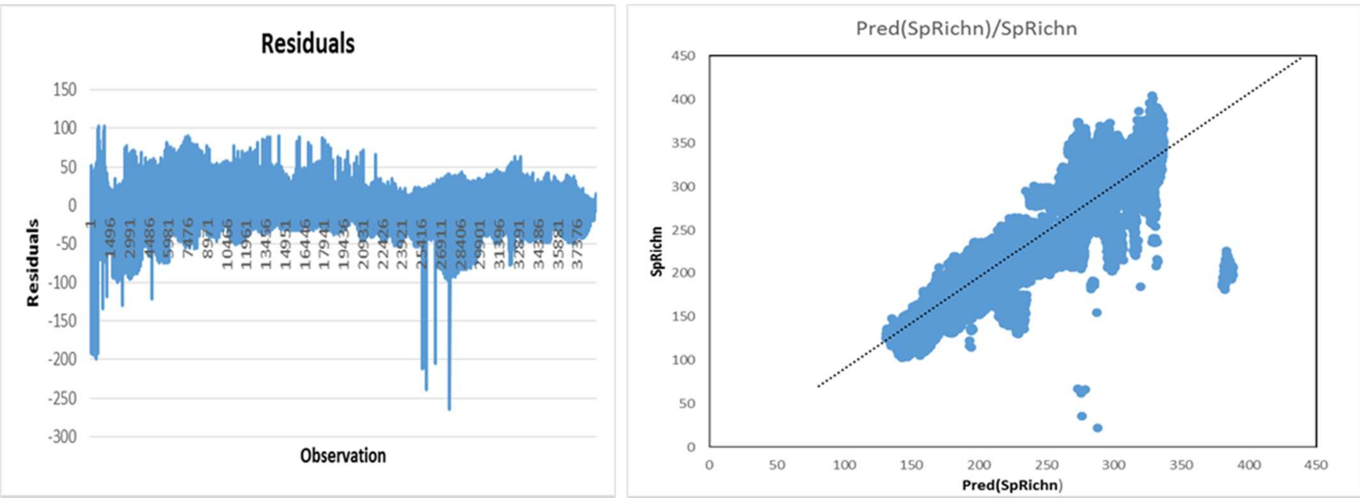


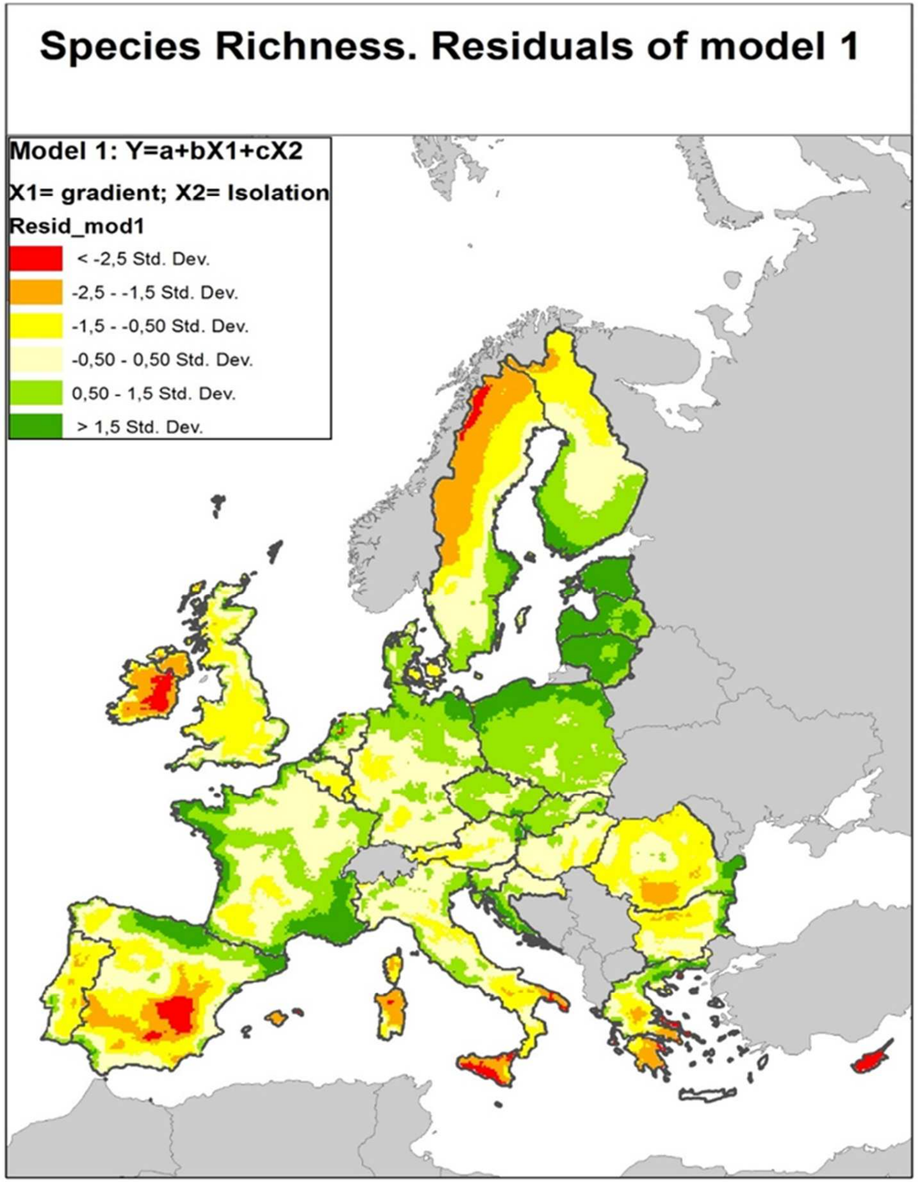
Figure 49: Residuals of model 4 (left) and plot of predicted vs observed values of species richness (right)

A2.4 Discussion of model results

The purpose of the models presented in the previous section is descriptive, with the aim to ascertain whether, once the main geographic and wide scale trends are identified and taken into account, examined data reveal some significant and informative trends.

To this end, the residuals of the four models (estimated minus observed value) have been calculated and mapped, to see if consistent patterns are identifiable. Figures 50 and 51 below show the spatial distribution of residuals from model 1-2 and 3-4 respectively. Although a certain degree of variation is visible, the general pattern is similar, especially for models Model 2-5. Regardless of the chosen model, hotspots and coldspots of species richness (areas where the observed values is significantly higher or lower than expected) are found in the same areas.

Moran's tests were carried out to verify whether spatial correlation of residuals occurs and confirmed that, in all cases (p always <0.001), model's residuals have a non-random distribution. A random spatial pattern of model's residuals is generally considered an evidence of the goodness of the model; conversely, autocorrelation of residuals implies that the model fails in fully describing the underlying relationships between the variables. However, in this case, the result is as expected: the analysis of model's descriptive statistics and residuals' distribution overall indicates that identified trends explains to a significant degree the general patterns, but that besides them, other factors indeed are acting at the European scale, possibly related to anthropic pressure, agricultural management and so on. This of course opens the way for many potential research developments which have been discussed in the conclusion section of this report



