European Environment Agency
European Topic Centre on
Biological Diversity

Technical paper N° 6/2020

Producing European habitat probability maps for wetlands and coastal habitats based on in-situ vegetation plots, environmental data and Copernicus land cover

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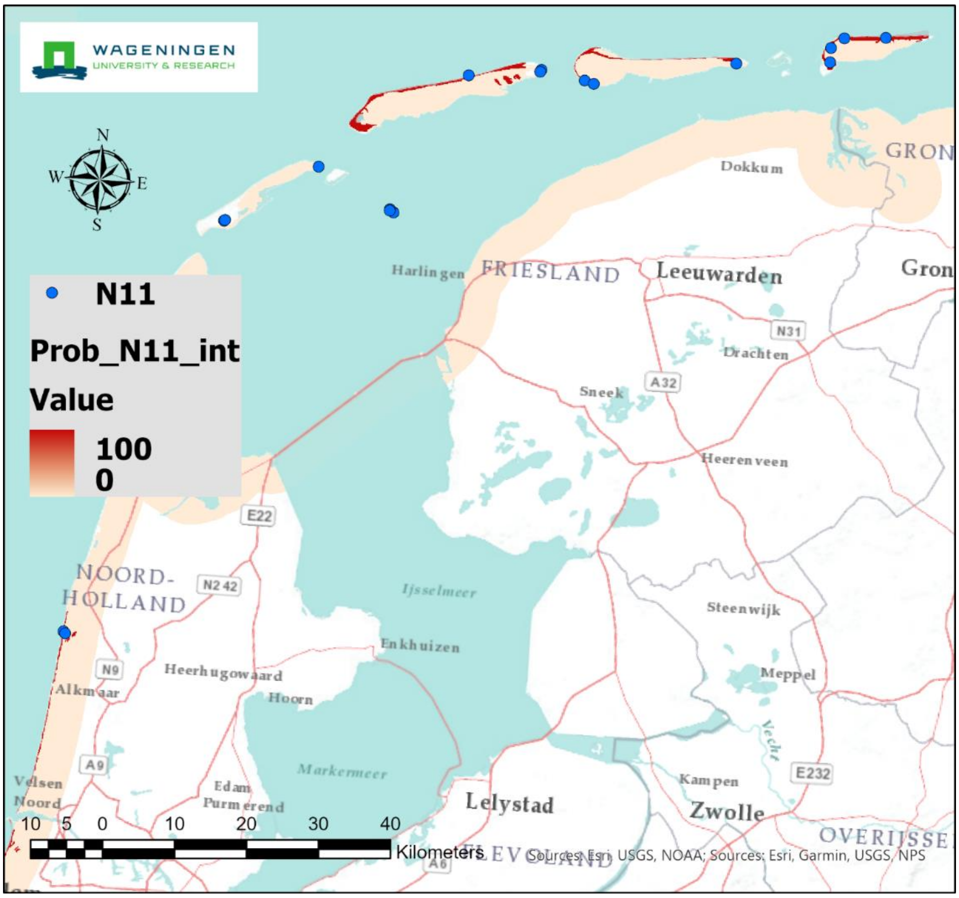

01/05/2020

The European Topic Centre on Biological Diversity (ETC/BD) is a consortium of eleven organisations under a Framework Partnership Agreement with the European Environment Agency for the period 2019-2022
MNHN EAA (UBA) Ecologic ILE-SAS JNCC NATURALIS NCA-CR S4E SLU URJC WENR

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Context:

The Topic Centre has prepared this Technical paper in collaboration with the European Environment Agency (EEA) under its 2020 work programmes as a contribution to the EEA's work on Biodiversity mapping.

Citation:

Please cite this report as
Mücher, S. and Hennekens, S., 2020. Producing European habitat probability maps for wetlands and coastal habitats based on in-situ vegetation plots, environmental data and Copernicus land cover. ETC/BD report to the EEA.

The withdrawal of the United Kingdom from the European Union did not affect the production of the report. Data reported by the United Kingdom are included in all analyses and assessments contained herein, unless otherwise indicated.

ETC/BD Technical paper N° 6/2020
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1 Background and objectives

1.1 Background

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

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

More information about ETC/BD can be found at: https://www.eionet.europa.eu/etcs/etc-bd

1.2 Objectives

The objective of this report within the specific task 1.7.5.1 of the ETC/BD Action Plan in 2020 is: **to enhance the spatial delineation of ecosystems/habitats with remote sensing data, environmental data and in-situ vegetation plot data to produce actual high-resolution habitat probability maps for EUNIS habitat types at level 3 for the formations wetlands (Q) and coastal habitats (N).**

In 2019 all EUNIS habitat types belonging to wetlands (Q) and coastal habitats (N) have been revised under the EEA Framework Contract Specific Contract No. 3417/B2019/EEA.57640 and Framework Service Contract No. EEA/NSS/17/002/Lot 1 (Schaminée et al. 2019). Within that specific framework contract almost all habitat types of the new categories N and Q could be crosswalked. For updating the crosswalks of the revised EUNIS Habitat Classification for coastal habitats and wetlands with EuroVegChecklist 2016 the latest version of the EUNIS list of habitat types at level 3 for coastal habitats (Group B) and wetlands (Group E) was provided by EEA as a 'working list'. During the process of crosswalking this list proved to be stable and it was only slightly modified (Schaminée et al. 2019). For the coastal habitat types (N), the only exception was habitat type N1k (Machair grasslands). Concerning the wetlands (Q), the exceptions were the habitat types Q13 (Ombrotrophic percolation mire) and Q32 (Aapa mire).

The revision resulted in an improved classification that was used to assign a large part of the European Vegetation Archive (EVA) to EUNIS habitat types and to enable their description. This work was the starting point for the current study for ETC/BD, Task 1.7.5.1 to deliver distribution, suitability and probability maps for the EUNIS habitat types belonging to group N and Q. This resulted in newly defined EUNIS habitat suitability maps which were also based on much more in-situ vegetation plot data (Hennekens, 2019).

Table 1.1 Targeted EUNIS formations, their old and new codes and their number

EUNIS Formation	Old code	New Code	Number of habitat suitability maps
Coastal habitats	B	N	# 19
Wetlands	D	Q	# 18
Total			#37

On basis of the 37 EUNIS habitat suitability maps for wetlands and coastal habitats, 35 new habitat probability maps have been processed by exploiting Copernicus land cover data. The Copernicus land cover data sets that have been exploited for the wetlands and coastal habitats were:

1. Corine land cover database 2018 (100 meter resolution)
2. High Resolution Layer (HRL) Wetness and Water 2015 (20 meter resolution)

Only for two habitats, namely N31 *'Atlantic and Baltic Rocky sea cliff and shore'* and N32 *'Mediterranean and Black Sea rocky sea cliff shore'*, no habitat probability maps have been produced due to a lack of appropriate environmental data sets. For those specific classes it meant a lack of geomorphological maps related to sea cliffs.

1.3 Content of the report

This report has 5 chapters on the production of the EUNIS wetlands and coastal habitat probability maps at level 3. Chapter 1 describes the background and the objectives of the project. Chapter 2 is an introduction on the habitat modelling, starting with the distribution, followed by habitat suitability and finally the habitat probability maps. The integration of in-situ vegetation plots, environmental data layers and Remote Sensing enabled Essential Biodiversity Variables (RS-EBVs), including Copernicus high resolution land cover information, plays an important role in the overall methodology. Chapter 3 explains how the EUNIS habitat suitability maps have been produced. Chapter 4 describes the Copernicus land cover data sources. Chapter 5 describes how the habitat probability maps have been processed based on the integration of the low resolution habitat suitability maps with the Copernicus land cover data.

Appendix 4 shows detailed examples of the # 17 Coastal habitat (N formation) probability maps. Since these habitats occur only along specific parts of the European coastline and are therefore highly fragmented.

Appendix 5 shows the # 18 Wetland (Q formation) probability maps, including the distribution map (original in-situ vegetation plots) and a detail of the probability maps that shows the real detail of the maps.

2 Habitat modelling

2.1 Introduction

Although it is quite rare to record or map EUNIS habitat types in the field, there are many data sources which allow mapping their distribution. The most important source of information are in-situ vegetation plots (also known as vegetation relevés), that have been translated to EUNIS habitat types. In the past few years a large number of national and regional databases with such data have been brought together within the European Vegetation Archive project (http://euroveg.org/eva-database). EVA allows the production of distribution map of as explained below, and forms the solid basis for the production of the habitat suitability and probability maps.

Distribution map – map of known occurrences based on recording of local in-situ vegetation plots which have been assigned to a EUNIS habitat class. They show localities where the habitat is known to occur and has been observed (at least at the time of survey), but give an incomplete record of the actual distribution across Europe.

Suitability maps– modelling of areas where the environment is suitable for the habitat. So in fact it shows more the potential suitable areas for that specific habitat.

Probability maps – the modelled suitability maps is refined by using actual land cover information, and in some cases by other actual environmental information.

2.2 Methodology

Figure 2.1 shows the various products as part of the methodology to obtain habitat probability maps.

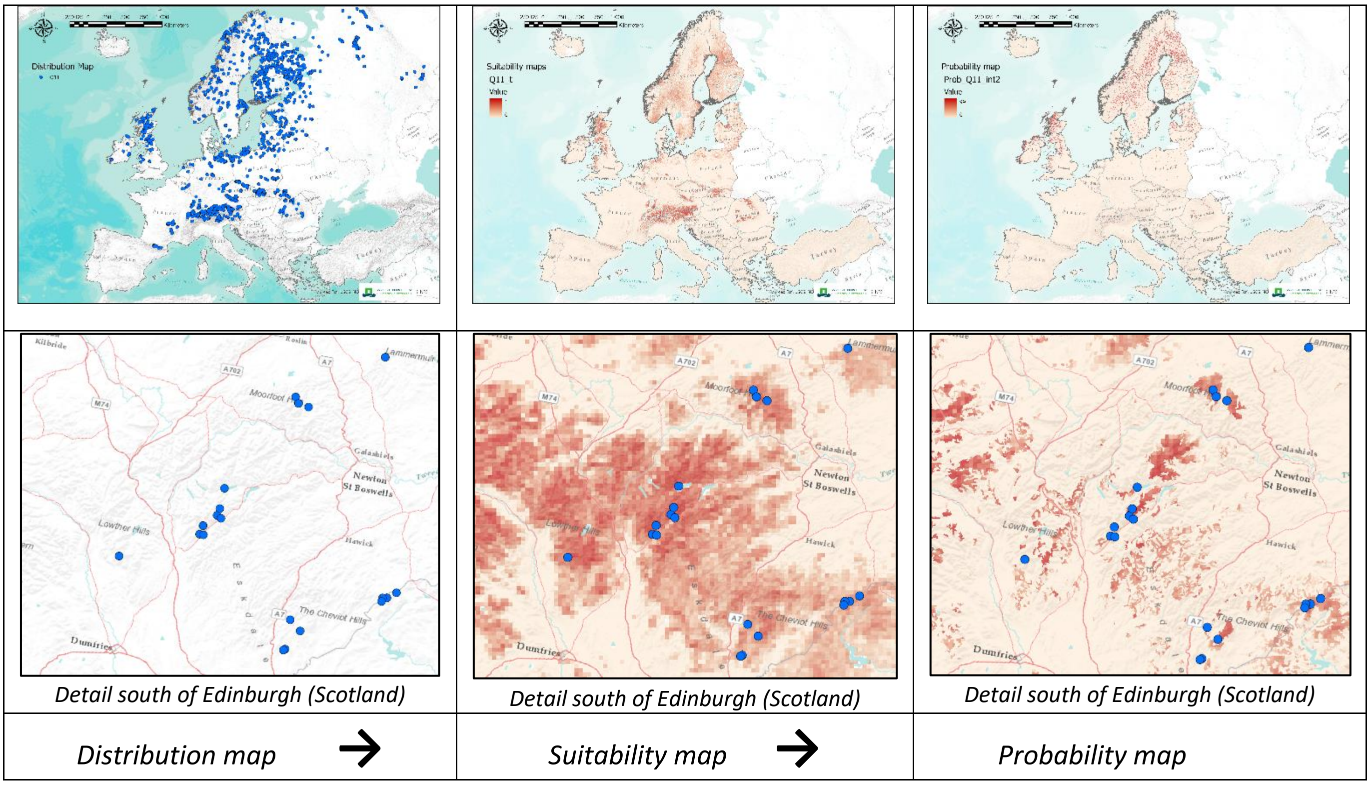


Figure 2.1 **Q11: Raised bog**

The methodological processing line from individual recorded vegetation plots into a final EUNIS habitat probability map, roughly comprises three steps (see also figure 2.1).

1. In-situ vegetation plot data stored in the European Vegetation Database (EVA) are assigned to EUNIS classes using expert rules. An expert rule defines the ***floristic composition*** (which species should be present and which species should be absent) of a class and is used to select those vegetation plots (relevés) that meet the imposed condition. The selection is used to create a **distribution map,** as far as the geographic location is tied to the recorded vegetation plots.
2. The distribution, by means of geographic locations of the recorded vegetation plots, see Figure 2.1, is used in the second step, the suitability model. The habitat suitability modelling is not only based on the distribution data but also based on climate, topographic, soil, remotely sensed Essential Biodiversity Variables (EBV's) and other environmental data that is stored in 1km resolution grid maps at a European scale. The modelling software Maxent (Phillips et al., 2006) calculates which environmental layers have the largest contribution to the model, in other words, explains the distribution of the recorded vegetation plot data the best. The major outcome of the MAXENT model is the **suitability map (**see Figure 2.1)**.** This map indicates how suitable, in terms of climate and soil conditions an area is for the specific EUNIS habitat class. This is expressed on a scale of 0 to 1.
3. While step 1 and 2 are bottom-up approaches, the third step is a top-down approach, where spaceborne observations such as satellite derived land cover data is used to refine the potential habitat suitability map into an actual **probability map,** see also Figure 2.1. As such, the probability map is a refinement of the suitability map, with a more targeted and limited extend.

While the suitability map can be considered as a potential distribution map, the probability map presents more the actual distribution of the habitat type. Although the probably map still represents a modelled distribution and the probably overestimates the actual distribution.

All three steps are explained more in detail in the published report 'Modelling the spatial distribution of EUNIS forest habitat types' by Mücher, et al. (2015).

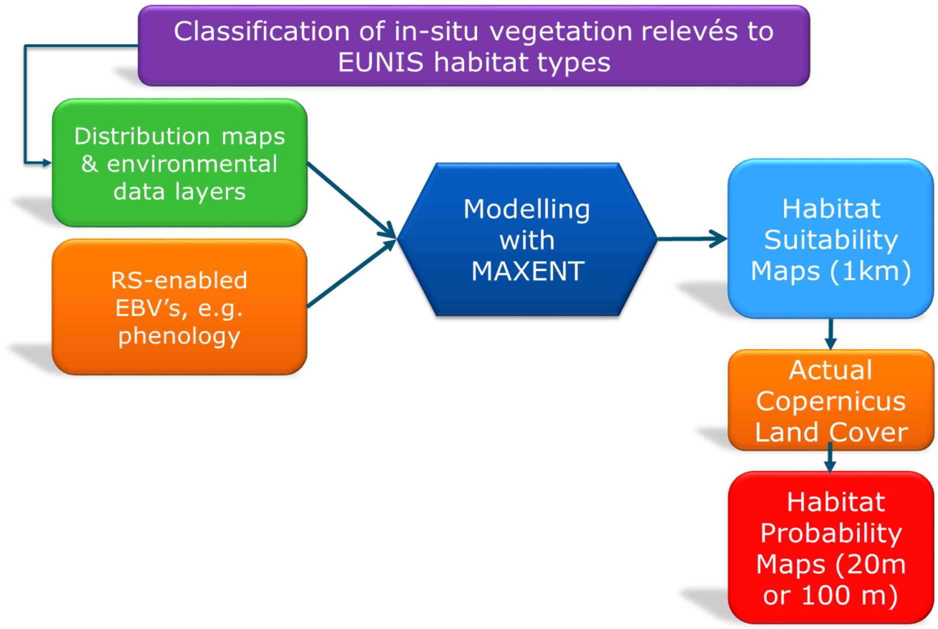


Figure 2.2 **Newly adjusted general workflow for the processing of refined EUNIS forest habitat probability maps (adjusted from Mücher et al., 2015)**

3 Habitat suitability maps

For habitat suitability modelling, the latest version of the widely used software Maxent[1] for maximum entropy modelling of species geographic distributions was used. Maxent is a general-purpose machine-learning method with a simple and precise mathematical formulation, and has a number of aspects that make it well-suited for species distribution modelling when only presence (occurrence) data but not absence data are available (Philips et al. 2006). Because EUNIS habitats have a particular species composition, they are assumed to respond to specific ecological requirements, allowing us to generate correlative estimates of geographic distributions. Modelling habitats that have been floristically defined is a well-known procedure for ecological modelling at local scales, and a promising technique to be applied also at the continental level.

The Maxent modelling procedure considers presence data (known observations of a given entity) and the so-called background data. Background data comprise a set of points used to describe the environmental variation of the study area according to the available environmental layers. It is assumed that these layers represent well the most important ecological gradients on a European scale. The layers were selected from meaningful environmental predictors commonly used for modelling non-tropical plant and vegetation diversity, and are not mutually strongly correlated. In addition to what was selected as predictors in previous years (Hennekens 2016, 2017), also so-called RS-enabled EBV's (Remote Sensed Essential Biodiversity Variables; predictors based on remote sensing data), such as LAI, phenology, land cover, chlorophyll content, inundation, vegetation height have now been applied (Skidmore et al, 2015, Pettorelli et al., 2016).

It is assumed that by using additional meaningful predictors such as the RS-EBV's, the modelling will result in more realistic suitability maps with less outliers (prediction in areas where the habitat is not expected to be present).

As a side effect of using the RS-EBS's the study area now excludes countries like Russia, Belarus and Ukraine in the east part of Europe. This also has led to better predictions because the very eastern part of Europe is currently not well represented in EVA.

As environmental predictors (and their sources) the following climate and soil layers have been used:

Climate

- Potential Evapotranspiration
  http://www.cgiar-csi.org/data/global-aridity-and-pet-database
- Solar radiation
  http://www.worldgrids.org/doku.php?id=wiki:inmsre3
- Temperature Seasonality (standard deviation *100)
  http://www.worldclim.org/bioclim
- Mean Temperature of Wettest Quarter
  http://www.worldclim.org/bioclim
- Annual Precipitation
  http://www.worldclim.org/bioclim

[1] Maxent version 3.4.1 was used. http://biodiversityinformatics.amnh.org/open_source/maxent/

- Precipitation Seasonality (Coefficient of Variation)
  http://www.worldclim.org/bioclim
- Precipitation of Warmest Quarter
  http://www.worldclim.org/bioclim

Topography

- Distance to water (rivers, lakes, sea)
  derived from the shapefile 'Inland_Waters.shp'
- Digital Elevation Map (DEM)

Soil

- Bulk density of the soil (kg/m³)
  Hengl et al. 2014
- Cation Exchange Capacity of the soil
  Hengl et al. 2014
- Weight in % of clay particles (<0.0002 mm)
  Hengl et al. 2014
- Volume % of coarse fragments (> 2 mm)
  Hengl et al. 2014
- Soil organic carbon content (‰)
  Hengl et al. 2014
- Soil pH (water)
  Hengl et al. 2014
- Weight in % of silt particles (0.0002-0.05 mm)
  Hengl et al. 2014
- Weight in % of sand particles (0.05-2 mm)
  Hengl et al. 2014

RS-EBV's

- Inundation; occurrence
  Global Surface Water Explorer, 1984-2015, 30m, resampled to 1km (resampling methods: average resampling and mode resampling (selects the value which appears most often of all the sampled points))
- Phenology; End of Season (day number)
  End of Season, defined as the point in time where the NDVI drops below the NDVI at the start of the growing season
- Phenology; Length of season (days)
  Length of season, number of days between EoS and Sos [days]
- Phenology; Low of season (day number)
  Phenology; Low of season (day number with lowest NDVI)
- Phenology; NDVI mean
  Mean NDVI

- Phenology; NDVI seasonality
  Minimum NDVI
- Phenology; Peak of season (day number)
  Phenology; Peak of season (day number with highest NDVI)
- Phenology; Start of Season (day number)
  Start of Season, defined as the point in the year with the largest positive rate of change (maximum of 1st derivative) [day of year 1..365]
- Vegetation height (m)
  3D Global Vegetation Map, 2000, 1km

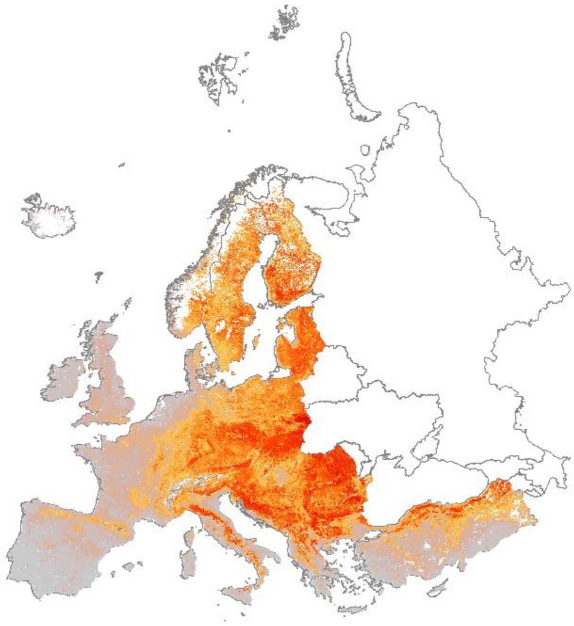
More information on predictors and particularly on RS-EBS's can be found here: https://www.synbiosys.alterra.nl/nextgeoss/docs/Description_Abiotic_and_RSEBVs.pdf

3.1 Suitability modelling

Maxent is expected to perform well for estimating the geographic distribution of EUNIS habitats in Europe. However, as with any other modelling techniques this method is sensitive to sampling bias, i.e. when the spatial distribution of presence data is reflecting an unequal sampling effort in different geographic regions. In Maxent, it has been proposed that the best way to account for sampling bias (when bias is known or expected to occur) is to generate background data reflecting the same bias of the presence data. When a complete set of presence data is available, a general recommendation is to generate background points from the occurrences of other species/communities that were sampled in a similar way (Elith et al. 2011).