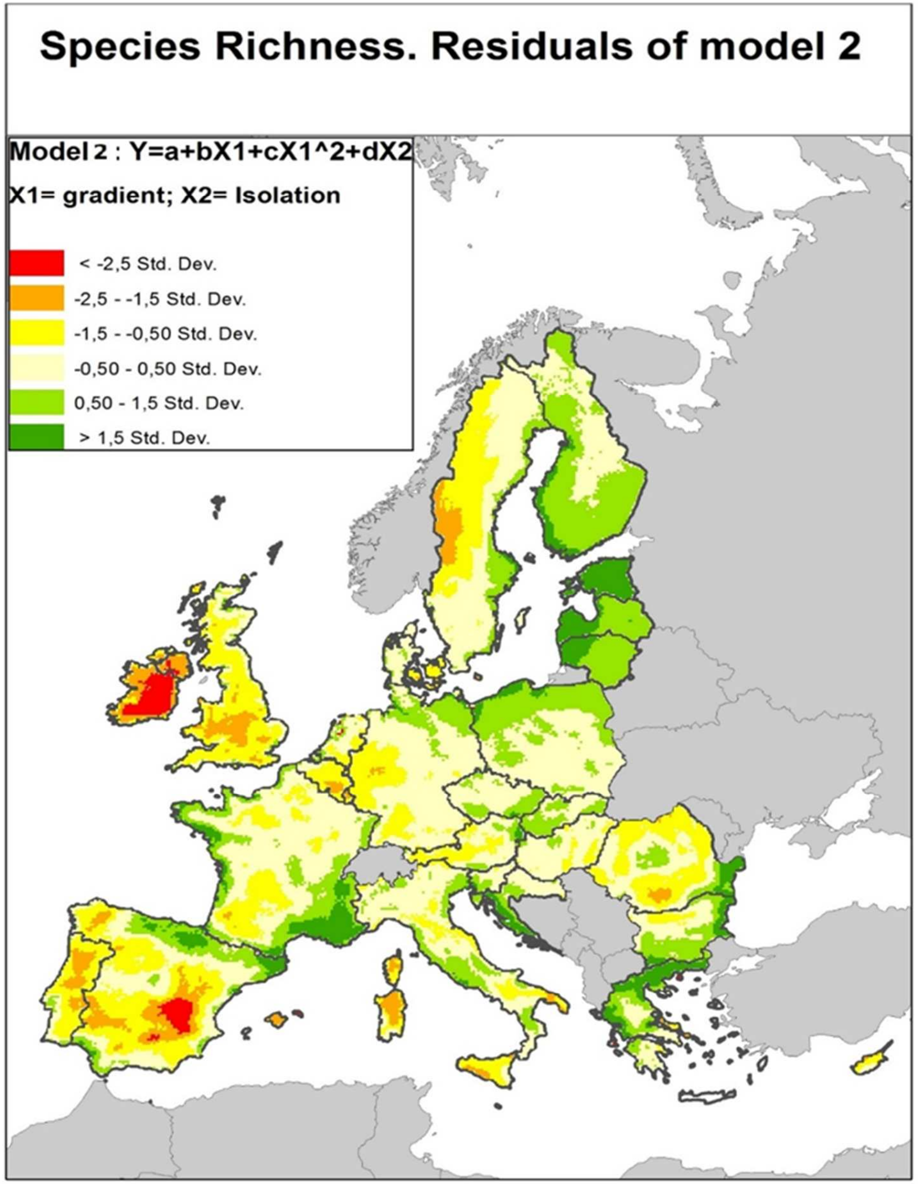
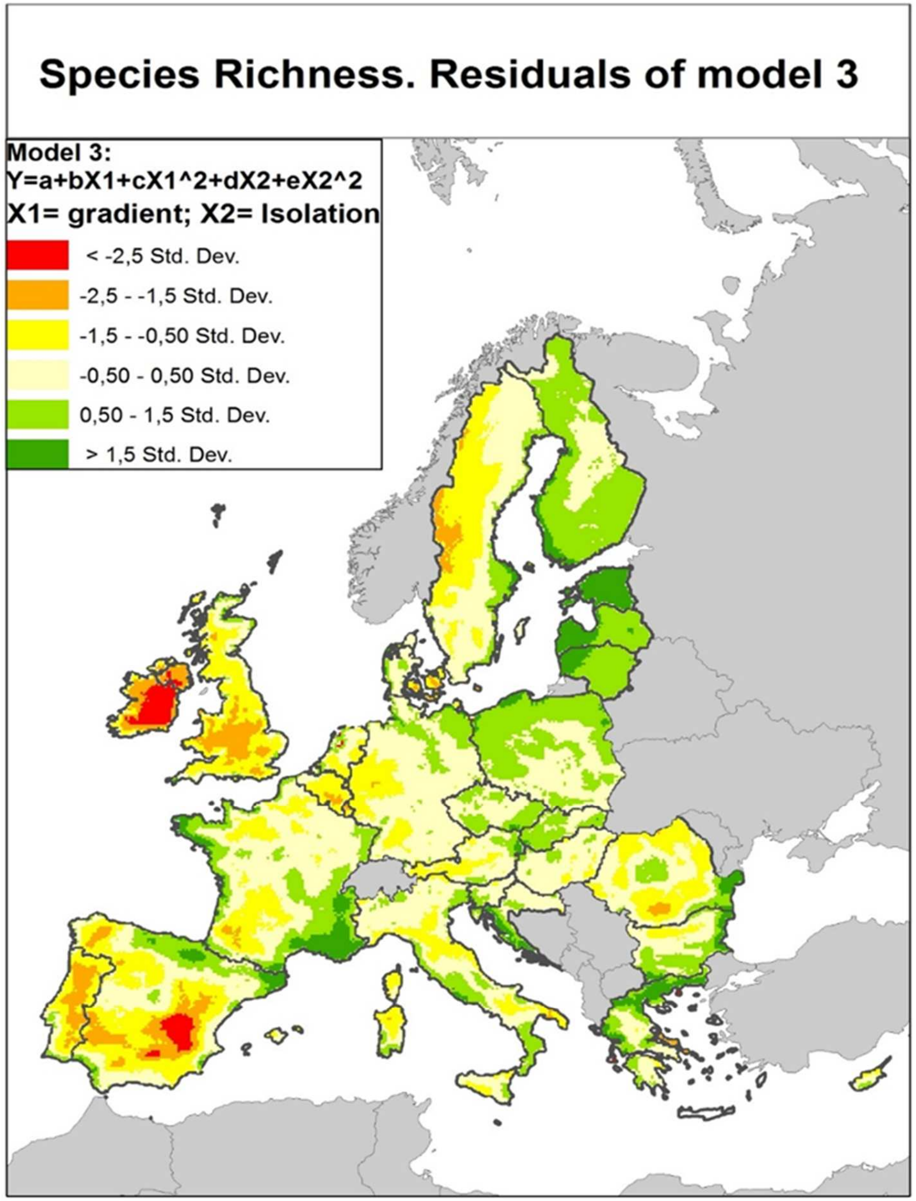