Two different approaches have therefore been followed for the selection of a maximum of 5,000 locations for the background data, assuming biased and non-biased presence data. For the first approach, 5,000 locations were randomly selected by Maxent from the study area, whereas the second approach concerns a random stratified (one sample per 1x1 km grid) selection of 5,000 background locations of plots present in the EVA database. Concerning the observed occurrences of the EUNIS types also a random stratified selection has been applied with a maximum of 5000 observations.

The two modelling approaches (assuming biased and non-biased data) were evaluated for each of the EUNIS habitat types in order to estimate which assumption is more likely. Surprisingly the current study showed that all maps using background data that was randomly selected by Maxent were far more better (by visual inspection) than the maps produced using background randomly derived from the EVA database. Figure 3.1 clearly shows on overestimation of habitat type F1.6a (Fagus forest on non-acid soils) in a large part of Europe, whereas figure 3.2 presents a more realistic picture.



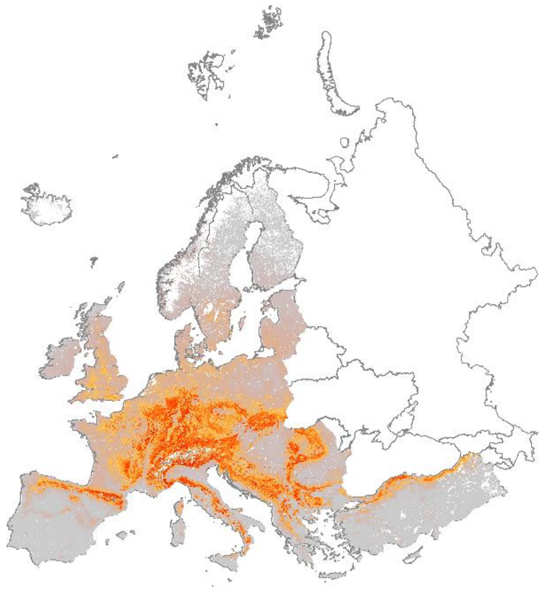
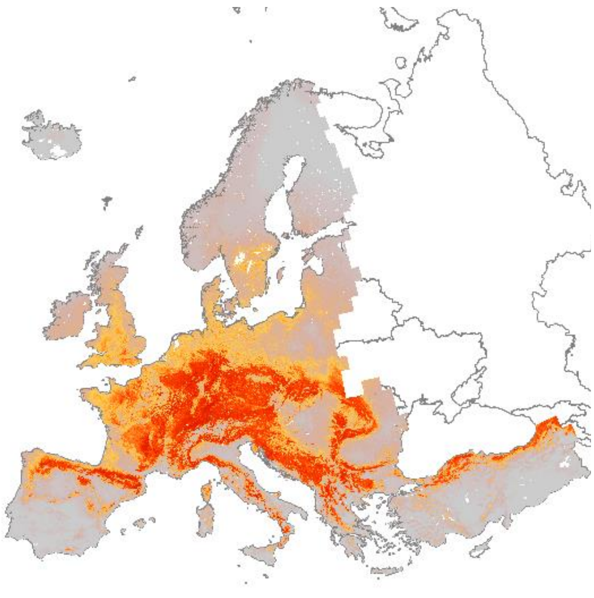


Figure 3.1 EUNIS type F1.6a; background data based on locations from randomly selected plots in the EVA database

Figure 3.2: EUNIS type F1.6a; background data randomly selected from the study area by Maxent

Another test that was performed was running all models with and without the RS-EBV's predictors. In figure 3.3 and 3.4 it is shown that leaving out RS-EBS's does not affect the distribution range. However it also shown that including RS-EBS's the suitability is more differentiated, compare figure 3.5 and 3.6.



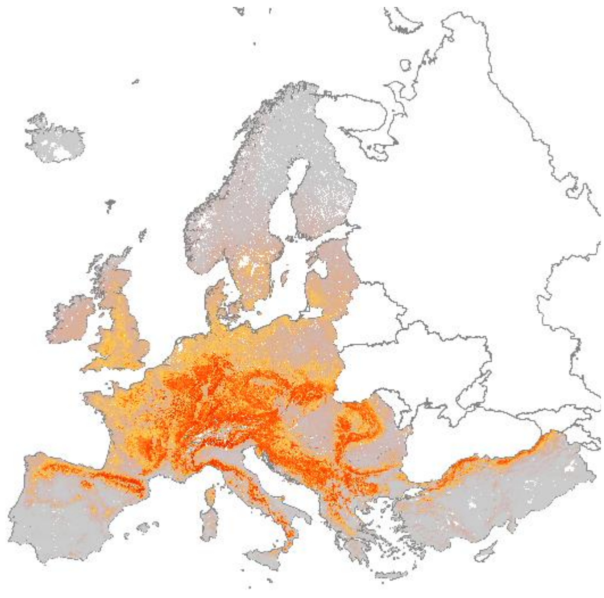


Figure 3.3: model without RS-EBV's

Figure 3.4 : model with RS-EBV's

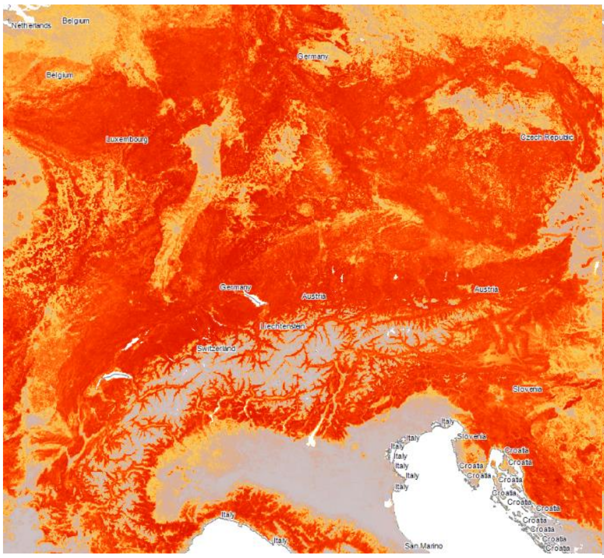


Figure 3.5: Detail of model without RS-EBV's

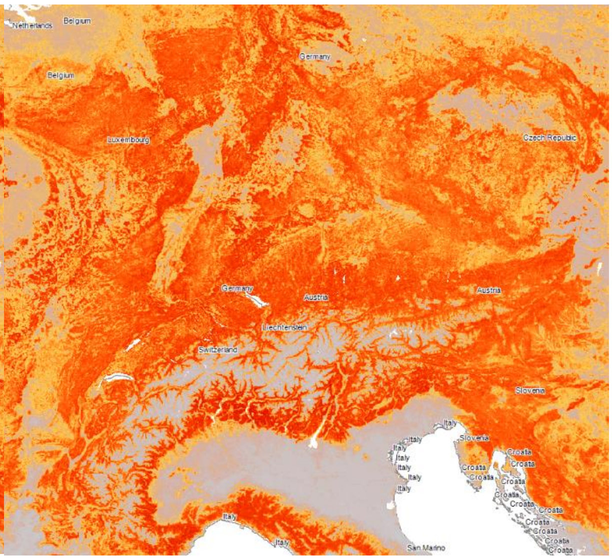


Figure 3.6: Detail of model with RS-EBV's

Table 3.1 shows the 35 habitat types for which the EUNIS habitat suitability maps have been refined by using the 10-percentile thresholds that were a result of the MAXENT models. It is assumed that suitability percentages lower that the 10-percentile threshold are not valid.

Table 3.1 List of 37 EUNIS habitat suitability types at level 3 and the associated 10-percentile thresholds that has been used as an input for the processing of the habitat probability maps based on actual land cover information

#		New code	Old code	10-perc threshold	New name
Coastal habitats (#19)					
1		N11	B1.1a	0.4461	Atlantic, Baltic and Arctic sand beach
2		N12	B1.1b	0.5747	Mediterranean and Black Sea sand beach
3		N13	B1.3a	0.3901	Atlantic and Baltic shifting coastal dune
4		N14	B1.3b	0.3996	Mediterranean, Macaronesian and Black Sea shifting coastal dune
5		N15	B1.4a	0.3743	Atlantic and Baltic coastal dune grassland (grey dune)
6		N16	B1.4b	0.4509	Mediterranean and Macaronesian coastal dune grassland (grey dune)
7		N17	B1.4c	0.4932	Black Sea coastal dune grassland (grey dune)
8		N18	B1.5a	0.5599	Atlantic and Baltic coastal Empetrum heath
9		N19	B1.5b	0.6223	Atlantic coastal Calluna and Ulex heath
10		N1A	B1.6a	0.4451	Atlantic and Baltic coastal dune scrub
11		N1B	B1.6b	0.5568	Mediterranean and Black Sea coastal dune scrub
12		N1D	B1.7a	0.4552	Atlantic and Baltic broad-leaved coastal dune forest
13		N1F	B1.7c	0.5928	Baltic coniferous coastal dune forest
14		N1G	B1.7d	0.4473	Mediterranean coniferous coastal dune forest
15		N1H	B1.8a	0.4378	Atlantic and Baltic moist and wet dune slack
16		N1J	B1.8b	0.7972	Mediterranean and Black Sea moist and wet dune slack
17		N21	B2.1a	0.2989	Atlantic, Baltic and Arctic coastal shingle beach

18		N31	B3.1a	0.3172	Atlantic and Baltic rocky sea cliff and shore
19		N32	B3.1b	0.2913	Mediterranean and Black Sea rocky sea cliff and shore
Wetlands (#18)					
20		Q11	D1.1	0.4119	Raised bog
21		Q12	D1.2	0.4977	Blanket bog
22		Q21	D2.1	0.3077	Oceanic valley mire
23		Q22	D2.2a	0.3651	Poor fen
24		Q23	D2.2b	0.4248	Relict mire of Mediterranean mountains
25		Q24	D2.2c	0.4059	Intermediate fen and soft-water spring mire
26		Q25	D2.3a	0.416	Non-calcareous quaking mire
27		Q3132	D3.1	0.5261	Palsa and polygon mires
28		Q41	D4.1a	0.3412	Alkaline, calcareous, carbonate-rich small-sedge spring fen
29		Q42	D4.1a	0.3995	Extremely rich moss-sedge fen
30		Q43	D4.1b	0.2982	Tall-sedge base-rich fen
31		Q44	D4.1c	0.3511	Calcareous quaking mire
32		Q45	D4.2	0.3597	Arctic-alpine rich fen
33		Q46	-	0.507	Carpathian travertine fen with halophytes
34		Q51	C5.1a	0.4318	Tall-helophyte bed
35		Q52	C5.1b	0.4376	Small-helophyte bed
36		Q53	C5.2	0.3955	Tall-sedge bed
37		Q54	C5.4	0.2941	Inland saline or brackish helophyte bed

In a next step, actual land cover information plays a key role to fine-tune the habitat suitability maps into habitat probability maps, and the land cover sources and processing are discussed in Chapter 4, while the methodology for the habitat probability maps is discussed in Chapter 5 .

4 Copernicus Land Cover

The European land cover databases with the highest spatial resolution are the Copernicus HRLs (High Resolution Layers with a 20 meter spatial resolution and they have specific themes: 1) imperviousness 2) forests; 3) permanent waterbodies; 4: grasslands and 5) wetlands (see also https://land.copernicus.eu/).

The Copernicus HRL that seems in the first instance to be the best affiliated with wetlands and coastal habitats is the Water and Wetness (WAW) product (Langanke, 2018). The 2015 reference year wetness and water product is a new baseline product, which fully replaces the previous 2012 separate "permanent water" and "wetland" products (https://land.copernicus.eu/pan-european/high-resolution-layers/water-wetness). The combined Water and Wetness product is a thematic product showing the occurrence of water and wet surfaces over the period from 2009 to 2015 (Langanke, 2018). This layer is based on multi-temporal and multi-seasonal optical high-resolution satellite imagery. In addition, this layer is also based on radar information (Sentinel-1 data) with a geometric resolution of 10m on a pan-European basis. A multitude of optical and SAR imagery is used, covering a prolonged time series of 7 years, which aim at capturing the intra-annual dynamics as much as possible within a given area and lead to one image composite per season (each season covered by 3 months) and year during the observation period (Langanke, 2018). They form the basis of the main Water and Wetness (WAW) product with defined classes of (Langanke, 2018):

(1) permanent water
(2) temporary water
(3) permanent wetness and
(4) temporary wetness.

The products show the occurrence of water and indicate the degree of wetness in a physical sense, assessed independently of the actual vegetation cover and are thus not limited to a specific land cover class and their relative frequencies. More detailed product specification in the technical document of Langanke (2018).

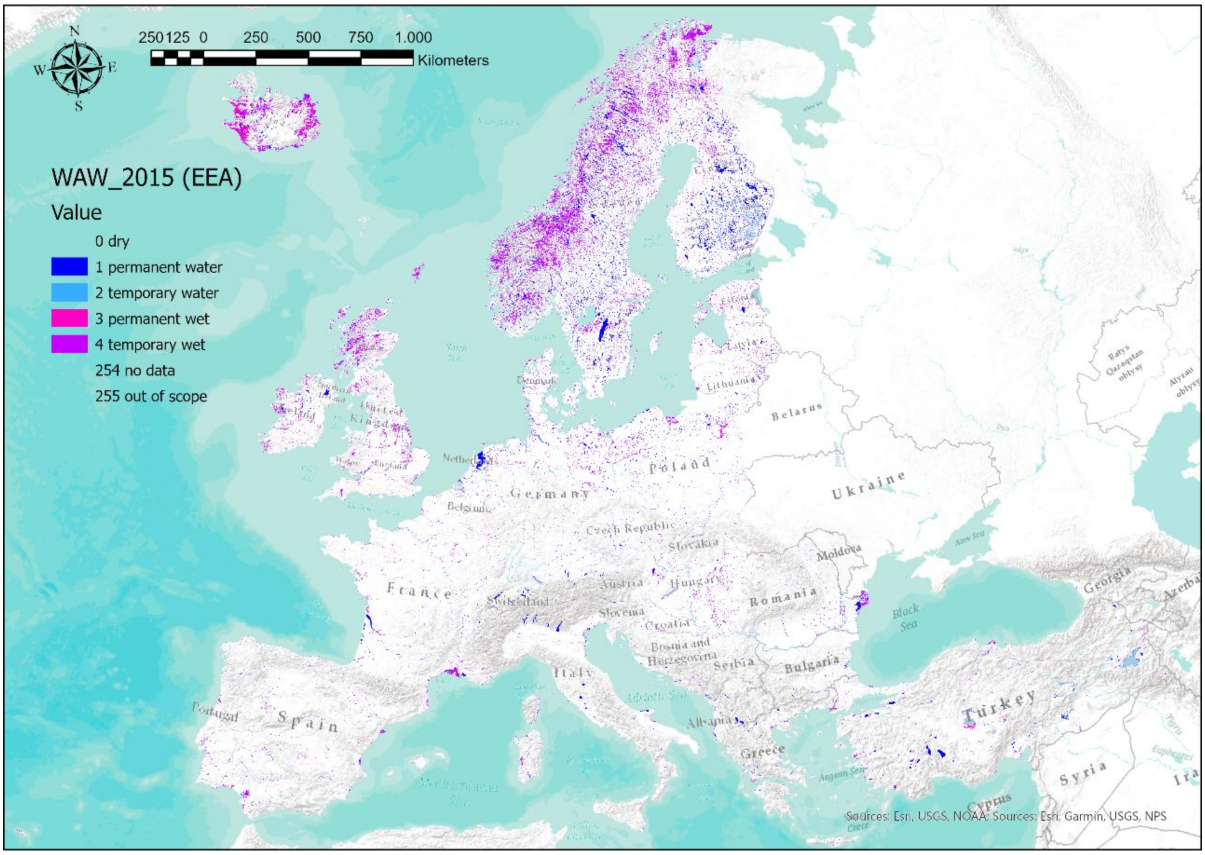


Figure 4.1. Copernicus High Resolution Layer (HRL) Water and Wetness 2015. Source: EEA

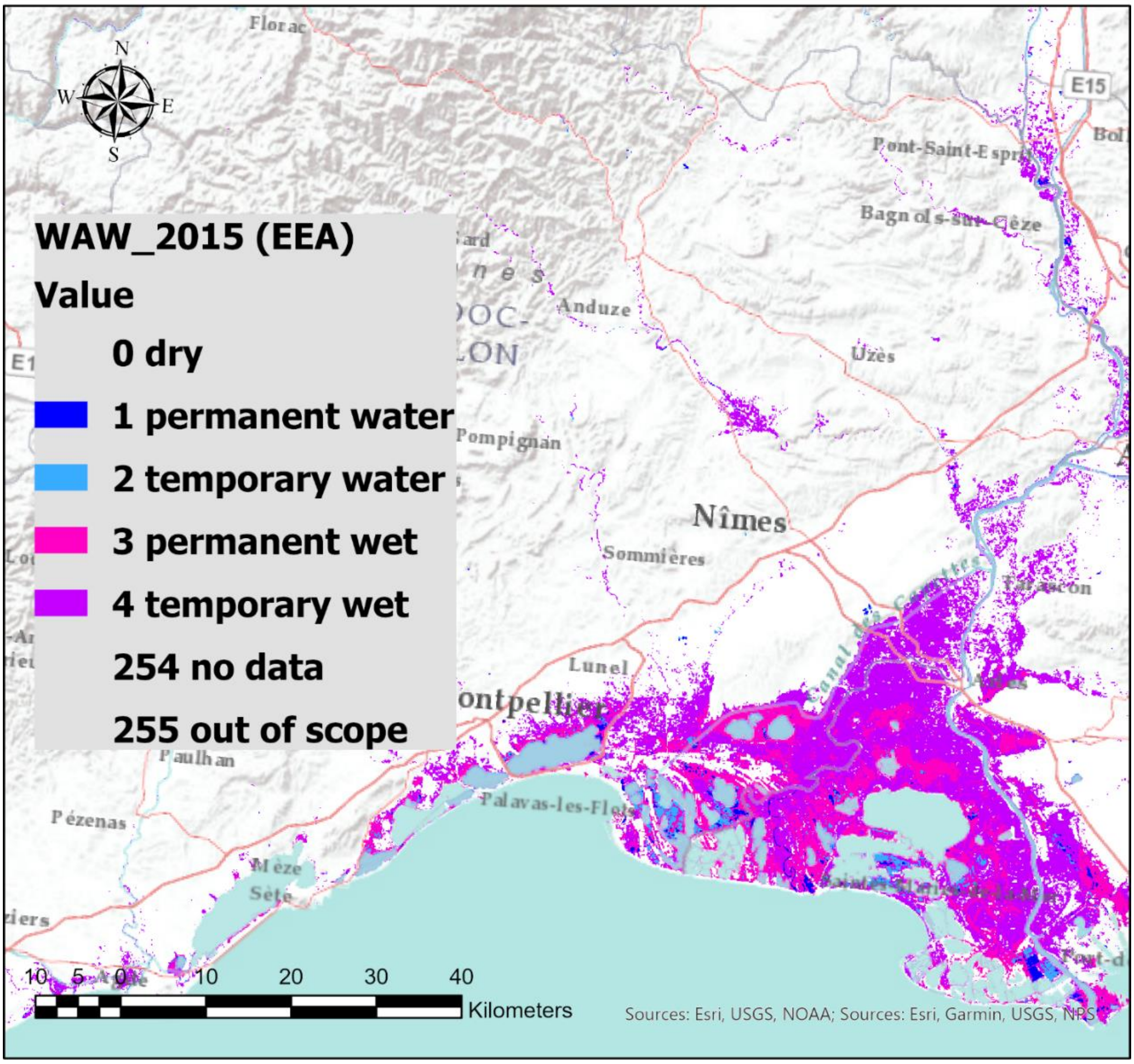


Figure 4.2. **Detail of the Camargue and surroundings from the Copernicus High Resolution Layer (HRL) Water and Wetness 2015. Source: EEA**

Table 4.1 **Definitions of the Water and Wetness classes (from Langanke, 2018)**

Code	Wetness/Water layer	Explanation	Examples
0	No water / no wet area	always dry (dry in at least 75% of all observations)	
1	Permanent water	always water (water in at least 80% of all observations)	• Permanent inland lakes (natural) • Artificial ponds (permanent fish ponds, reservoir) • Natural ponds (permanent open water surfaces of inland or coastal wetlands • Rivers • Channels (permanently with water)

			• Coastal water surfaces: lagoons, estuaries within the boundaries of the EEA coastline for analysis V2. • Liquid dump sites (permanent) • Water surfaces with floating vegetation where detectable with remote sensing techniques.
2	Temporary water	alteration of dry and water or alteration of wet and water (water in >25% to 80% of all observations, with varying degrees of wet and dry; water dominates over wet)	• Temporary water surfaces associated to permanent water bodies (e.g. oscillating shoreline areas of reservoirs) • Temporary natural (e.g. steppe) lakes and temporary artificial lakes (e.g. cassettes of fishponds) • Intermittent rivers and temporarily flooded river banks • Flood areas • Water-logged areas • Temporary flooded agricultural fields e.g. rice fields • Intertidal areas • Temporarily inundated areas (due to snow melt, floods or rain)
3	Permanently wet areas (wetness)	always wet (wet in at least ~60% of all observations, region dependent)	• Reeds • Peat land • Inland and coastal wetlands (incl. salt marshes)
4	Temporary wet area (wetness	alteration of dry and wet (wet in >25% to 60% of all observations, with varying degrees of wet and dry; wet dominates over dry)	• Inland saline marshes • Intermittent wetlands • Temporary wet agricultural fields • Temporary wet meadows
254	unclassifiable	No satellite image available, clouds, shadows, snow and glaciers	
255	Outside production unit	Sea and ocean, land area outside the production unit	

For the wetlands and coastal habitats we used in addition the most recent CORINE land cover information from 2018 (https://land.copernicus.eu/pan-european/corine-land-cover/clc2018).