Figure 50: Spatial distribution of species richness residuals from models 1 (left) and 2 (right)



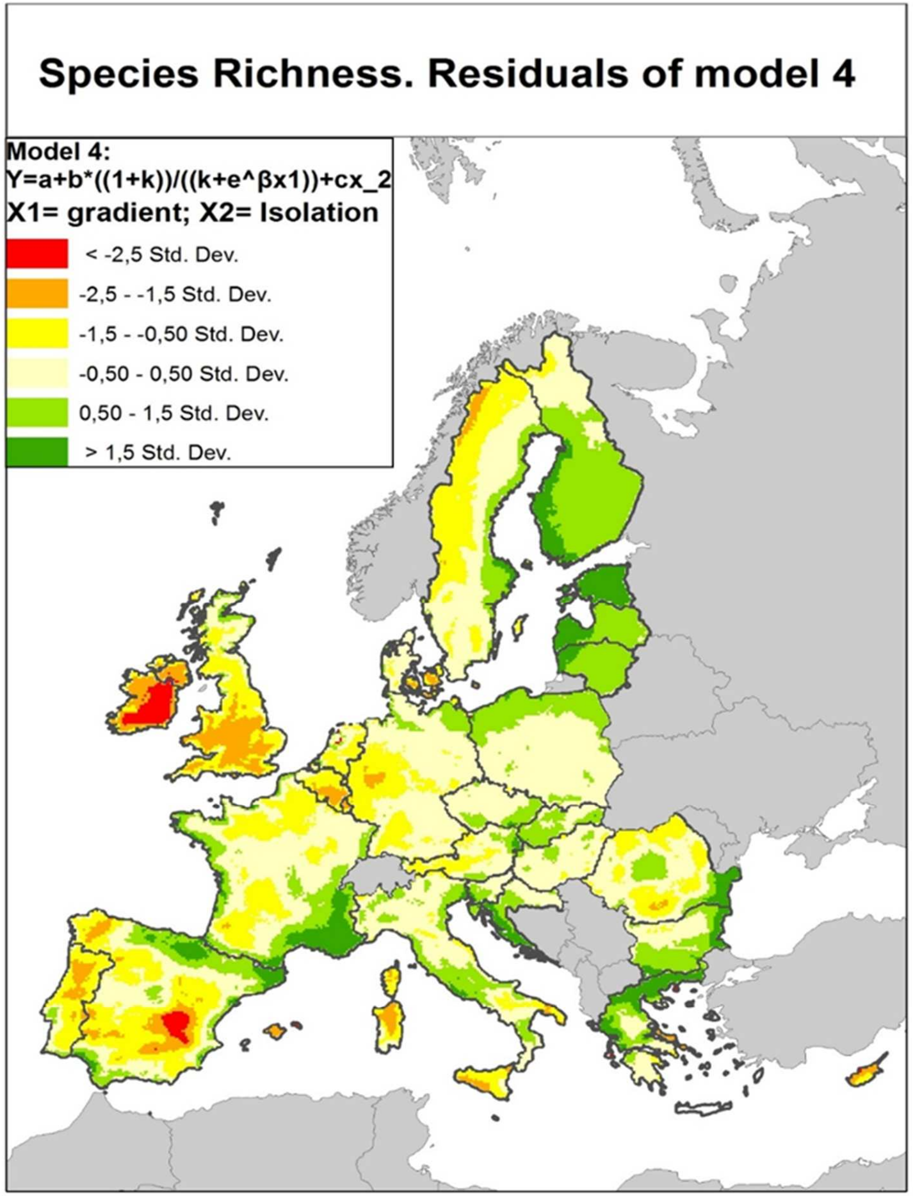


Figure 51: Spatial distribution of species richness residuals from models 3 (left) and 4 (right)

A2.5 Geographical Trends of the Red List Index

Given the strong correlation on species richness with the identified geographical gradient, it may be interesting to investigate whether similar trends can be identified in relation to the Red List Index. Again, we resorted to an empirical polynomial model were the independent variable is the position along the NNW-SSE gradient and the dependent variable is the Red List Index value (see section 4.3).

Using a third degree polynomial, a strong correlation was found indeed, as shown by the following Table 13 and Figure 52.

Third degree Polynomial Fit: $y = a + bx + cx^2 + dx^3$

Y = Red List Index (range 0-1)

X = position of cell's centre along the gradient (values normalized between 0-1)

Table 13: Descriptive statistics and parameters' estimated values of 3rd degree polynomial fit for Red List Index

Descriptive statistics		Parameters' estimated values	
R^2	0.871	a	9.664E-001
MSE	0.0032023	b	-5.394E-002
RMSE	0.056589	c	2.330E-001
		d	0.031