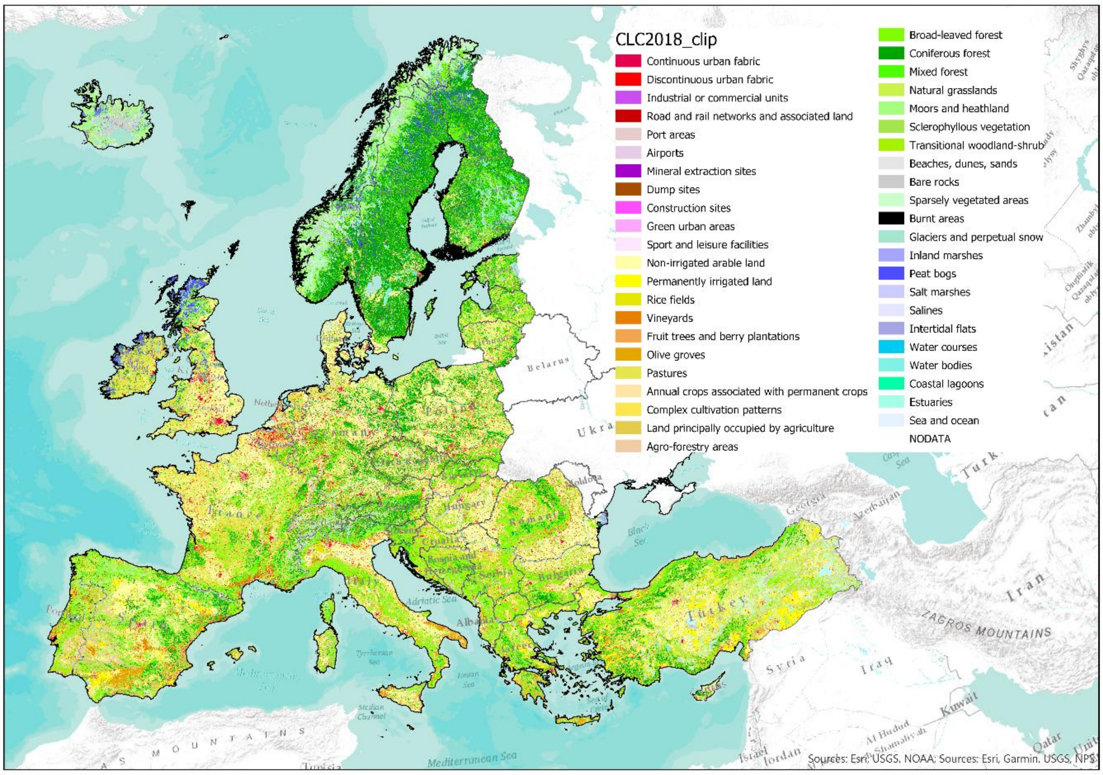


Figure 4.3 Corine land cover 2018 (source: EEA, CLC2018_CLC2018_V2018_20.tif)

For Corine land cover (CLC) there is an existing crosswalk between the EUNIS habitats and CLC made by Moss (2012). However such as crosswalk does not exists with the Water and Wetness (WAW) HRL product. Therefore we made an additional analysis by overlaying the individual habitat distribution maps (point data) with the land cover layers CLC2018 and WAW2015 by using the Sample tool in Spatial Analyst of ArcGIS Pro. In summary it creates a table that shows the values of cells from a raster, or set of rasters, for defined locations. The locations are defined by raster cells, polygon features, polyline features, or by a set of points (https://pro.arcgis.com/en/pro-app/tool-reference/spatial-analyst/sample.htm). The figure below shows how such a model looks like.

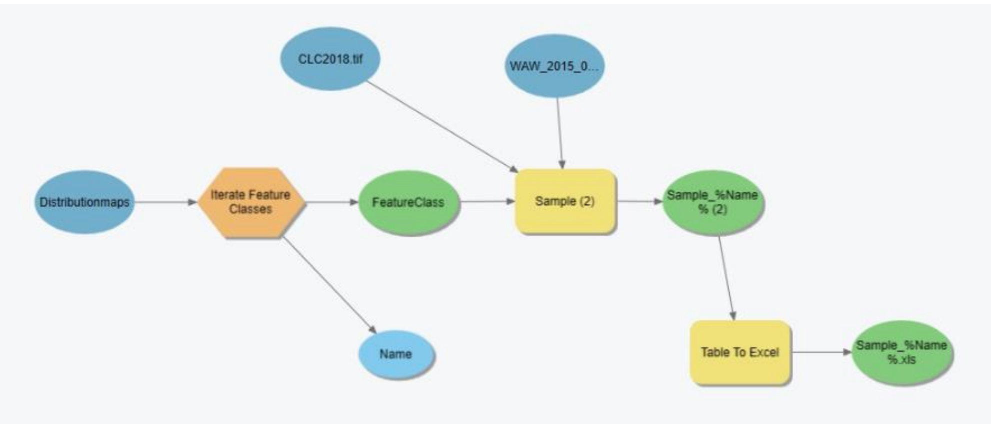


Figure 4.4 Spatial model in ArcGIS Pro showing the use of the Sample tool (Spatial Analyst) to create the crosswalks between the ditribution point data of the 37 wetlands and coastal habitats and the Copernicus land cover layers; Corine Land Cover and HRL Water and Wetness.

The spatial model as in Figure 4.4. leads to a crosswalk (in a Excell sheet) for each of the 37 wetlands and coastal habitats. In Appendix 1 a summary is given of this analysis and is used in the next section to set up the decision rules. So the decision rules are based on the crosswalk of Moss (2012), the new crosswalk analysis based on the distribution maps and the Copernicus land cover layers, and the existing ecological knowledge at ETC/BD & WENR.

The crosswalk in Appendix 1 shows that for wetlands and coastal habitats there is a strong relationship between the recorded vegetation plots and the actual land cover, although the relationship is many to many. Surprisingly there is in most cases no strong relationship between the recorded vegetation plots and the HRL Water and Wetnes, while it was in a first instance assumed that there would be a strong relationship with the classes 3) 'Permanently wet areas' and 4) 'Temporary wet areas'. Only with the WAW2015 class 4 'Temporary wet areas' there was a significant relationship with the recorded vegetation plots for the following 6 habitat classes: i) N1H '*Atlantic and Baltic moist and wet dune slack*'; ii) N1J '*Mediterranean and Black Sea moist and wet dune slack'*; iii) Q3132 '*Palsa and polygon mires*'; iv) Q44 '*Calcareous quaking mire*'; v) Q45 '*Arctic-alpine rich fen*' ; vi) Q54 '*Inland saline or brackish helophyte bed*'. See also Apendix 1 for more details.

Besides, the distribution maps also helped to analyse the distance to the coastline of all coastal habitats (N formation), which were all encountered within 5 kilometers from the coast, see also Table 4.2. Table 4.2 shows the decision rules for each habitat type in their relation with CORINE land cover classes, see Appendix 2 for the Corine land cover nomenclature (Bossard et al, 2000) .

Table 2.2 Final decision rules for the EUNIS wetlands and coastal habitat types in relation to CLC2018, HRL Water and Wetness 2015, and distance the the coast

New code	**Habitat name**	CLC (EUNIS Crosswalk, Moss 2012)	Final decision rules CLC	Final decision rules WAW	Distance to Sea (km)
N	Coastal habitats				
N1	Coastal dunes and sandy shores				
N11	Atlantic, Baltic and Arctic sand beach	331	**331**	**-**	**5**
N12	Mediterranean and Black Sea sand beach	331	**331**	**-**	**5**
N13	Atlantic and Baltic shifting coastal dune	331	**331**	**-**	**5**
N14	Mediterranean, Macaronesian and Black Sea shifting coastal dune	331	**331**	**-**	**5**
N15	Atlantic and Baltic coastal dune grassland (grey dune)	331	**331, 321**	**-**	**5**
N16	Mediterranean and Macaronesian coastal dune grassland (grey dune)	331	**331, 323**	**-**	**5**
N17	Black Sea coastal dune grassland (grey dune)	331	**331, 321**	**-**	**5**
N18	Atlantic and Baltic coastal Empetrum heath	322	**322, 321, 312**	**-**	**5**
N19	Atlantic coastal Calluna and Ulex heath	322	**322, 321**	**-**	**5**

N1A	Atlantic and Baltic coastal dune scrub	322	**322, 321, 331**	**-**	**5**
N1B	Mediterranean and Black Sea coastal dune scrub	322	**322, 323, 312, 331**	**-**	**5**
N1D	Atlantic and Baltic broad-leaved coastal dune forest	311	**311, 321**	**-**	**5**
N1F	Baltic coniferous coastal dune forest	312	**312, 331**	**-**	**5**
N1G	Mediterranean coniferous coastal dune forest	312	**312, 313, 323**	**-**	**5**
N1H	Atlantic and Baltic moist and wet dune slack	331	**331, 321, 322**	**4**	**5**
N1J	Mediterranean and Black Sea moist and wet dune slack	331	**331, 421, 521, 322**	**4**	**5**
N2	Coastal shingle				
N21	Atlantic, Baltic and Arctic coastal shingle beach	331	**331, 423,**	**-**	**5**
N3	Rock cliffs, ledges and shores, including the supralittoral				
N31	Atlantic and Baltic rocky sea cliff and shore	332	**??**	**-**	**5**
N32	Mediterranean and Black Sea rocky sea cliff and shore	332	**??**	**-**	**5**
Q	Wetlands				
Q1	Raised and blanket bogs				
Q11	Raised bog	412	**412, 324, (312*)**	**-**	**-**
Q12	Blanket bog	412	**412, 322**	**-**	**-**
Q2	Valley mires, poor fens and transition mires				
Q21	Oceanic valley mire	411	**412, 322**	**-**	**-**
Q22	Poor fen	411	**412, 312**	**-**	**-**
Q23	Relict mire of Mediterranean mountains	411	**412, 321, 322, 333**	**-**	**-**
Q24	Intermediate fen and soft-water spring mire	411	**412, 321, 322, (312*)**	**-**	**-**
Q25	Non-calcareous quaking mire	411	**412, 322, (312*)**	**-**	**-**
Q3	Palsa and polygon mires				
Q3132	Palsa and polygon mires	412	**412, 312, 322**	**4**	**-**
Q4	Base-rich fens and calcareous spring mires				
Q41	Alkaline, calcareous, carbonate-rich small-sedge spring fen	411	**411, 321, 312, 231**	**-**	**-**

Q42	Extremely rich moss-sedge fen	411	**411, 312, 231, 412**	**-**	**-**
Q43	Tall-sedge base-rich fen	411	**411, 231, 312,**	**-**	**-**
Q44	Calcareous quaking mire	411	**411, 412, 312, 231**	**4**	**-**
Q45	Arctic-alpine rich fen	411	**411, 321, 322, 333**	**4**	**-**
Q46	Carpathian travertine fen with halophytes	411	**411, 231**		**-**
Q5	Helophyte beds				
Q51	Tall-helophyte bed	411	**411, 231, 512**	**-**	**-**
Q52	Small-helophyte bed	411	**411, 231**	**-**	**-**
Q53	Tall-sedge bed	411	**411, 512, (231*)**	**-**	**-**
Q54	Inland saline or brackish helophyte bed	411	**411, 421, 231, 512**	**4**	**-**

* For these habitat classes, the land cover class between brackets has been removed in a second stage since the probability maps were covering in the first stage an area much too large.

For the nomenclature of Corine Land Cover, see Appendix 1 and for the nomenclature of HRL Water and Wetness, Table 4.1. Also notice that no useful decision rules could be made for habitats N31'Atlantic and Baltic rocky sea cliff and shore' and N32 'Mediterranean and Black Sea rocky sea cliff and shore' due to a lack of geomorphological data. This implied that for two out of the 37 habitat suitability maps, no propability maps could be produced, leading to a new total of 35 habitat probability maps.

5 Habitat probability maps

The habitat probability maps are created by downscaling the habitat suitability maps with a 1km resolution by the actual land cover. This report concerns European wetland and coastal habitat types. For this purpose we used the most actual land cover information. The Copernicus land cover databases that we exploited for this purpose were the HRL product Water and Wetness from 2015 (WAW2015) and Corine Land Cover database from 2018 (CLC2018), with spatial resolutions of respectively 20 and 100 meter. Since only the distribution data for 6 habitats showed a clear relationship with WAW2015, we depended much more on CLC2018 that we expected in the first instance, see also Table 4.2 for the decision rules that were applied. Therefore all 35 habitat probability maps have been produced at a 100 meter resolution. Figure 5.1 shows once more the principle of the methodology that we follow. In principle the habitat suitability maps were refined on basis of the actual Copernicus land cover, the WAW2015 for some classes, and the distance to the coast for the coastal habitats (<= 5km).

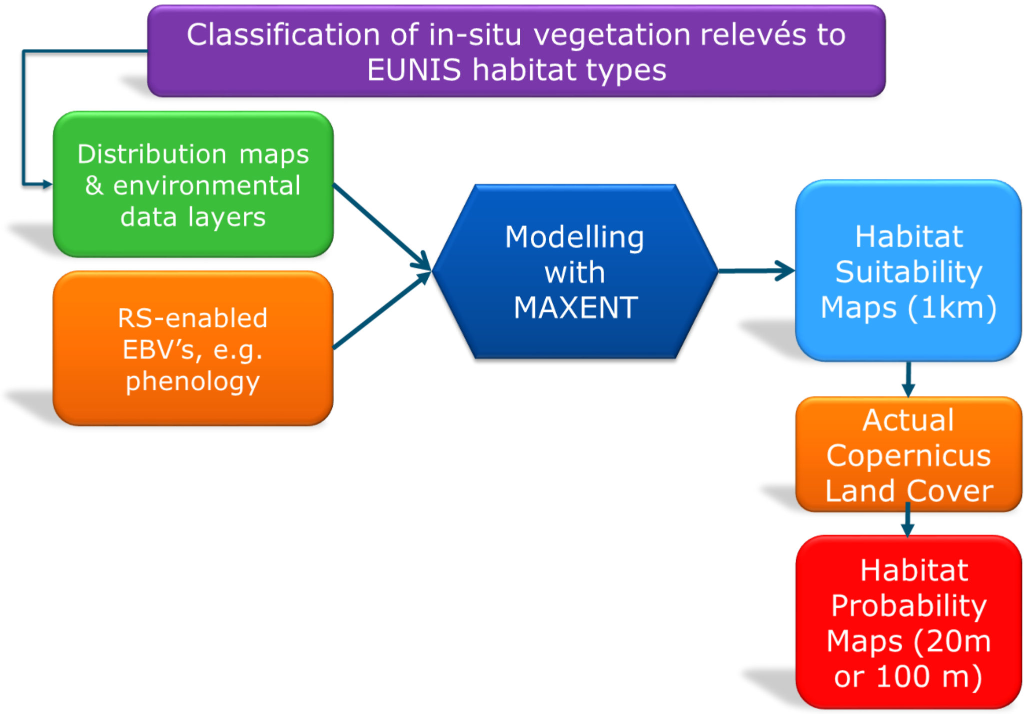


Figure 5.1 Flowchart of the methodology implemented to obtain habitat probability maps

In principle, we used four models in ARCGIS PRO for each EUNIS habitat, namely:

1. Thresholding the habitat suitability maps with the 10 percentile thresholds
2. Crosswalk analysis (Sample tool) between the distribution maps and the actual land cover information (CLC2018 & WAW2015) to support the decision rules.
3. Process the probability maps at 100 meter spatial resolution by integrating the actual land cover with the habitat suitability maps on basis of decision rules
4. Export the probability maps to geotiffs.

All methodological steps have to be repeated for each of the 35 wetland and coastal habitats.

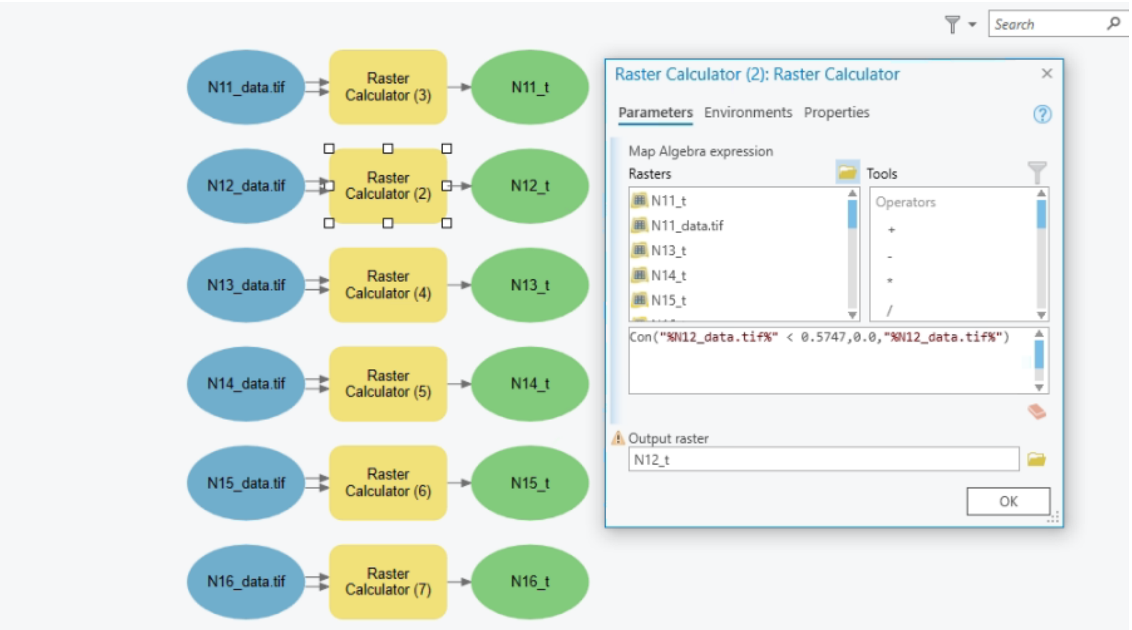


Figure 5.2 **Model 1. ARCGIS PRO graphical model for thresholding each habitat suitability map**

The 10p-thresholds for each of the 37 habitat suitability types can be found in Table 3.1. Since all habitat suitability maps have a 1 kilometer spatial resolution the thresholding goes very fast.

The crosswalk analysis (Sample tool, see also Figure 4.4) between the distribution maps and the actual land cover information (CLC2018 & WAW2015) to support the decision rules, went also quite fast but to sort out the final decision rules from the results in Appendix 1 was a quite difficult task since the relationships are not always straightforward and the existing crosswalk between the EUNIS habitats and CLC made by Moss (2012) was not sufficient.

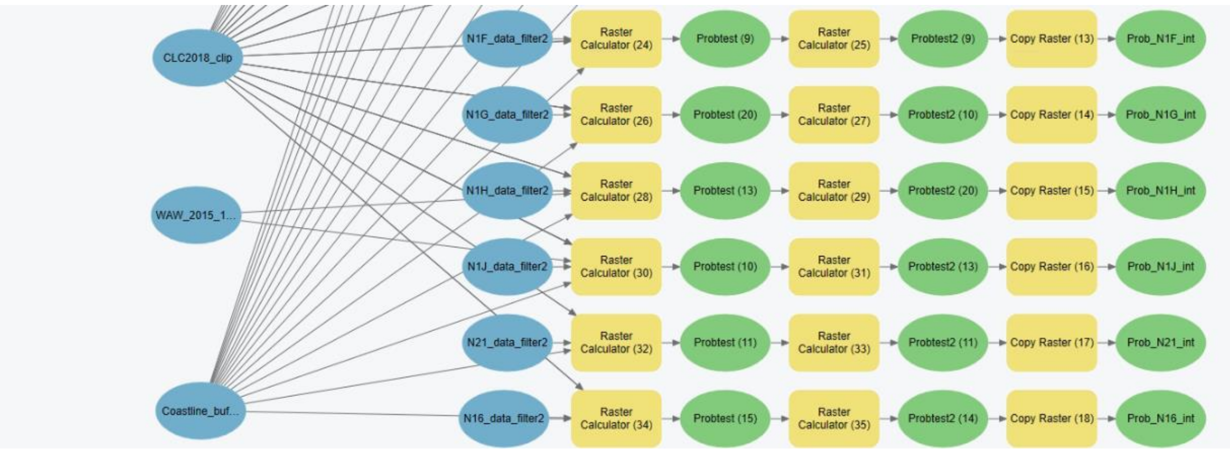


Figure 5.3 **Model 3. ARCGIS PRO graphical model to process the habitat probabiliy maps**

During the processing of habitat probability maps it became clear that for the coastal habitats the habitat suitability maps did not cover the exact coastline, leading to empty probability maps. Main reason is that most coastal habitats only occur in a small fringe along the coastline, for example affiliated with the land cover class 331 'beaches, sand and dunes'. Therefore a solution had to be found so that the original suitabilty maps could be extended towards to coastline. The solution that we found was by applying a low pass filter. The low pass filter option is an averaging (smoothing) filter (https://pro.arcgis.com/en/pro-app/tool-reference/spatial-analyst/filter.htm). We used the low pass filter twice with the option ‘Ignore NoData in calculations’. And as shown in Figure 5.4. the resulting suitability map is a more smoothed map that covers the coastline. The double low pass filter was applied on the original suitabilty maps, meaning without applying the 10-percentile thresholds. However, the suitability maps with a 10-percentile thershold were still applied for the wetlands habitats, while for the coastal habitats we used the suitabililty maps that had been extended with a low pass filter.

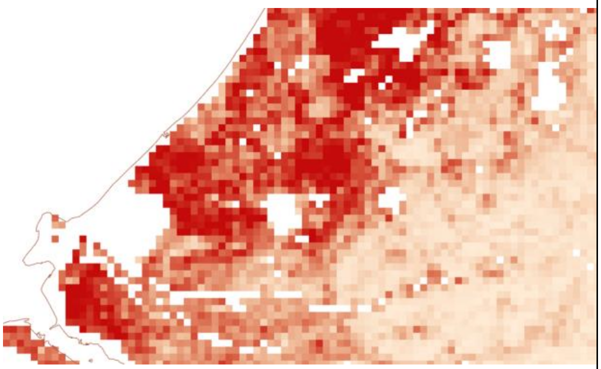
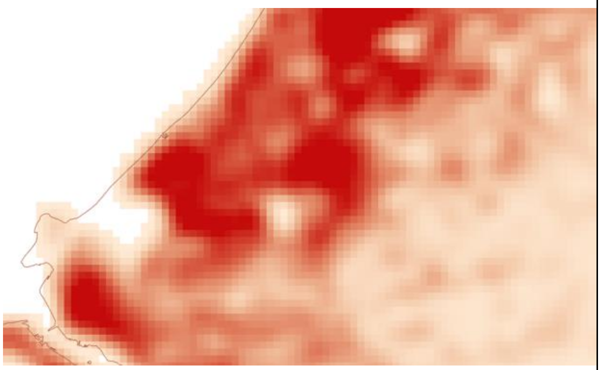
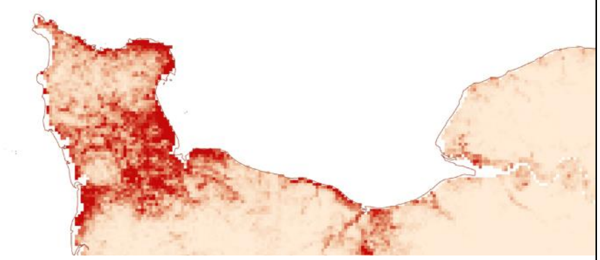
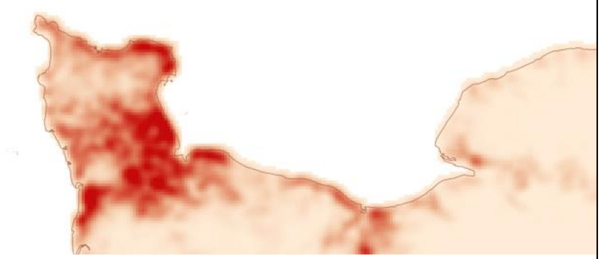
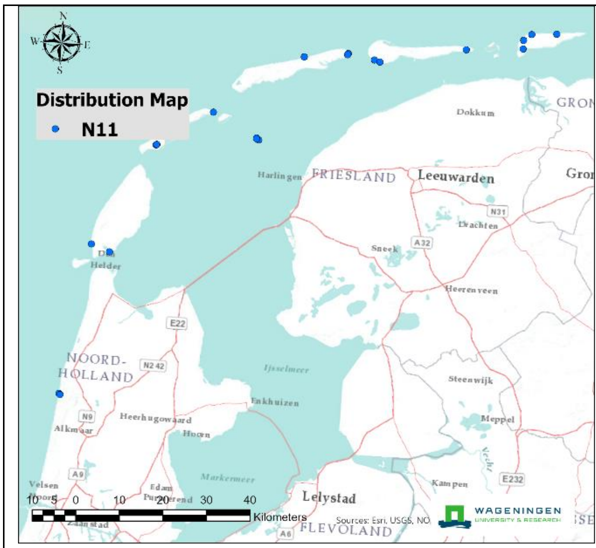
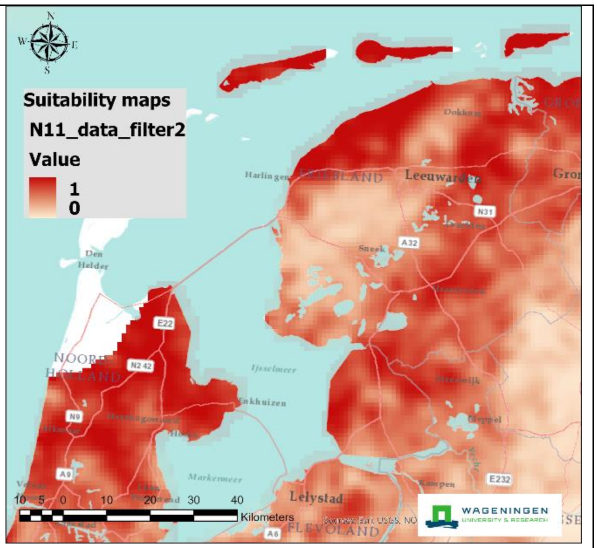
Original suitability map not covering the exact coastline	Adjusted suitability maps using a low pass filter twice.
Exampe from the Dutch Coast 	Exampe from the Dutch Coast 
Exampe from the French Coast 	Exampe from the French Coast 

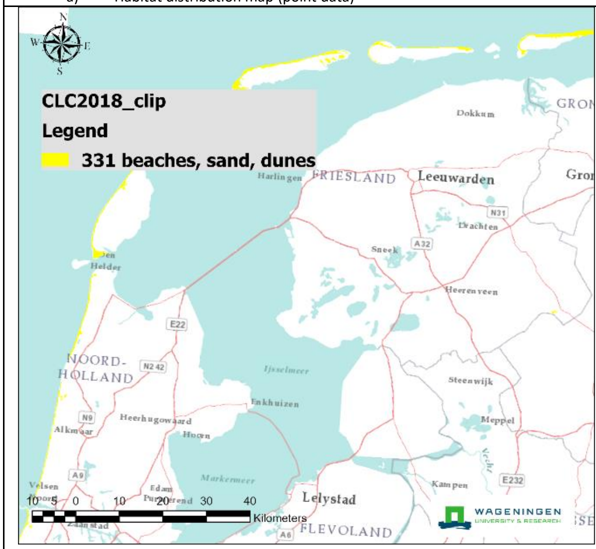
Figure 5.4 Extending the habitat suitability maps towards the coastline by applying a low pass filter



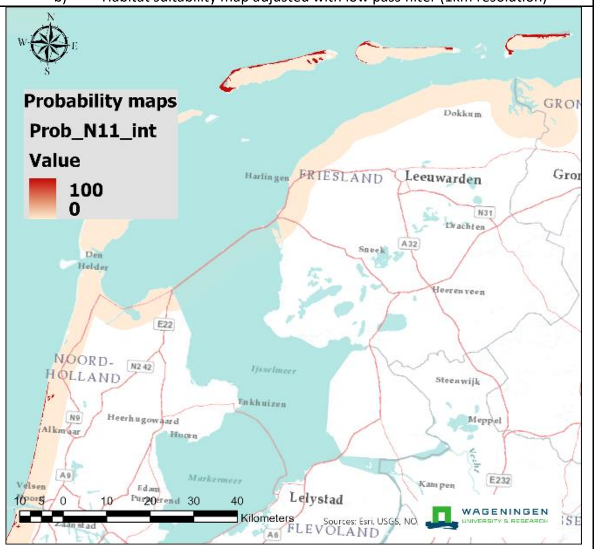
a) Habitat distribution map (point data)



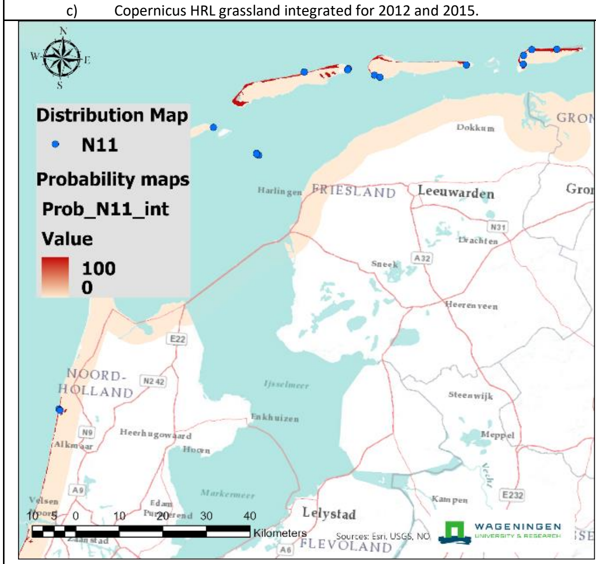
b) Habitat suitability map adjusted with low pass filter (1km resolution)



c) Copernicus HRL grassland integrated for 2012 and 2015.



d) Habitat probability map (100 m resolution)



e) Habitat probability map overlaid with recorded vegetation plots (distrubution map)

Figure 5.5 Figures sumarizing all the methodological steps for a small area on Northern part of the Netherlands for EUNIS habitat type N11 *'Atlantic, Baltic and Arctic sand beach'*

Figure 5.5 makes it clear that going from habitat suitability maps into habitat probability maps through actual land cover information makes a big difference. It is also nice to see in Figure 5.4 that the final habitat probability represents well the actual distribution of the habitat as reflected by the distribution map (in-situ vegetation plot data used ground truth). But despite this fact, many of the wetland and coastal habitat probability maps in the Appendix I show local misfits between the probability maps and the recorded vegetation plots (distribution maps). This can be due to several reasons:

1. The geographic location of the in-situ vegetation plot is sometimes not accurate enough.
2. The Copernicus land cover layer misses sometimes smaller patches related to wetlands and coastal habitats. Notice that the smallest mapping unit of Corine land cover is 25 ha. So the HRL's are preferred, but as mentioned before the relationship between Water and Wetness product (WAW2015) and the wetlands and coastal habitats is quite disappointing, and therefore could not play a major role.
3. Some of the recorded vegetation plot might have disappeared over the last twenty years.

Therefore we recommend always an independent assessment of the habitat probability maps based on e.g. Article 17 database.

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Appendix 1 Summarized crosswalk analysis between distribution maps and Coperncus land cover data (CLC2018) and HRL Water and Wetness (WAW2015) using Sample tool in ArcGIS to support decision rules

New code	Habitat name	CLC (EUNIS Crosswalk). Moss (2012)	Sampling (Spatial Analyst) CLC2018	Sampling (Spatial Analyst) HRL Wet 2015
N	Coastal habitats			
N11	Atlantic, Baltic and Arctic sand beach	331	523 (22,2%), 411 (11,0%), 331 (10,3%), 521 (7,1%)	0 (79,5%), 4 (15,7%)
N12	Mediterranean and Black Sea sand beach	331	523 (21,9%), 331 (14,7%), 323 (12,3%),112 (13,1%), 312 (8,4%)	0 (95,6%)
N13	Atlantic and Baltic shifting coastal dune	331	331 (23,7%), 523 (17,6%), 321 (10,6%), 423 (8,6%)	0 (84,3%), 4 (11,8%)
N14	Mediterranean, Macaronesian and Black Sea shifting coastal dune	331	331 (24,1%), 523 (18,8%), 112 (10,7%), 312 (9,3%)	0 (94,5%)
N15	Atlantic and Baltic coastal dune grassland (grey dune)	331	321 (27,2%), 523 (13,9%), 331 (12,5%)	0 (75,7%), 4 (18,8%)
N16	Mediterranean and Macaronesian coastal dune grassland (grey dune)	331	331 (19,3%), 523 (18,6%), 323 (12,5%), 112 (9,8%)	0 (91%)
N17	Black Sea coastal dune grassland (grey dune)	331	331 (38,2 %), 142 (16,7%), 112 (14,6%)	0 (95,5%)
N18	Atlantic and Baltic coastal Empetrum heath	322	321 (44,5%), 523 (18,1%), 312 (9,9%), 322 (8,2%)	0 (87,8%), 4 (8,8%)
N19	Atlantic coastal Calluna and Ulex heath	322	322 (24,5%), 321 (15,4%), 523 (15,4%), 112 (8,4%)	0 (94,1%)
N1A	Atlantic and Baltic coastal dune scrub	322	321 (65,9%), 322 (7,6%), 331 (6,3%)	0 (79,1%), 4 (20,1%)
N1B	Mediterranean and Black Sea coastal dune scrub	322	323 (16,6%), 312 (15,6%), 331 (12,2%), 211 (7,7%), 523 (6,8%)	0 (93%)
N1D	Atlantic and Baltic broad-leaved coastal dune forest	311	321 (27,6%), 312(17,7%), 112 (16,8%), 311 (11,9%)	0 (96%)

N1F	Baltic coniferous coastal dune forest	312	112 (41,4%), 312 (34,1%), 331 (9,6%)	4 (100%)
N1G	Mediterranean coniferous coastal dune forest	312	312 (51,1%), 313 (13,8%), 323 (6,9%)	0 (95,6%)
N1H	Atlantic and Baltic moist and wet dune slack	331	321 (29,7%), 322 (20,5%), 331 (13,9%)	0 (78,8%), 4 (17,3%)
N1J	Mediterranean and Black Sea moist and wet dune slack	331	421 (26%), 521 (11,8%), 523 (8,6%), 322 (7,7%), 331 (7,4%)	0 (45,8%), 1 (28,5%), 4 (19,7%)
N21	Atlantic, Baltic and Arctic coastal shingle beach	331	523 (23,3%), 423 (13,2%), 231 (11,2%), 331 (7,9%)	0 (82,1%), 4 (13,0%)
N31	Atlantic and Baltic rocky sea cliff and shore	332	523 (25,3%), 423 (18,2%), 322 (15,4%), 112 (6,9%)....332 (1.7%)	0 (87,9%), 4 (10,8%)
N32	Mediterranean and Black Sea rocky sea cliff and shore	332	323 (30,3%), 523 (27,2%), 112 (7,3%)	0 (91,5%), 4 (5,9%)
Q	Wetlands			
Q11	Raised bog	412	312 (29,0%), 412 (19,4%), 324 (11,2%)	0 (87,1%), 4 (10.1%)
Q12	Blanket bog	412	412 (57,4%), 333 (11,7%), 243 (11,1%), 322 (7,9%)	0 (85,2%), 4 (13,8%)
Q21	Oceanic valley mire	411	412 (39,6%), 322 (12,2%), 312 (9,2%), 311 (6,9%)	0 (83,9%), 4 (12,3%)
Q22	Poor fen	411	312 (24,3%), 231 (10,1%), 313 (7,8%), 412 (7,2%)	0 (89,7%), 4 (5,3%)
Q23	Relict mire of Mediterranean mountains	411	321 (39,4%), 322 (17,6%), 333 (14,5%), 324 (9,7%)	0 (97,6%)
Q24	Intermediate fen and soft-water spring mire	411	312 (16,3%), 321 (10,7%), 231 (9,8%), 322 (9,8%), 412 (7,3%)	0 (85,9%), 4 (9,6%)
Q25	Non-calcareous quaking mire	411	312 (26,3%), 412 (17,2%), 313 (8,7%), 322 (7,1%), 324 (6,2%)	0 (81,7%), 4 (11,8%)
Q3132	Palsa and polygon mires	412	412 (38,5%), 312 (23,1%), 322 (15,4%)	0 (46,2%), 4 (46,2%)
Q41	Alkaline, calcareous, carbonate-rich small-sedge spring fen	411	321 (15,4%), 312 (13,4%), 231 (12,6%)	0 (93,6%), 4 (3,8%)

Q42	Extremely rich moss-sedge fen	411	312 (21,2%), 231 (15,3%), 412 (8,1%), 313 (7,2%), 322 (6,2%), 411 (6,2%)	0 (83,7%), 4 (12,9%)
Q43	Tall-sedge base-rich fen	411	231 (21,4%), 312 (10,3%), 211(8,4%), 412 (8,6%), 411 (7,7%), 313 (7,5%), 311 (7,5%)	0 (87,6%), 4 (10,3%)
Q44	Calcareous quaking mire	411	312 (17,9%), 412 (17,1%), 411 (11,5%), 231 (9,5%), 311 (7,2%)	0 (73,9%), 4 (19,4%)
Q45	Arctic-alpine rich fen	411	321 (25,7%), 322 (23%), 333 (20,1%), 311 (9,6%)	0 (72,0%), 4 (22,5%)
Q46	Carpathian travertine fen with halophytes	411	231 (30,3%), 243 (24,2%), 112 (24,2%)	0 (100%)
Q51	Tall-helophyte bed	411	231 (17,5%), 512 (16,3%), 211 (11,7%), 311 (10,6%)	0 (72,5%), 1 (8.2%), 4 (9,8%)
Q52	Small-helophyte bed	411	231 (23,7%), 211 (14,1%), 311 (11,1)	0 (83,0%), 4 (8,6%)
Q53	Tall-sedge bed	411	231 (16,6%), 211 (12,6%), 311 (10,4%), 512 (13,1%), 411 (8,3%)	0 (79,3%), 4 (10,3%), 1 (7,5%)
Q54	Inland saline or brackish helophyte bed	411	211 (20,1%), 421 (12,7%), 231 (10,5%), 512 (9,7%)	0 (67,6%), 4 (22,9%)

Appendix 2 Nomenclature of the Corine Land Cover

	CORINE land cover				
	level 1	level 2		Code	Level 3 CORINE land cover class
1.	Artificial surfaces	1.1	urban fabric	1.1.1	continuous urban fabric
				1.1.2	discontinuous urban fabric
		1.2	industrial, commercial and	1.2.1	industrial and commercial units
			transport units	1.2.2	road and rail networks and associated land
				1.2.3	port areas
				1.2.4	airports
		1.3	mine, dump and	1.3.1	mineral extraction sites
			construction sites	1.3.2	dump sites
				1.3.3	construction sites
		1.4	artificial non-agricultural	1.4.1	green urban areas
			vegetated areas	1.4.2	port and leisure facilities
2.	Agricultural areas	2.1	arable land	2.1.1	non-irrigated arable land
				2.1.2	permanently irrigated land
				2.1.3	rice fields
		2.2	permanent crops	2.2.1	vineyards
				2.2.2	fruit trees and berry plantation
				2.2.3	olive groves
		2.3	pastures	2.3.1	pastures
		2.4	heterogeneous agricultural areas	2.4.1	annual cops associated with permanent crops
			agricultural areas	2.4.2	complex cultivation patterns
				2.4.3	land principally occupied by agriculture with significant natural vegetation
				2.4.4	agro-forestry areas

3.	Forests and semi-natural	3.1	forest	3.1.1	broad-leaved forest
	Areas			3.1.2	coniferous forest
				3.1.3	mixed forest
		3.2	shrub and/or herbaceous	3.2.1	natural grasslands
			vegetation associations	3.2.2	moors and heath lands
				3.2.3	sclerophyllous vegetation
				3.2.4	transitional woodland-scrub
		3.3	open spaces with little or no	3.3.1	beaches, sand, dunes
			vegetation	3.3.2	bare rocks
				3.3.3	sparsely vegetated areas
				3.3.4	burnt areas
				3.3.5	glaciers and perpetual snow
4.	Wetlands	4.1	inland wetlands	4.1.1	inland marshes
				4.1.2	peat bogs
		4.2	coastal wetlands	4.2.1	salt marshes
				4.2.2	salines
				4.2.3	intertidal flats
5.	Water bodies	5.1	inland waters	5.1.1	water courses
				5.1.2	water bodies
		5.2	marine waters	5.2.1	coastal lagoons
				5.2.2	estuaries
				5.2.3	sea and ocean

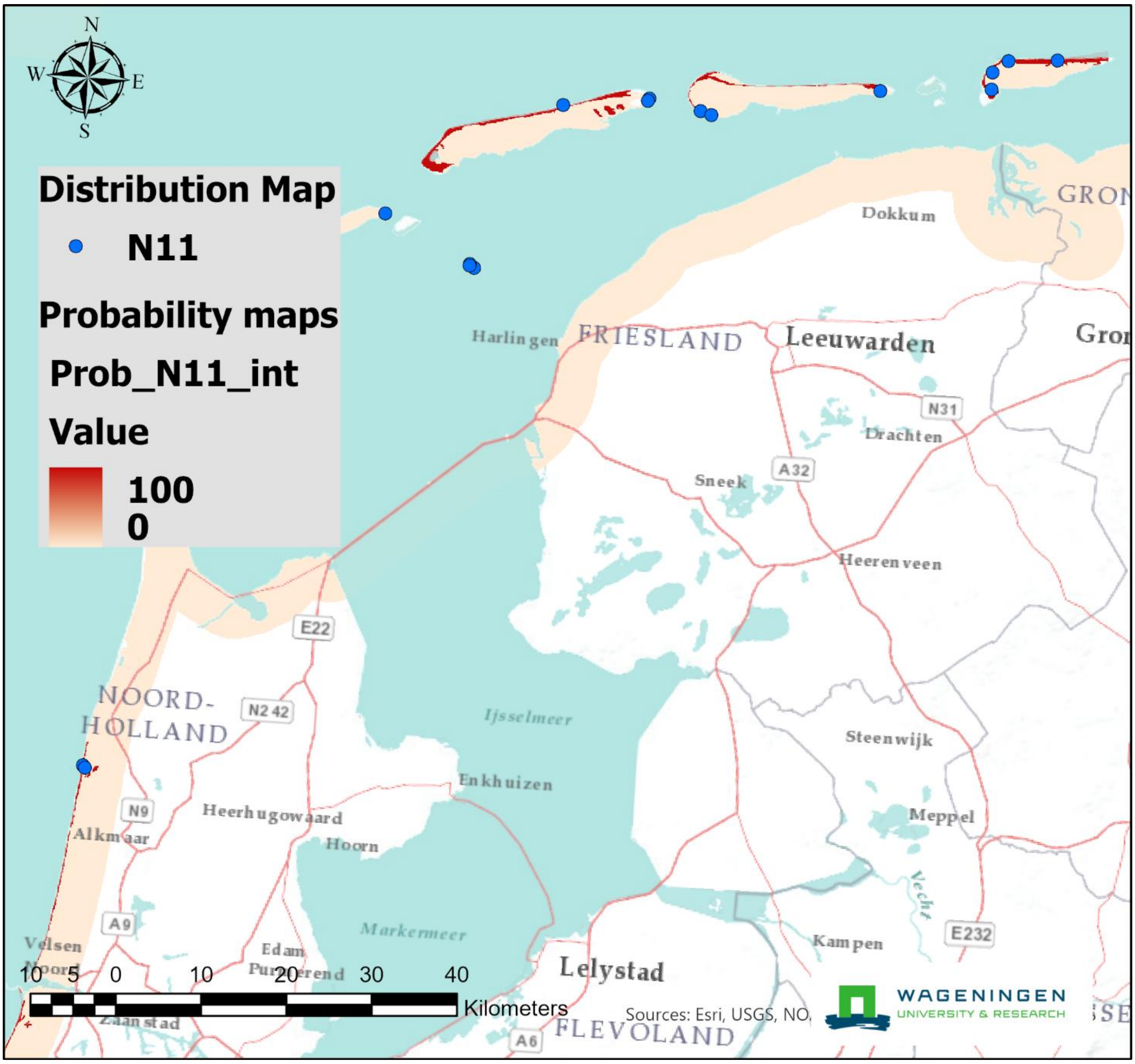
Corine land cover nomenclature is described in the Corine technical guide (Bossard et al., 2000)