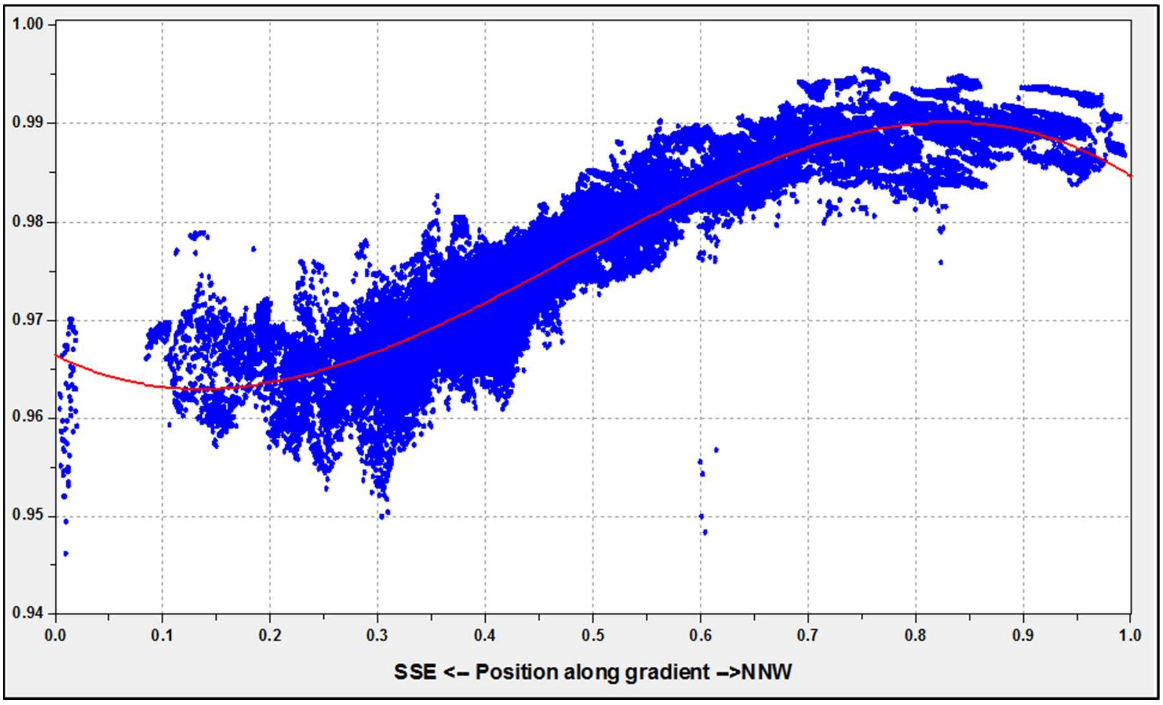


Figure 52: Red List Index values (Y axis) and position along the NNW-SSE gradient (X axis). Red line: 3rd degree polynomial fit

Remembering that the lower the average value of the Index in a cell, the more threatened the species found therein, diagram shows how species status increases from South-south East towards North-North-West up to a maximum and then slightly decreases again in the most remote areas (northern Sweden and Finland).

The results of this modelling exercise indicate that not only species richness, but also their status in terms of distance from the risk of extinction are strongly affected at the continental scale by wide geographic trends that shall be carefully considered when interpreting and using the raw data. However, a straightforward interpretation is not possible based only on the identified trends. De-trending data as it was done for species richness was not deemed appropriate as it may lead to biased results. In fact, in this case, some anthropic factors likely to affect the index values are in turn correlated with the geographic trend – notably, the density of human population and thus the anthropic pressure is lower in Northern Europe.

This aspect deserves further investigation, which goes beyond the scope of this report; further research could aim for example to develop a comprehensive multi regression model incorporating both geographic (including isolation) and “anthropic” variables, such as presence and density of urban areas, intensity of agricultural management, presence of protected areas etc. so to identify the main drivers affecting species status. Finally, is shall be recalled that IUCN data used in this exercise refers to the threaten status of species at the *global* level, as the aim was to put the European Union in the global perspective. A main development of the study would be to carry out the same analysis using the IUCN European assessment.

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List of abbreviations and definitions

AIC: Akaike's information criterion

ALP: Alpine Bioregion

ATL: Atlantic Bioregion

BOR: Boreal Bioregion

CON: Continental Bioregion

CR: Critically endangered

DD: Data Deficient

EC: European Commission

EEA: European Environmental Agency

EN: Endangered

ETRS 89: European terrestrial Reference System 1989

EU: European Union

EW: Extinct in the wild

EX: Extinct

LAEA: Lambert Azimuthal Equal Area

IUCN: International Union for Conservation of Nature

LC: Least Concern

MAC: Macaronesia Bioregion

MED: Mediterranean Bioregion

NT: Near Threatened

PAN: Pannonian Bioregion

RLI: Red List Index

SAR: Species Area Relationship

VU: Vulnerable

List of figures

List of tables

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