Appendix 3 Nomenclature of the HRL product Water and Wetness (from Langanke, 2018)

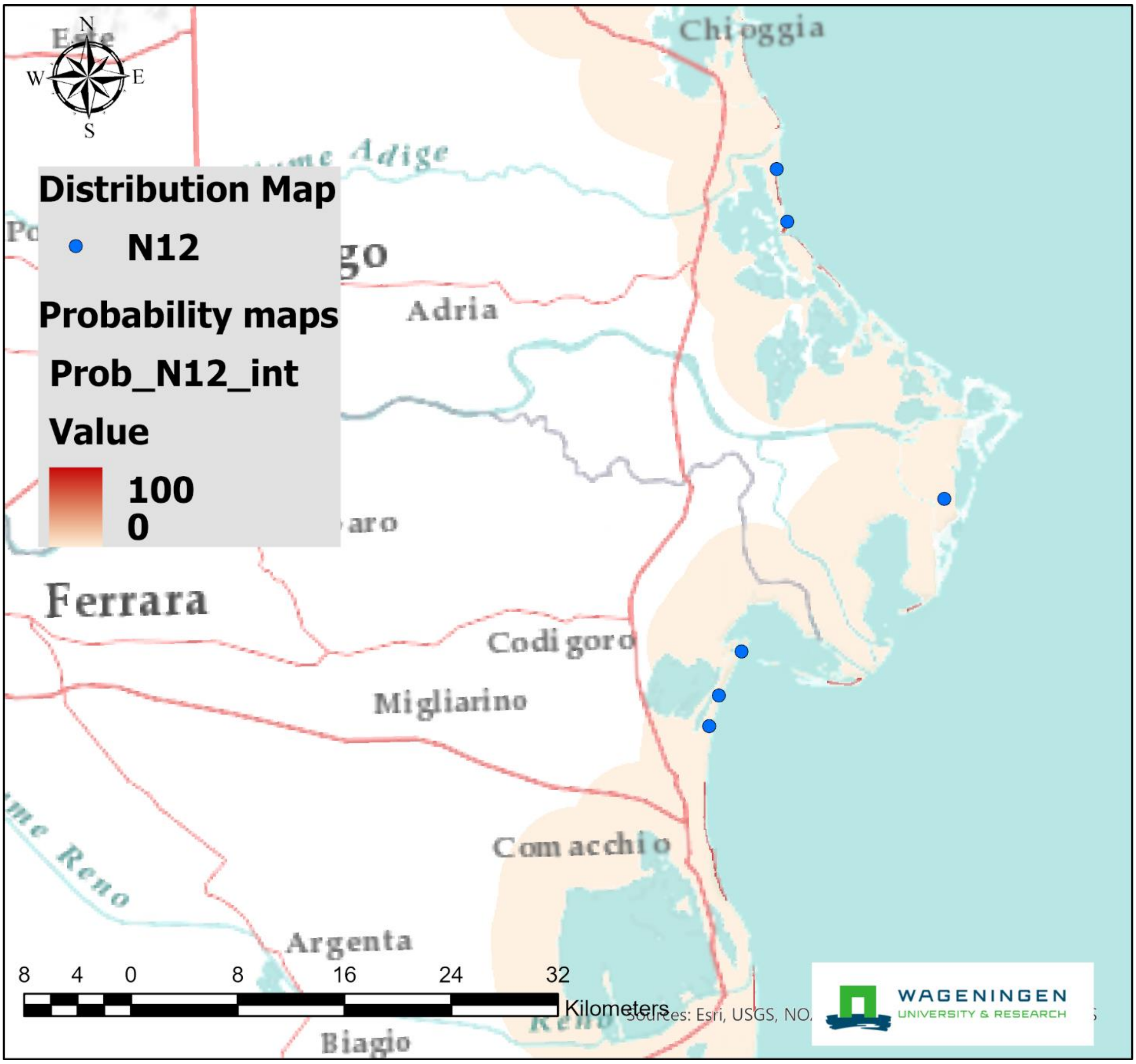
Code	Wetness/Water layer	Explanation	Examples
1	Permanent water	always water (water in at least 80% of all observations)	• Permanent inland lakes (natural) • Artificial ponds (permanent fish ponds, reservoir) • Natural ponds (permanent open water surfaces of inland or coastal wetlands • Rivers • Channels (permanently with water) • Coastal water surfaces: lagoons, estuaries within the boundaries of the EEA coastline for analysis V2. • Liquid dump sites (permanent) • Water surfaces with floating vegetation where detectable with remote sensing techniques.
2	Temporary water	alteration of dry and water or alteration of wet and water (water in >25% to 80% of all observations, with varying degrees of wet and dry; water dominates over wet)	• Temporary water surfaces associated to permanent water bodies (e.g. oscillating shoreline areas of reservoirs) • Temporary natural (e.g. steppe) lakes and temporary artificial lakes (e.g. cassettes of fishponds) • Intermittent rivers and temporarily flooded river banks • Flood areas • Water-logged areas • Temporary flooded agricultural fields e.g. rice fields • Intertidal areas • Temporarily inundated areas (due to snow melt, floods or rain)
3	Permanently wet areas (wetness)	always wet (wet in at least ~60% of all observations, region dependent)	• Reeds • Peat land • Inland and coastal wetlands (incl. salt marshes)
4	Temporary wet area (wetness	alteration of dry and wet (wet in >25% to 60% of all observations, with varying degrees of wet and dry; wet dominates over dry)	• Inland saline marshes • Intermittent wetlands • Temporary wet agricultural fields • Temporary wet meadows

Appendix 4 Details* of produced probability maps for coastal habitats overlaid with related in-situ vegetation plots

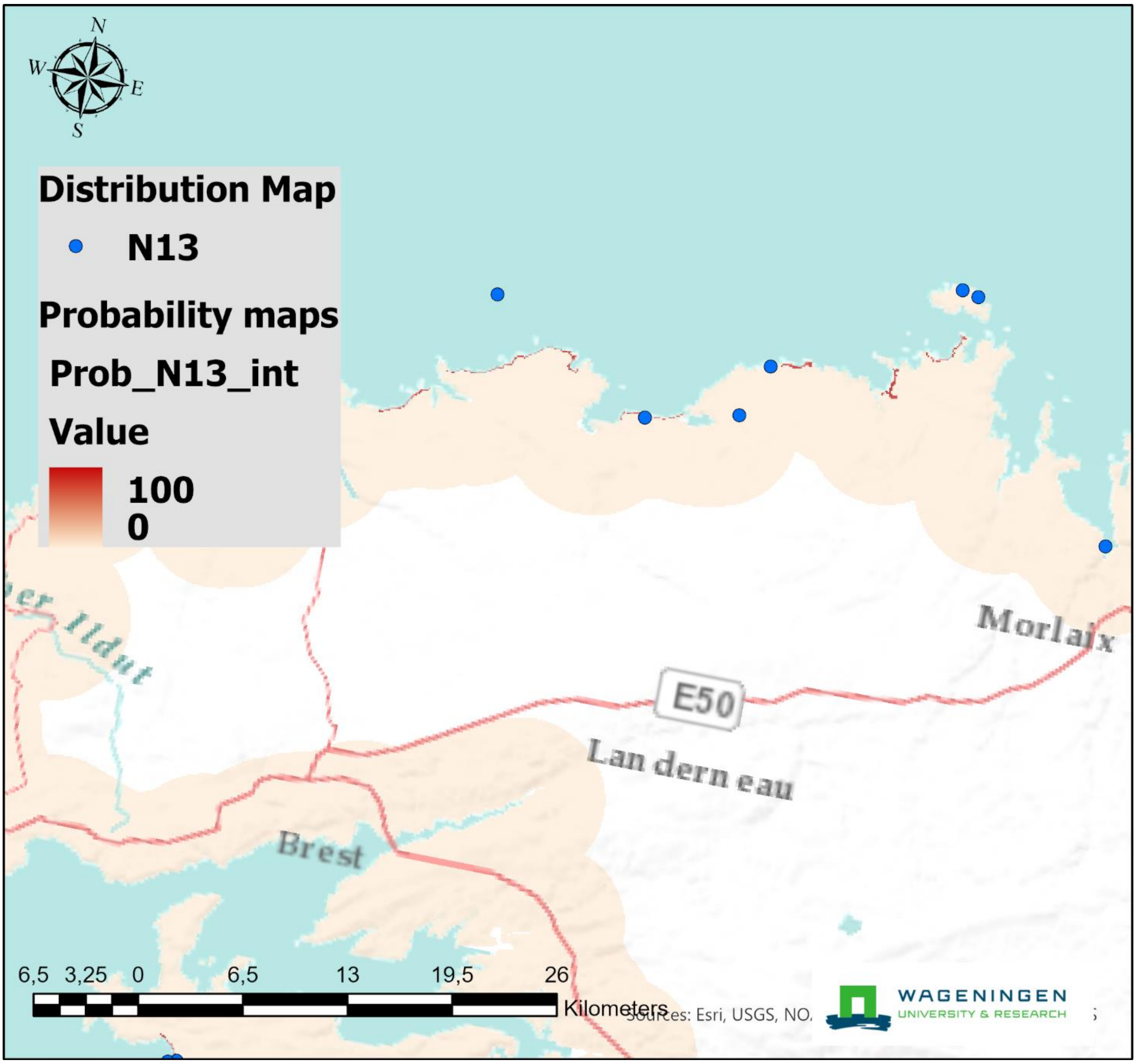
* Coastal habitats are too fragmented to show a European map. If you display Europe as a whole you cannot see any habitat.



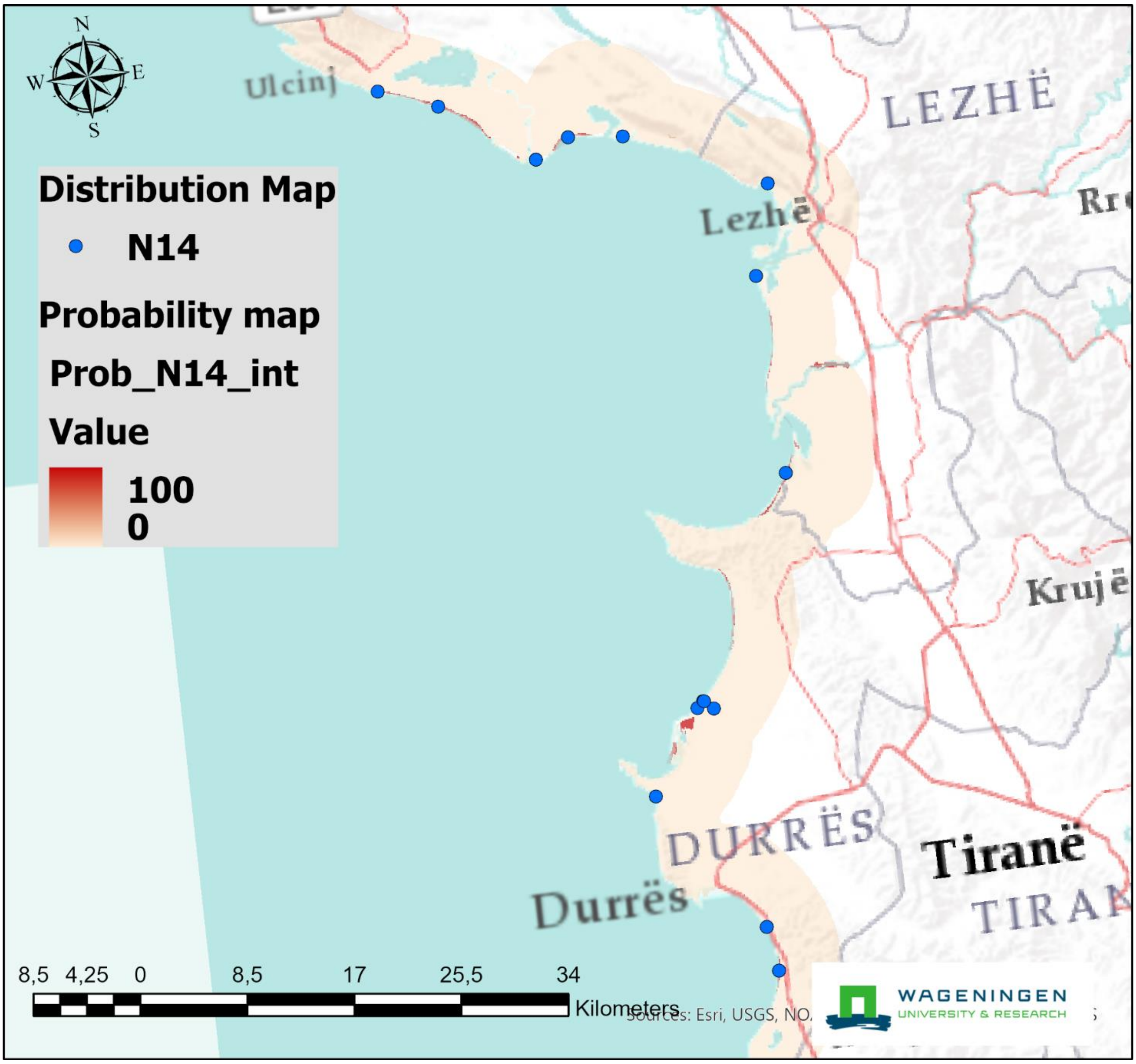
N11 'Atlantic, Baltic and Arctic sand beach'. Atlantic, Baltic and Arctic sandy beach is a linear habitat, occurring on sandy shores of the Atlantic and Arctic Oceans and the North and Baltic Seas. It is mainly an unvegetated habitat with low species diversity. Annual halophytes are the typical plant species, appearing temporarily on strandline sediments. On less dynamic beaches, as around the Baltic, perennials including some brackish and freshwater marsh plants are characteristic. Volcanic sediments can provide a distinctive character around Icelandic shores. Distinctive invertebrates characterise beaches and their driftlines, providing food for some wading birds.



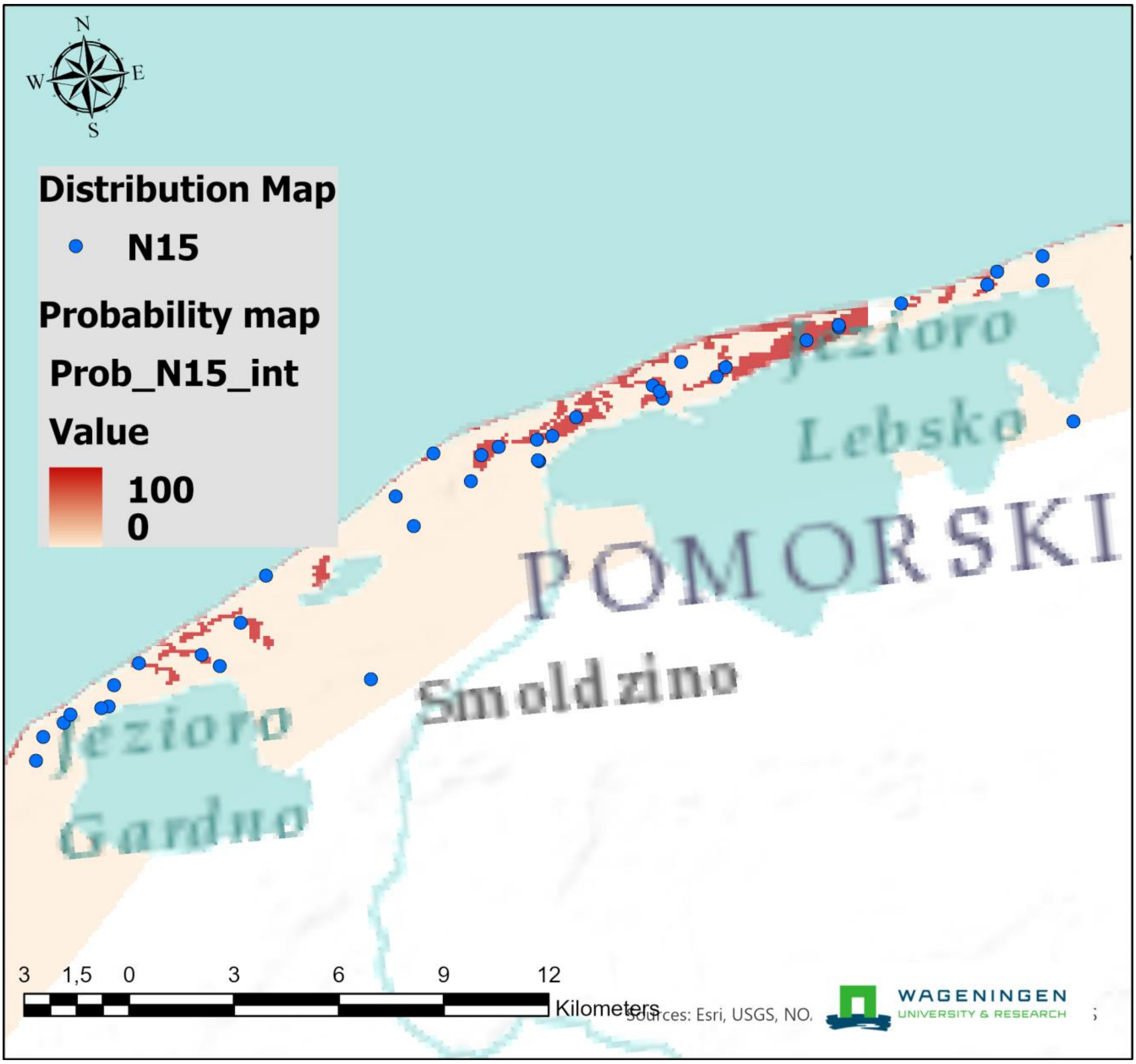
N12 'Mediterranean and Black Sea sand beach'. A largely unvegetated linear feature of sheltered coastlines around the Mediterranean and Black Seas, with fragmentary and sporadic vegetation cover developing on the accumulated sand, gravel and decaying plant material. Typically, the vegetation cover comprises scattered annual halophytes, although pioneer dune perennials can appear where sand ridges get pushed by storms beyond the normal tidal limit.



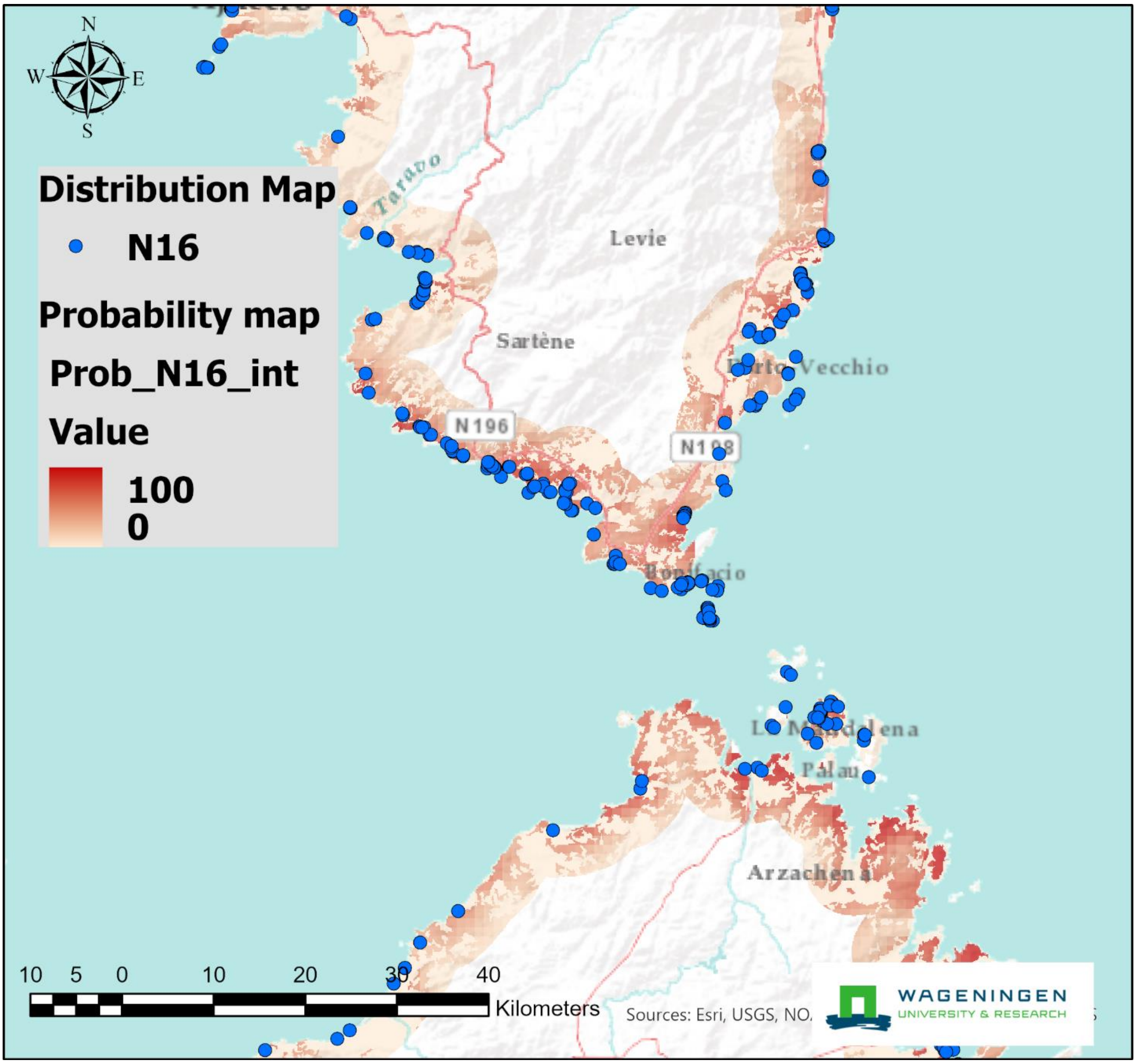
N13 'Atlantic and Baltic shifting coastal dune' Primary, shifting (so-called 'white') dunes of dynamic coastal sands along the Atlantic, North Sea and Baltic coasts. Early pioneers upshore from the strandline catch sand blown from the beach and initiate foredune, then embryo dune, development stages. They may come and go with subsequent storms, or continue to build higher, mobile dunes that move inland, sometimes to enormous size and in distinct ridges with intervening valleys. Ammophila arenaria is the widespread dominant in the middle to later stages. This grass is especially well-equipped to cope with rapid upbuild and continually shifting sands. Leymus arenarius and ×Ammocalamagrostis baltica play a similar role in colder regions. The vegetation cover on the sharply-draining, nutrient-poor sand is typically open with few, but distinctive, associates, some indicative of the regional temperature contrasts, and some striking fungi. Specialised beetles are also characteristic.



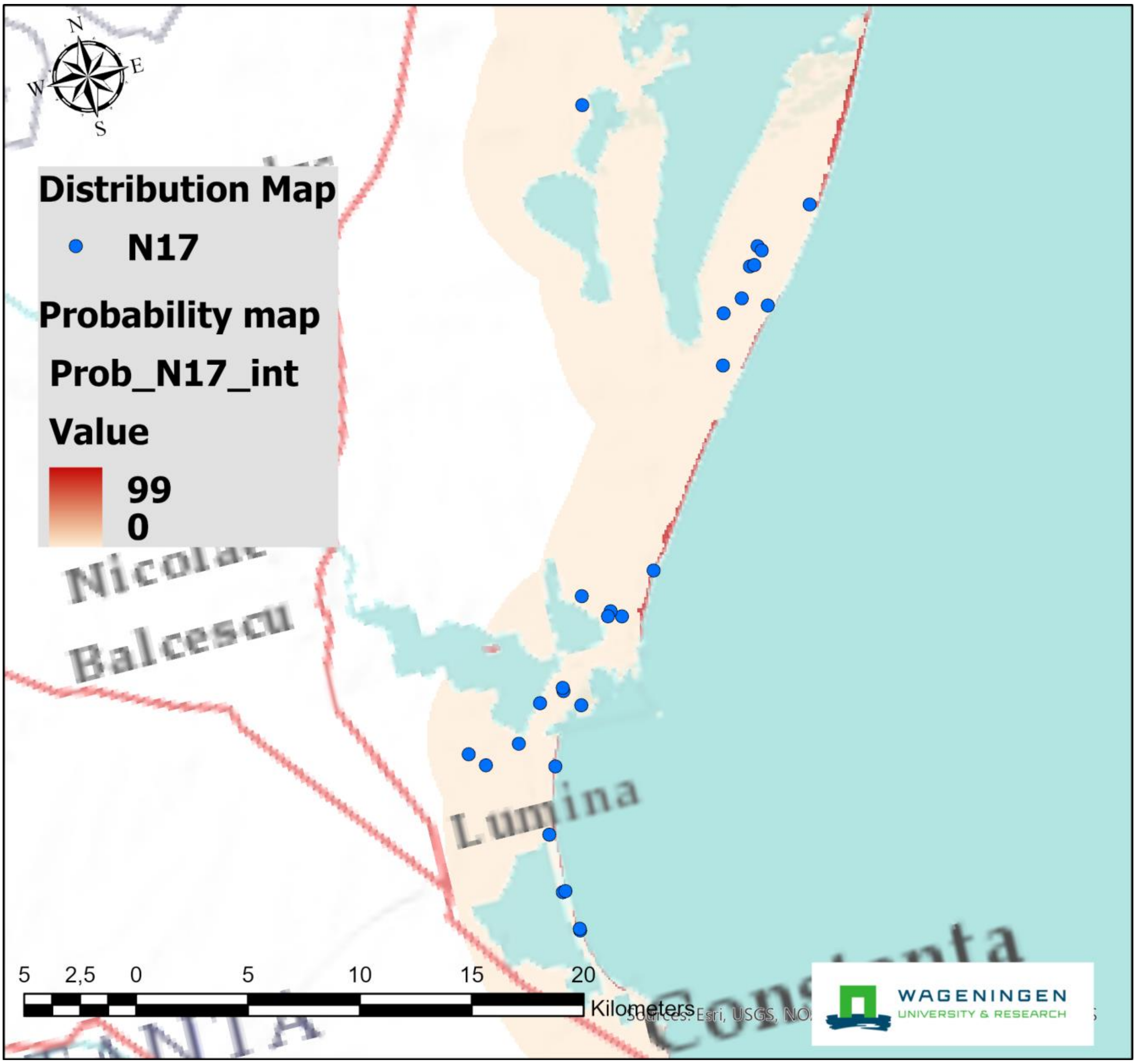
N14 'Mediterranean, Macaronesian and Black Sea shifting coastal dune'. Primary, shifting ('white') dunes of dynamic coastal sands around the Black and Mediterranean Seas, and into the Atlantic around SW Iberia and Macaronesia. Early pioneers upshore from the strandline catch sand blown from the beach and initiate embryo dune development. These may come and go with subsequent storms, or continue to build higher mobile white dunes that move inland. Except in Macaronesia, the dominant plant in the middle to later stages is Ammophila arenaria (subsp. arundinacea in the Mediterranean), and the associated flora on the permeable, impoverished sands is limited and sparse.



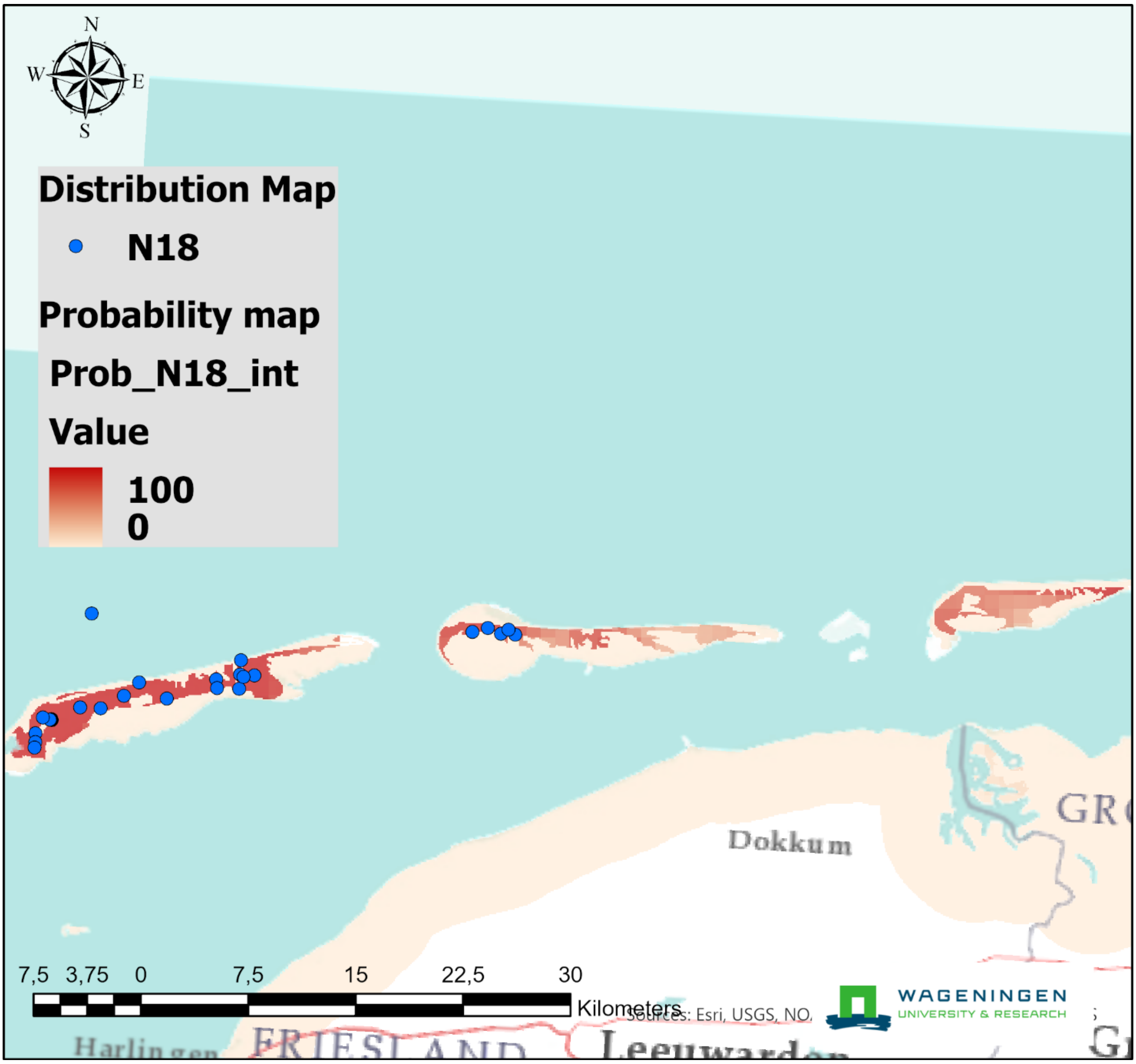
N15 'Atlantic and Baltic coastal dune grassland (grey dune)'. Grasslands that develop on the stabilised sands of older (grey) dunes along the Atlantic (southern to middle Portugal), North Sea and Baltic coasts. The sandy substrate, thinly enriched with accumulating humus, is well-drained and can dry out during summer. Typically with a more or less complete cover of (relatively low) grasses, herbs, bryophytes and lichens, sometimes with low shrubs, they comprise one of the most species-rich habitats on the temperate European coast. The flora can vary with the regional climate, with the character of the substrate, from acid to highly calcareous, and with the local dune topography. Individual dune systems can vary from narrow strips to enormous stretches, though most are not a dynamic stage in succession, but maintained in a more or less stable fixed state. They were often grazed or mown in the past, which prevented the development of scrub and woodland. The habitat is threatened in most countries by abandonment of traditional farming, by eutrophication through nitrogen deposition, overuse and urbanisation, often related to tourism.



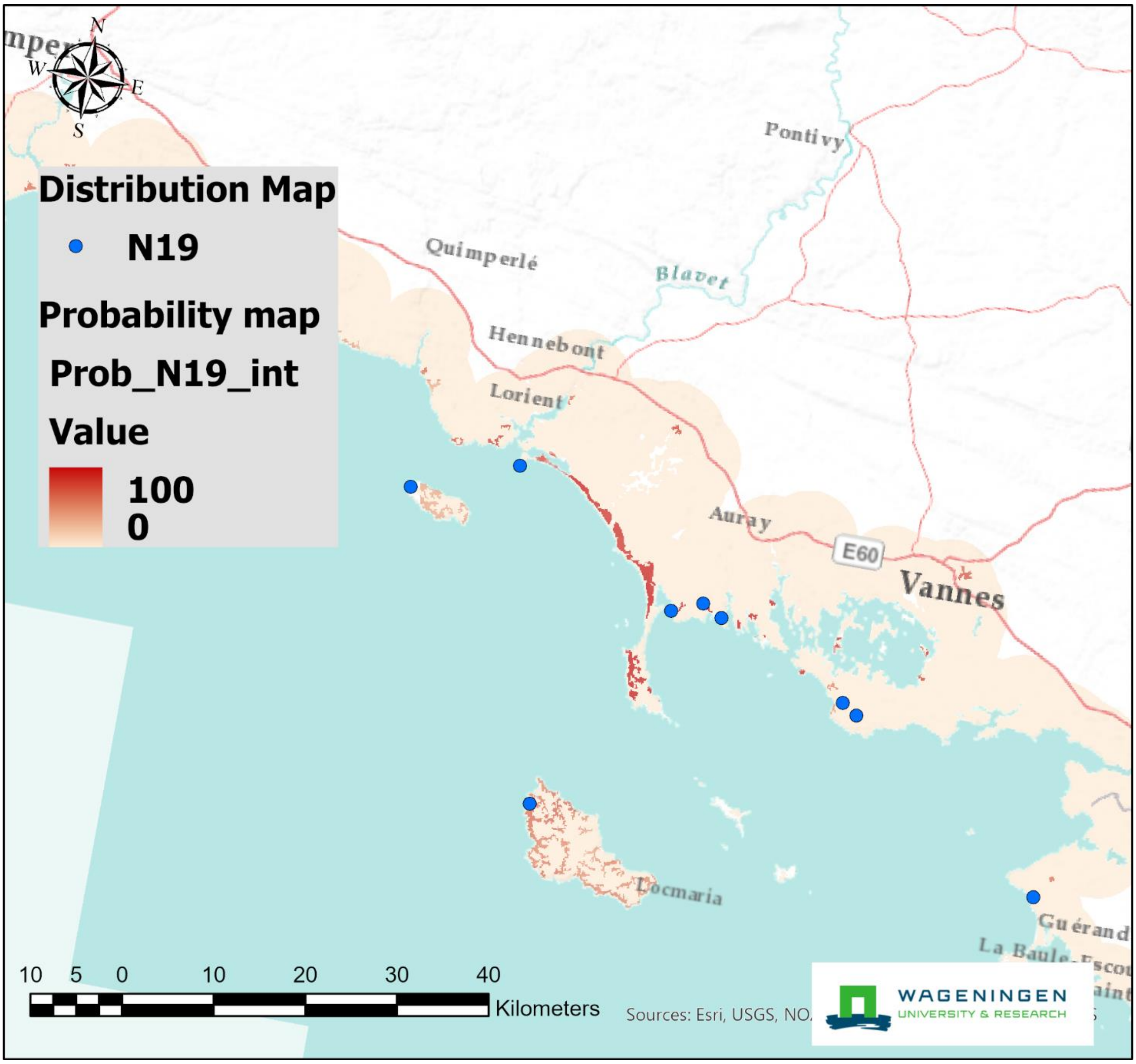
N16 'Mediterranean and Macaronesian coastal dune grassland (grey dune)'. Stable (grey) dunes of fixed sands along the Mediterranean and Macaronesian coasts, and of the thermo-Atlantic coasts of Portugal, southwestern Spain and North Africa inland from wind erosion and salt deposition. They have a more or less complete cover of graminoids and herbs, often with a contingent of colourful spring annuals capitalising on early rains. The flora varies according to regional climate and dune topography. They may represent a temporary phase, giving way to evergreen sclerophyll scrub and woodland, or may form more permanent grassland at sites not suitable for shrubland. Through much of the Mediterranean, the habitat has been destroyed, contaminated by the invasion of non-native species or is much influenced by tourism, urbanization, infrastructure development, arable cultivation, nitrogen deposition and afforestation.



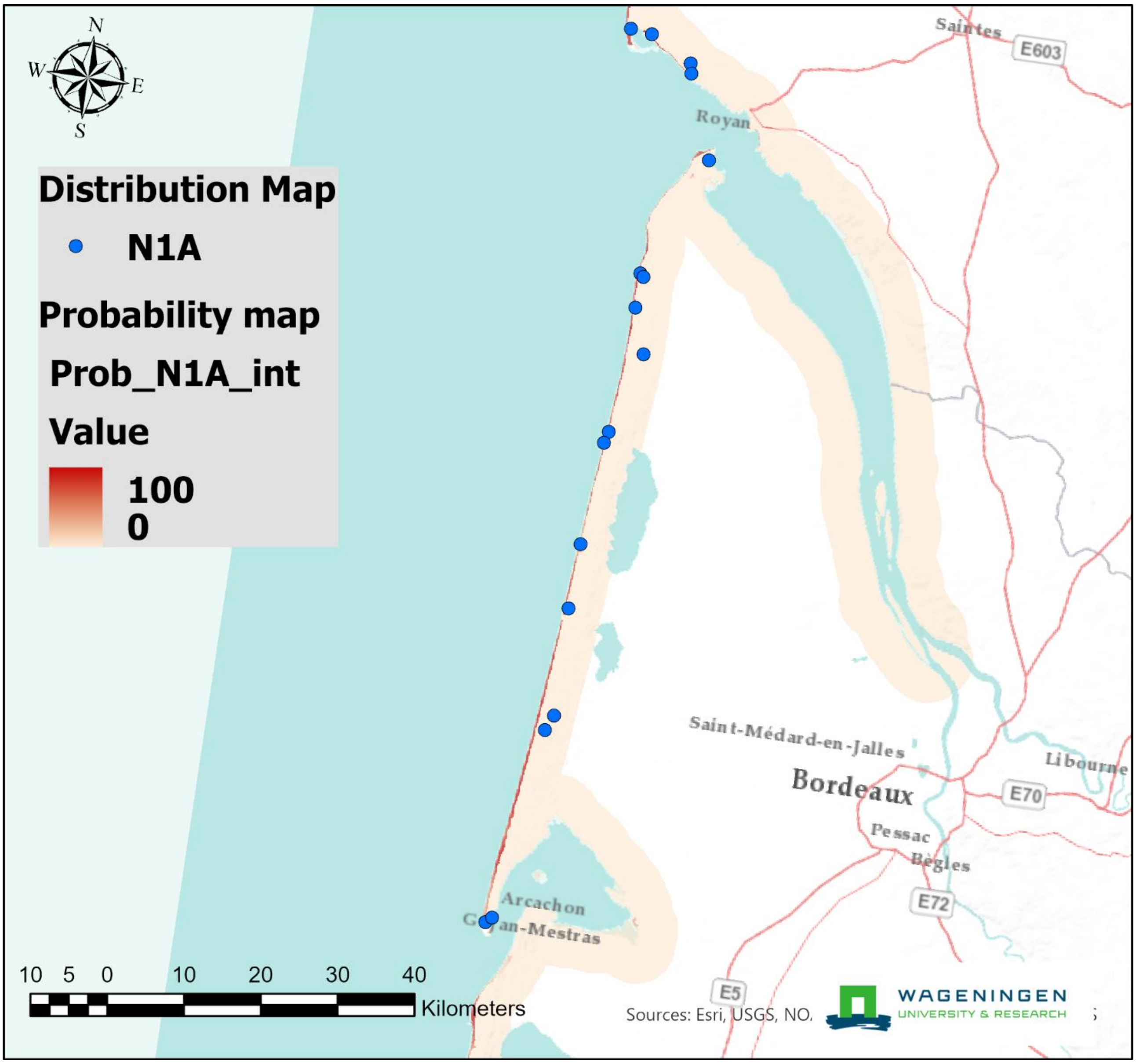
N17 'Black Sea coastal dune grassland (grey dune)' Dune grassland on stabilised or semi-stabilised coastal sands around the Black Sea, mostly on the western and north-western stretches and now only very locally. The dunes are best developed on broader flatter shores, and the ridges can vary in height from just a few metres to over 50 m, with moister depressions between. The flora is variable with a shift from the Mediterranean to Pontic regions moving northwards, with many regional endemic plant species among its grasses and herbs. Perennials predominate, but there can be striking contingents of annuals on more mobile stretches of sand on the ridges. Mosses and lichens can be extensive on north-facing, less sunny slopes.



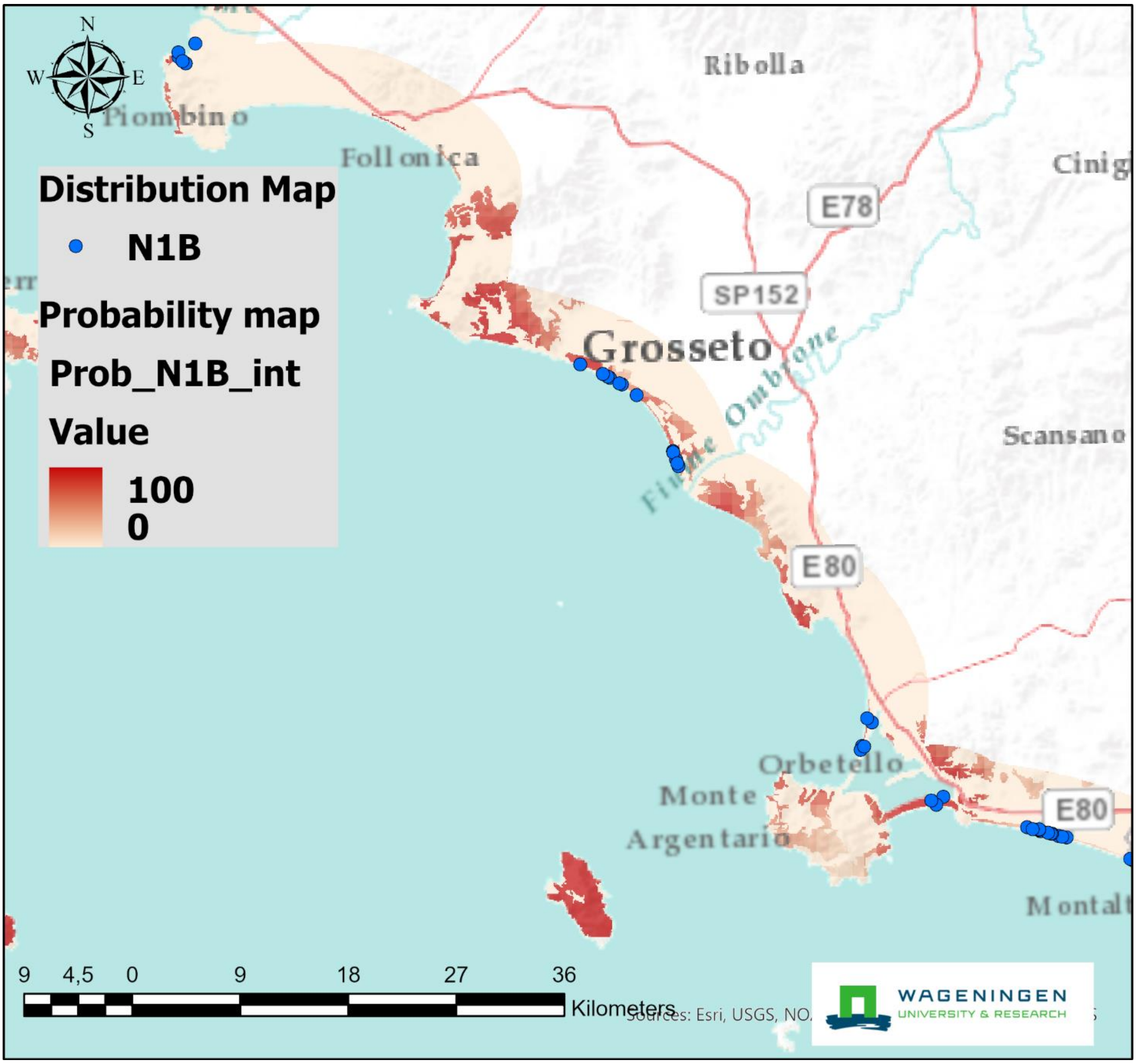
N18 'Atlantic and Baltic coastal Empetrum heath'. Heath on stable, decalcified dune sands along the cooler north Atlantic and Baltic coasts of Europe, dominated by Empetrum nigrum, with or without Calluna vulgaris, or occurring in dune slacks where Erica tetralix may also be abundant or even replace Empetrum with the same suite of associates. Persistent where wind-exposure or light grazing prevent succession to scrub or woodland.



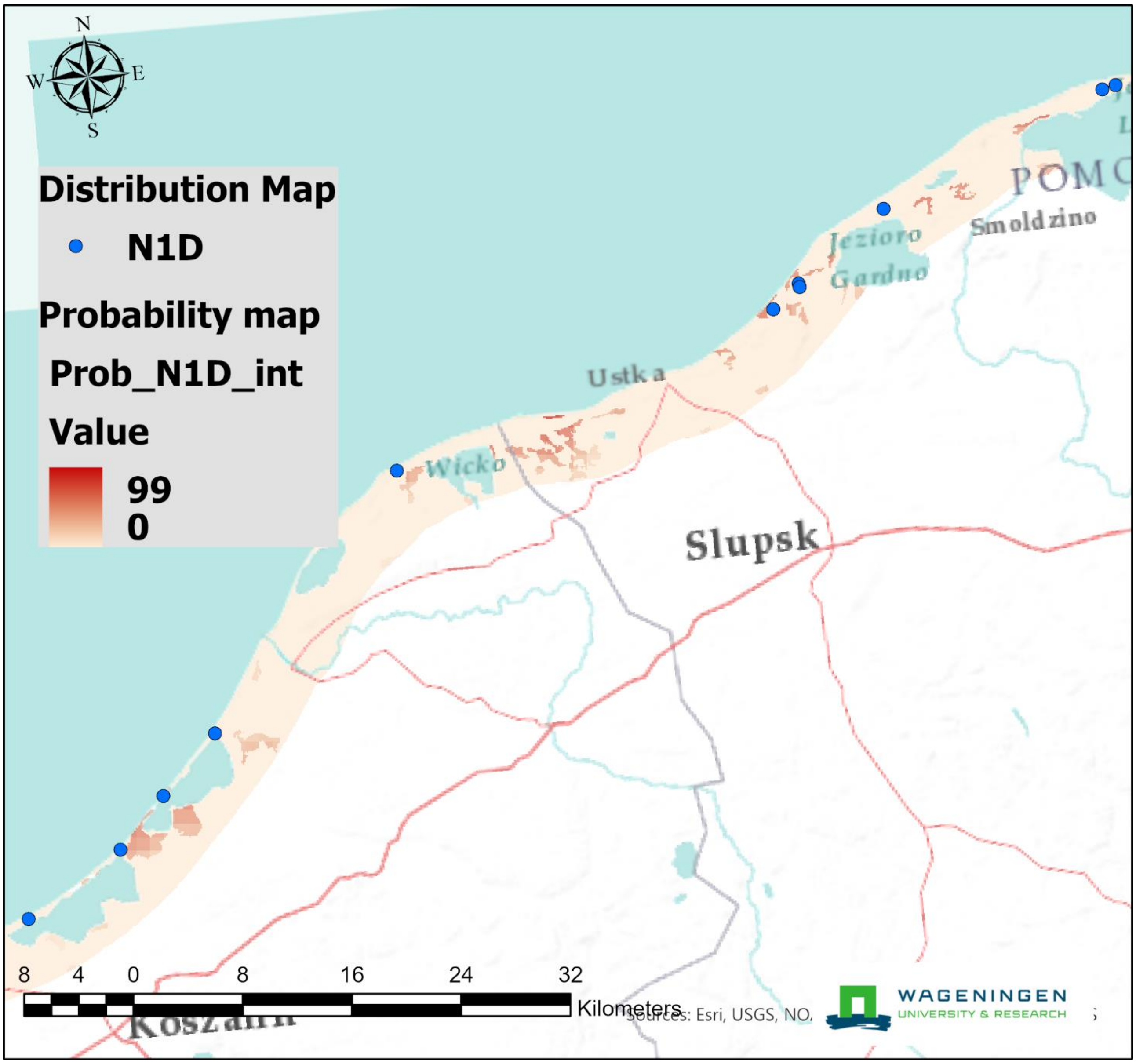
N19 'Atlantic coastal Calluna and Ulex heath'. Heath on stable, decalcified, sharply-draining dune sands along the warmer, more humid Atlantic coast of Europe, dominated by Calluna vulgaris, Erica spp., Ulex spp. or other low spiny legumes, often with a strong contingent of grasses and sedges. Persistent where wind-exposure or light grazing prevent succession to scrub or woodland.



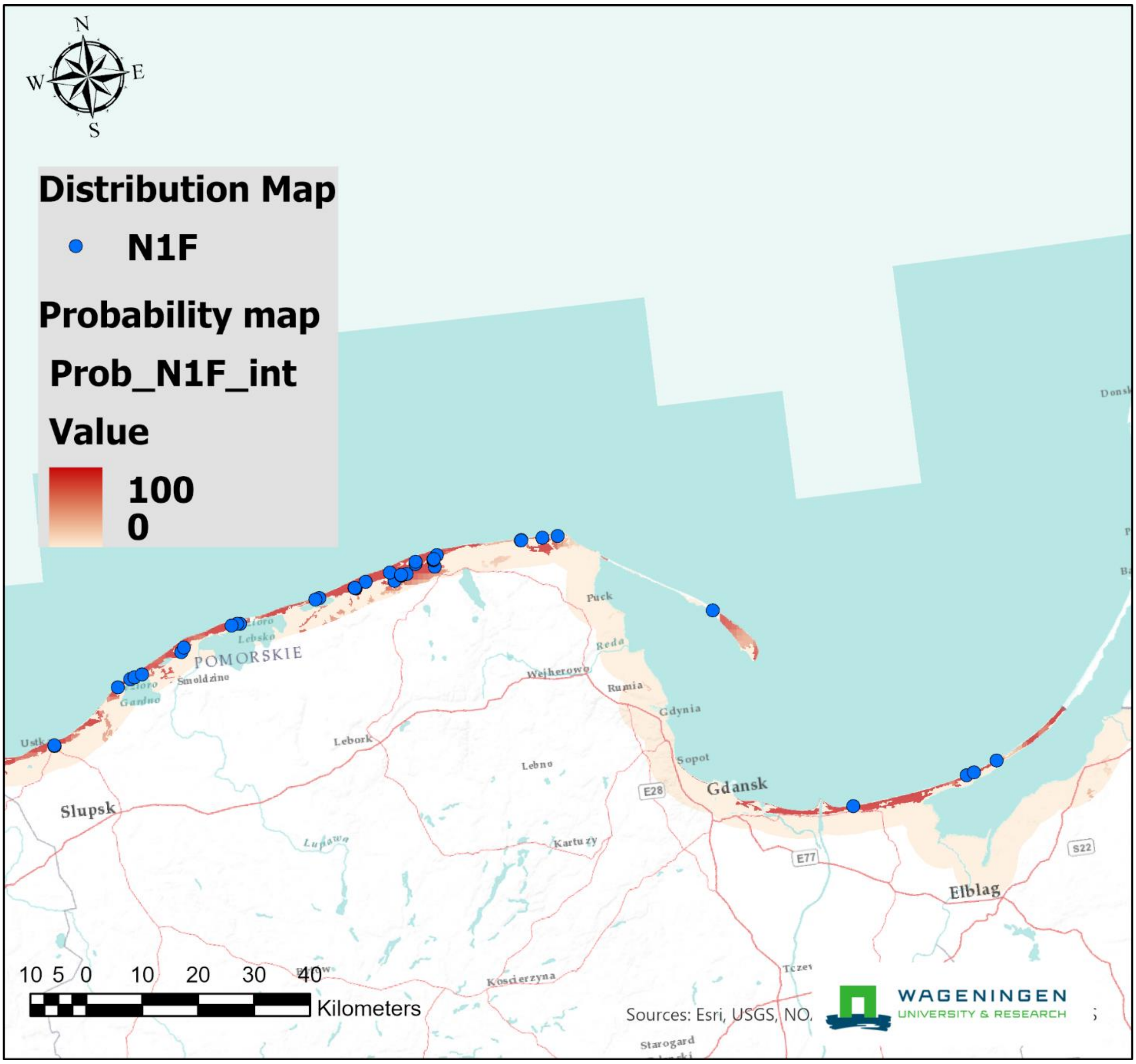
N1A Atlantic and Baltic coastal dune scrub Scrub dominated by a wide diversity of low to tall shrubs on stabilised dry dune sands and in dune slacks along the Atlantic and Baltic coasts. The composition varies according to regional climate and soil conditions. Fen vegetation with low Salix repens or grasslands with Rosa spinosissima are not included.



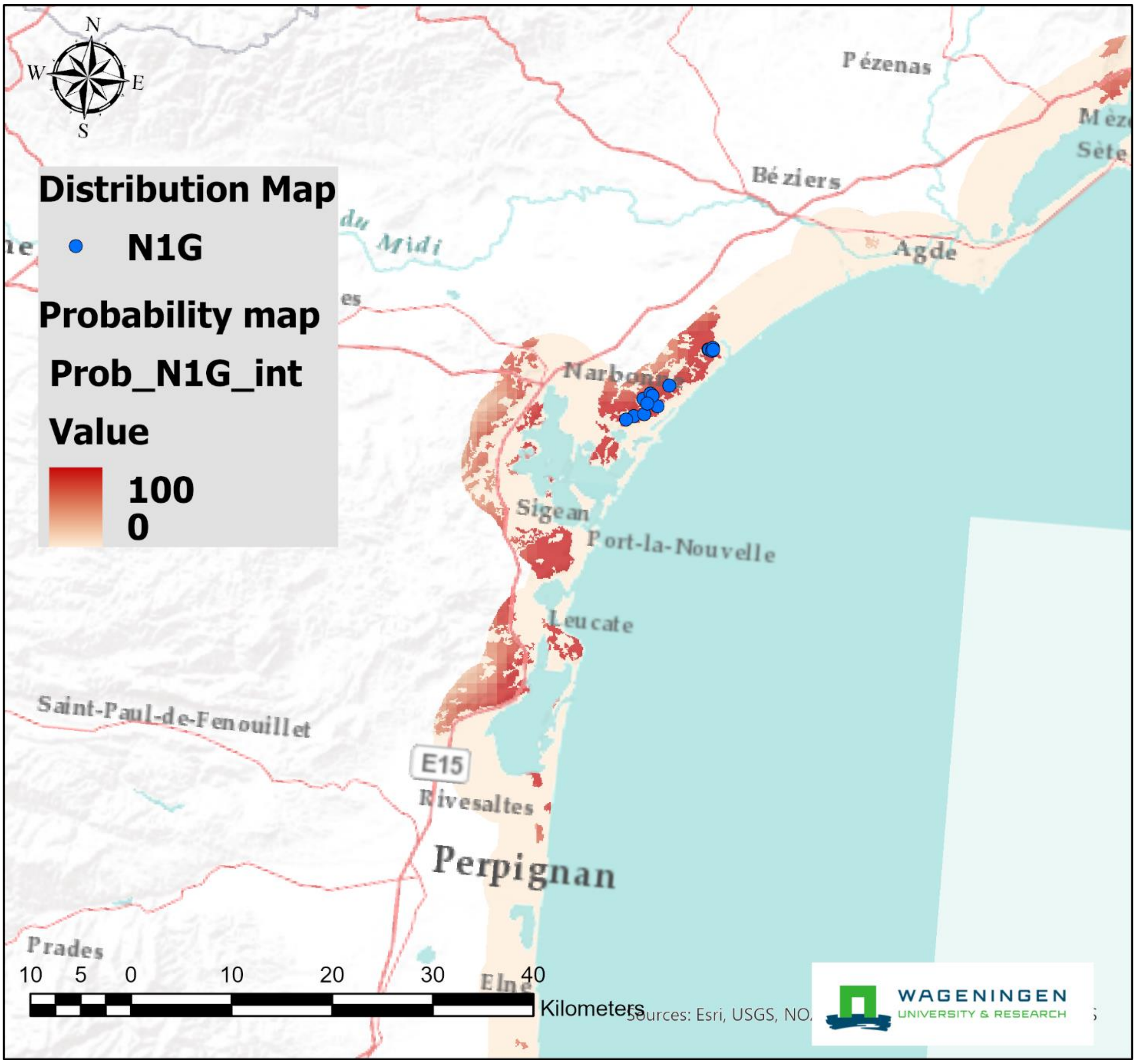
N1B 'Mediterranean and Black Sea coastal dune scrub'. Scrub dominated by a wide diversity of low to tall shrubs on stabilised dry dune sands along the Mediterranean and Black sea coasts, often grading to dune grassland or woodland, the associated herb flora showing elements from these neighbouring vegetation types or mosaics.



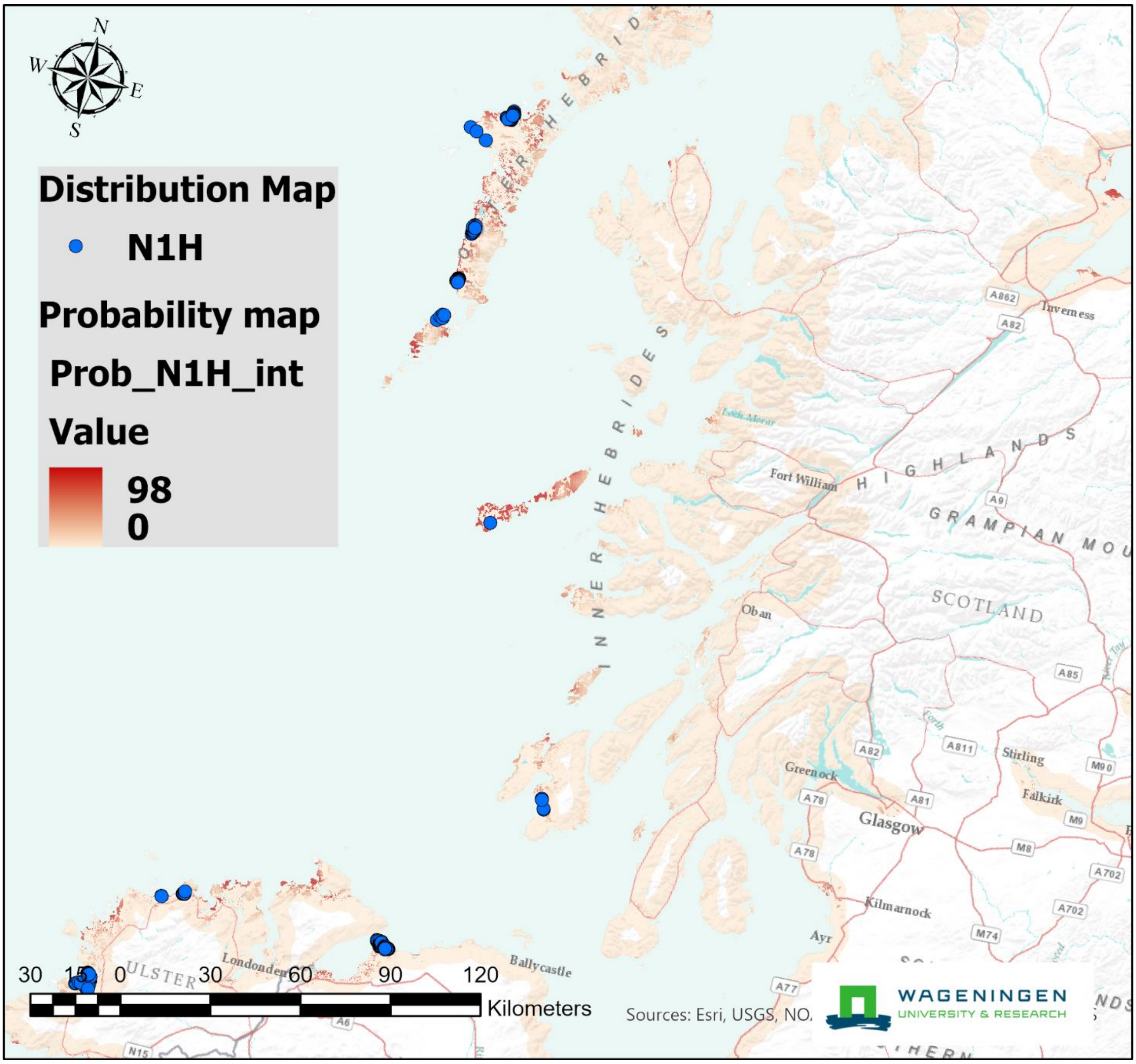
N1D 'Atlantic and Baltic broad-leaved coastal dune forest'. A forest type with a wide range of variation, comprising a diversity of relatively open to closed forests on Atlantic and Baltic coastal dunes. It develops where more stable coastal sands are invaded by broadleaved trees typical of the local soil and climatic conditions. It includes forests in dry and wet conditions, on calcareous and acidic sands and along the climatic gradient from southern Norway and the Baltics towards central Portugal. Many of these forests are indistinguishable in their floristic composition from inland examples of the same general type.



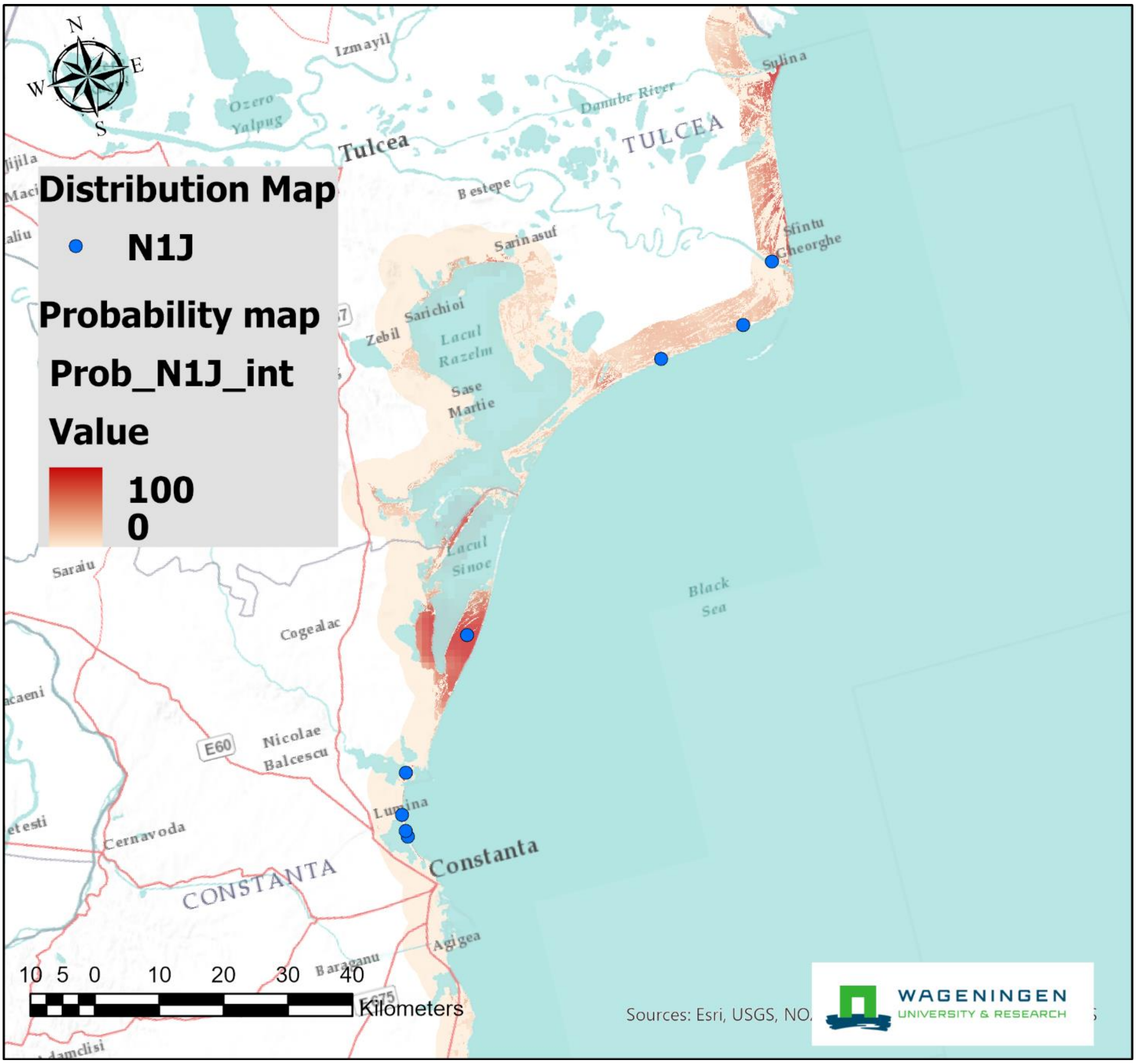
N1F 'Baltic coniferous coastal dune forest' Forests on coastal dunes on the Baltic coast dominated by Pinus sylvestris. Many of these forests are indistinguishable in their floristic composition from inland examples of the same general type.



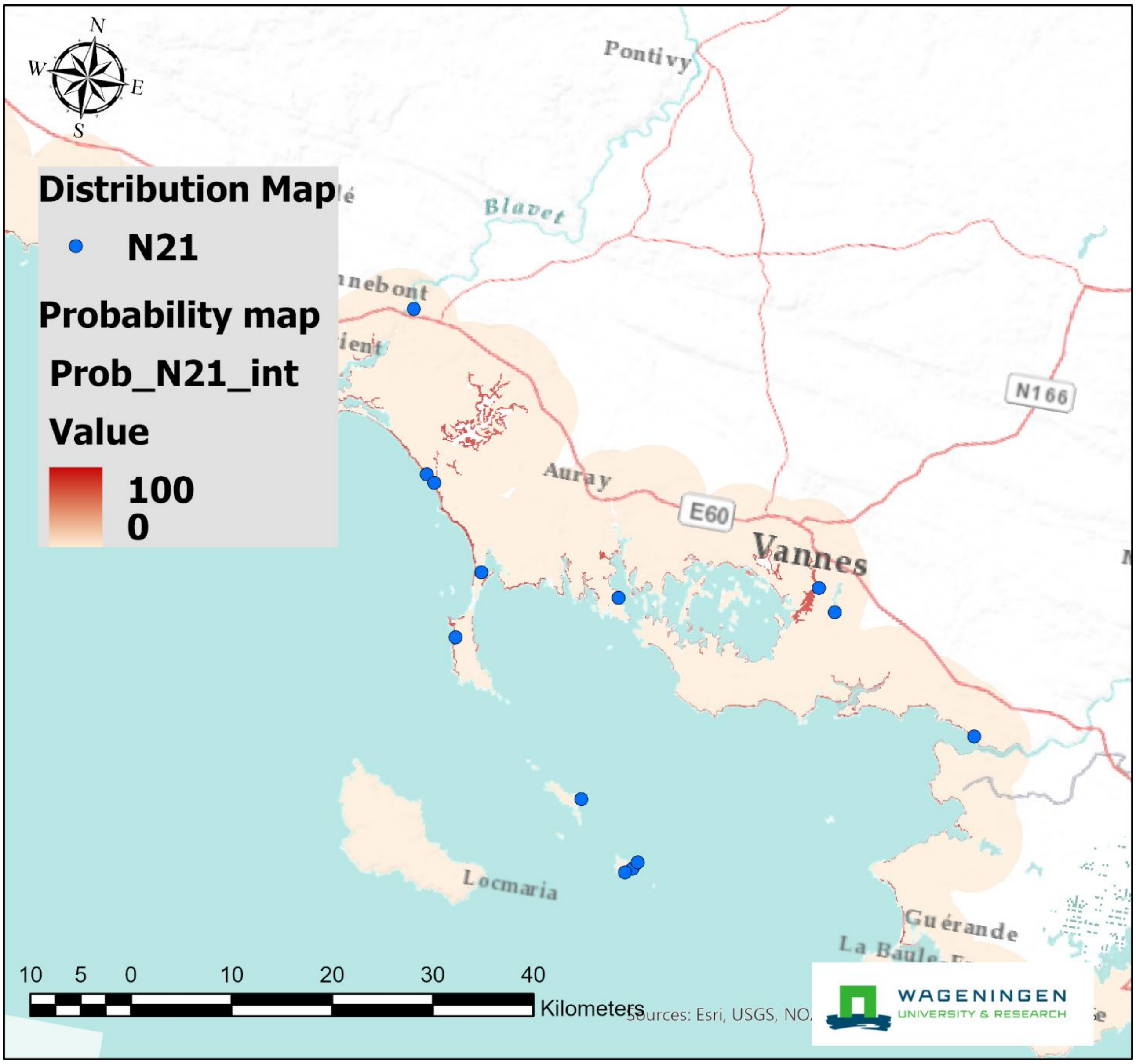
N1G 'Mediterranean coniferous coastal dune forest' Forests on coastal dunes in the Mediterranean Basin are dominated by different species of pine. Many stands are of planted origin. A variety of other woody species occur including shrubs such as junipers. Where shrubs exceed the cover of pine, the habitat should be considered N19 Mediterranean and Black Sea coastal dune scrub.



N1H 'Atlantic and Baltic moist and wet dune slack' Dune slacks develop in Atlantic and Baltic dune systems as moist-wet depressions between dune ridges, where blow-outs have lowered the sand level to that of groundwater or, unusually in the Wadden Sea, where barrier islands are occasionally flooded by tidal inundation. The water table fluctuates seasonally, less so around the Baltic, and the mean wetness of slacks can vary so that the range of vegetation is considerable from dwarf rush and bryophyte pioneer vegetation, through wet grasslands, to various kinds of mire and swamp, with persistent areas of open water with aquatic plants.

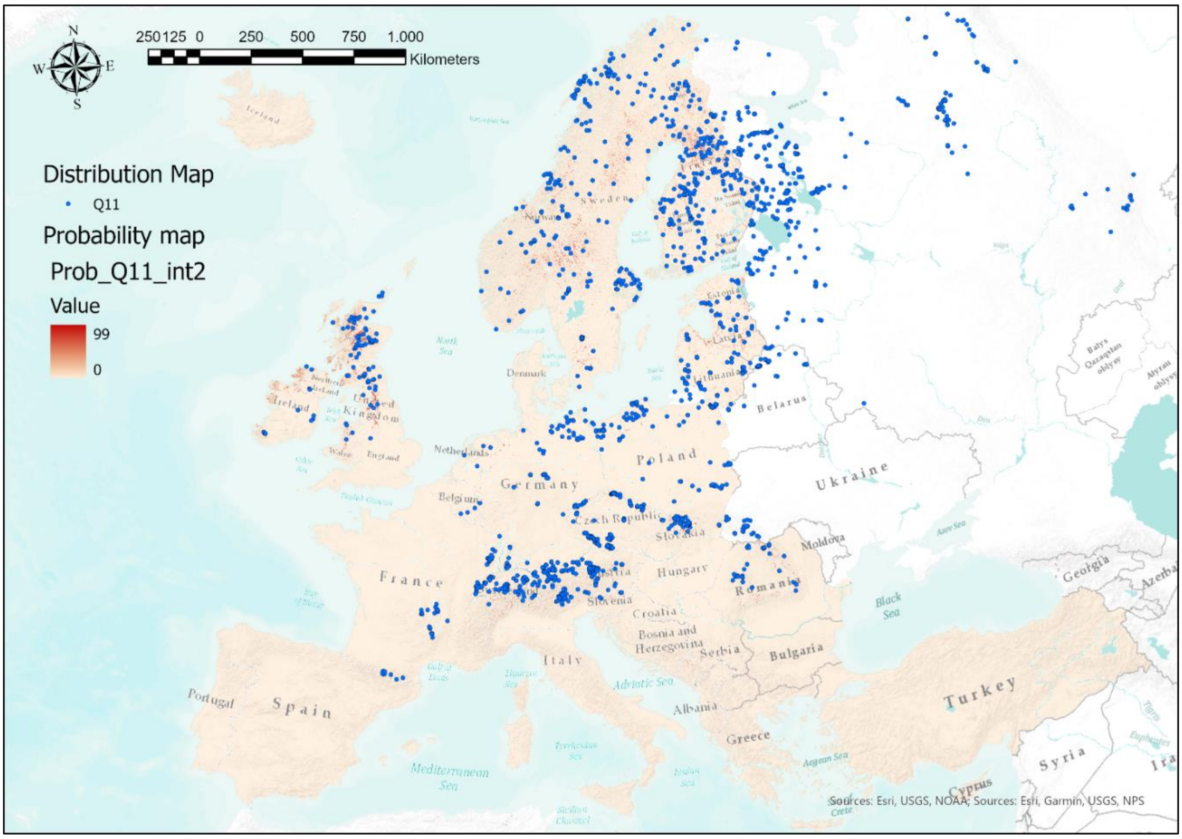


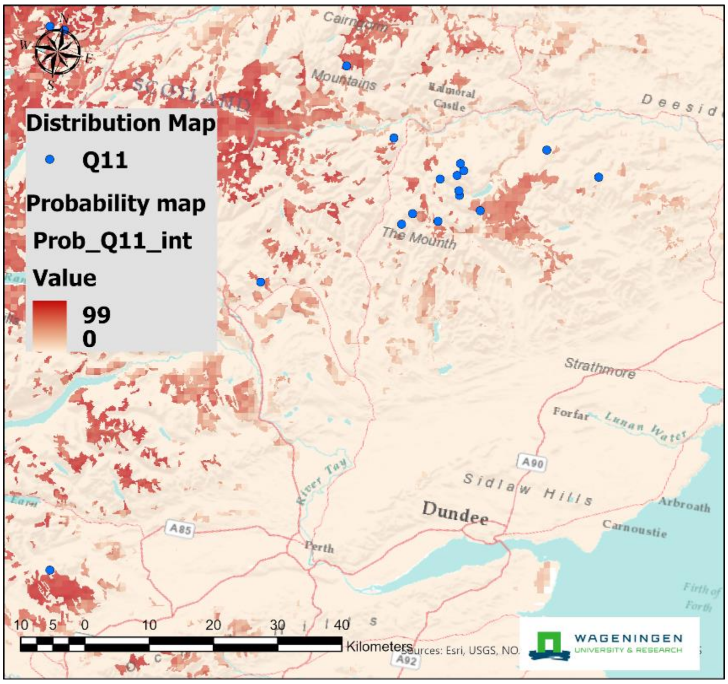
N1J 'Mediterranean and Black Sea moist and wet dune slack' Small permanent or temporary freshwater bodies that develop in the depressions between sand ridges in the dune systems along the Mediterranean and Black Sea coasts. The constituent vegetation depends on the depth and persistence of the water which is very variable, and also on the level of enrichment, which is usually eutrophic to mesotrophic, though locally dystrophic. There can be aquatic communities in the open waters and swamps around the margins and, where the slacks dry out in summer, conditions can become saline with ephemerals colonising.



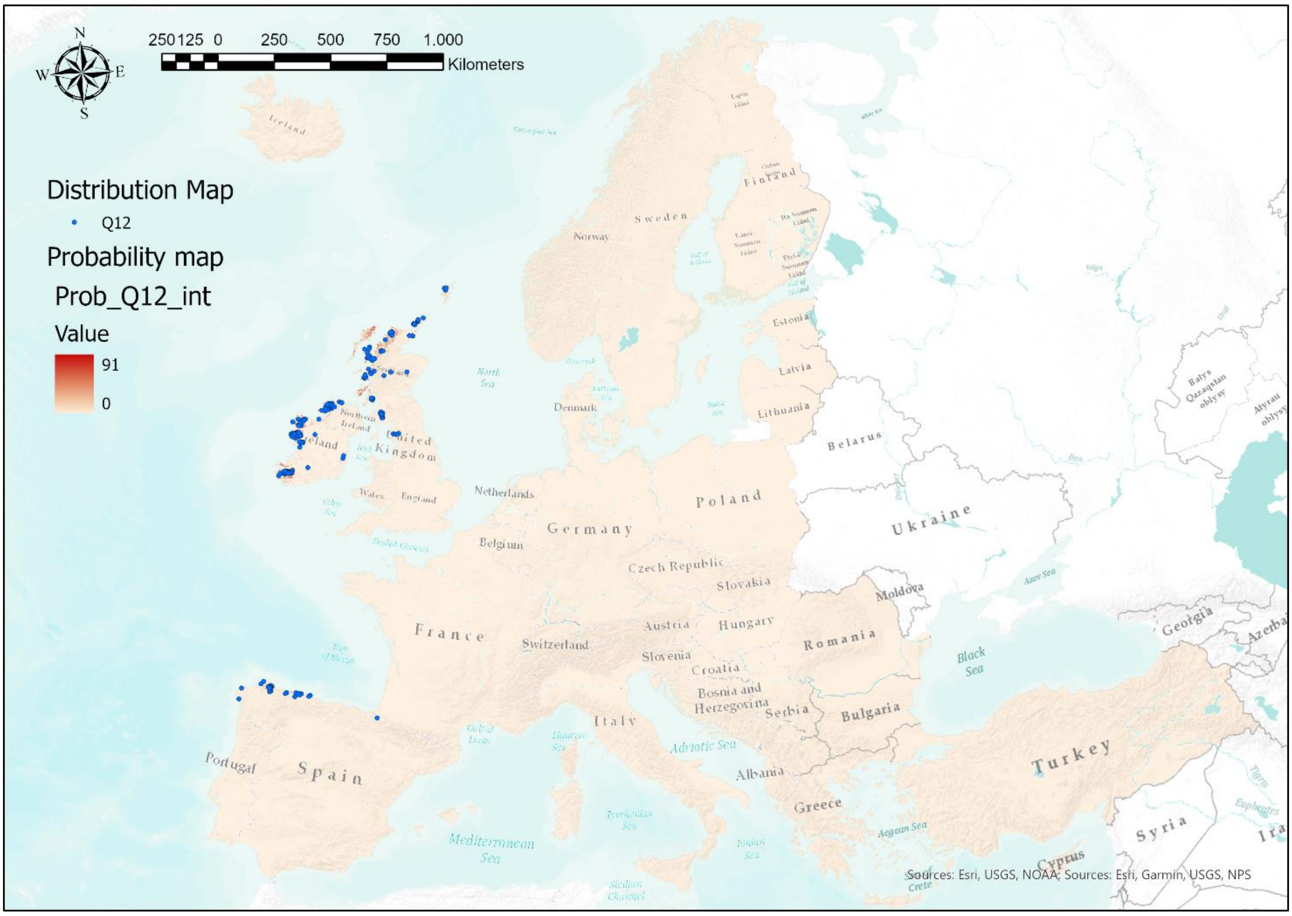
N21 'Atlantic, Baltic and Arctic coastal shingle beach' These deposits of shingle are most typical of highly dynamic beaches along the Atlantic, Arctic and Baltic coasts, with concentrations along the English Channel. Often mobile and largely bare, they provide an inhospitable environment colonised only in more stable situations, with some deposition of finer material and drift detritus, by a distinctive suite of salt-tolerant and nitrophilous perennial plants. They also provide a habitat suitable for some nesting waders and seabirds and a variety of distinctive invertebrates. Locally, in southern England and the Baltic, larger apposition beaches are more extensively colonised by vegetation.

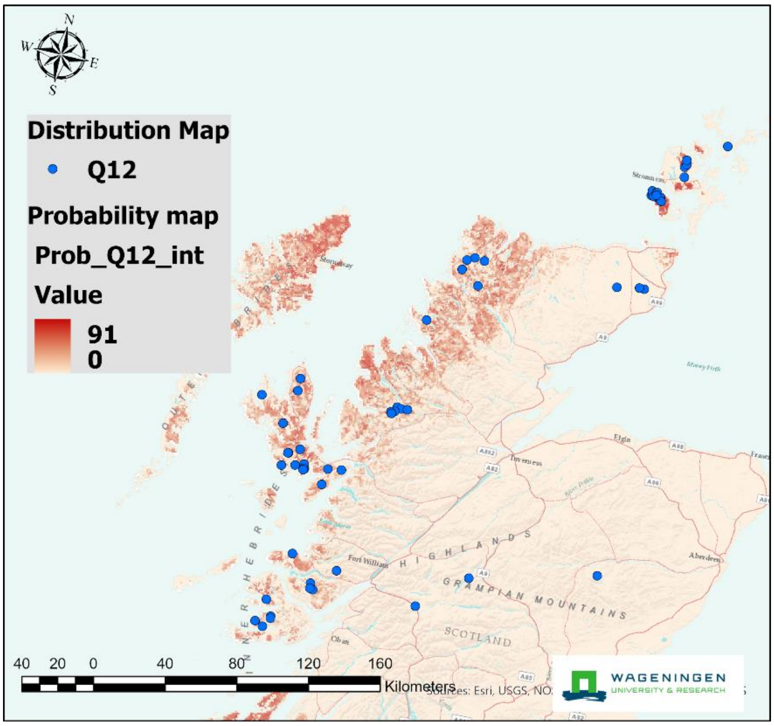
Appendix 5 Produced probability maps for wetland habitats overlaid with related in-situ vegetation plots



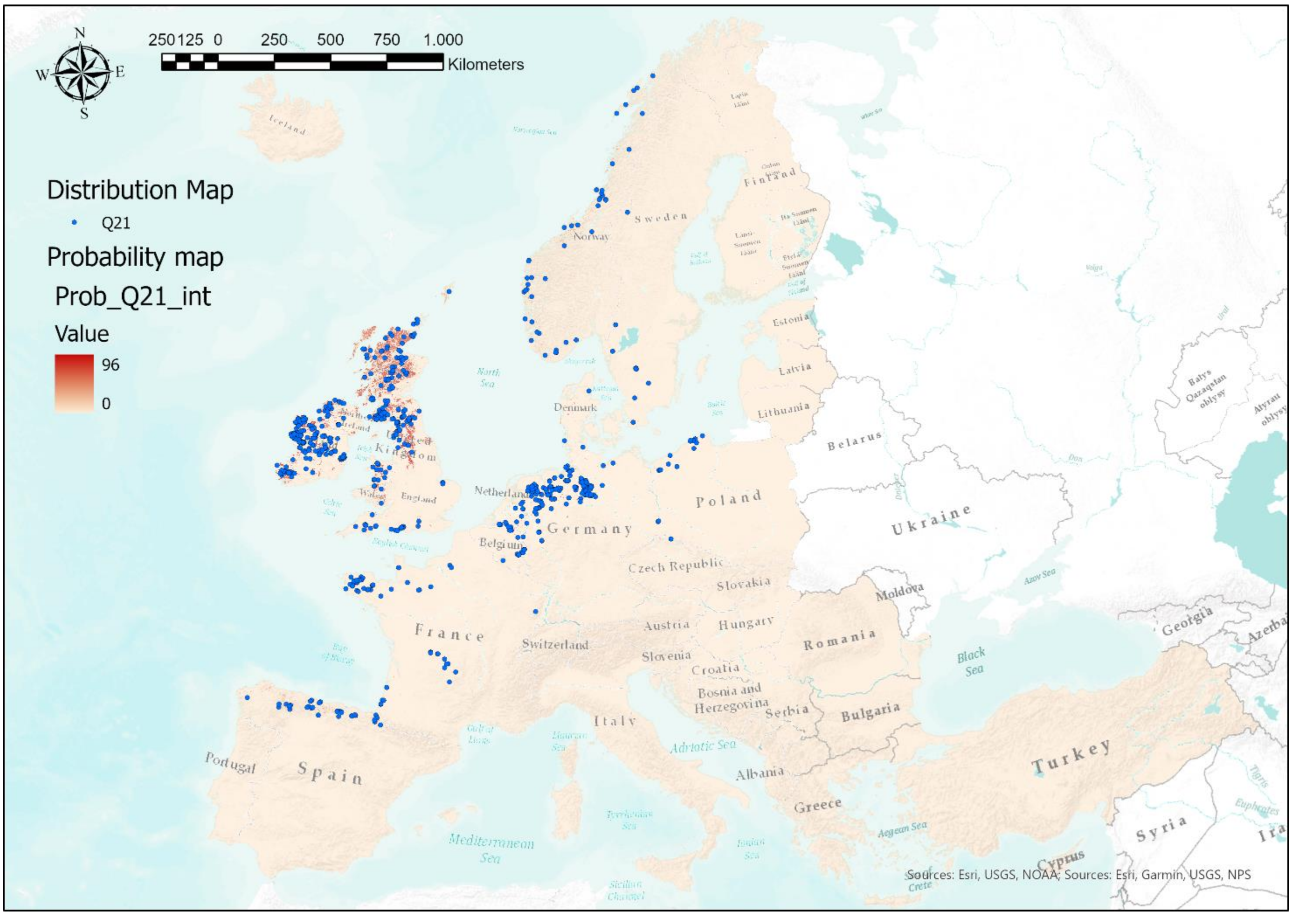


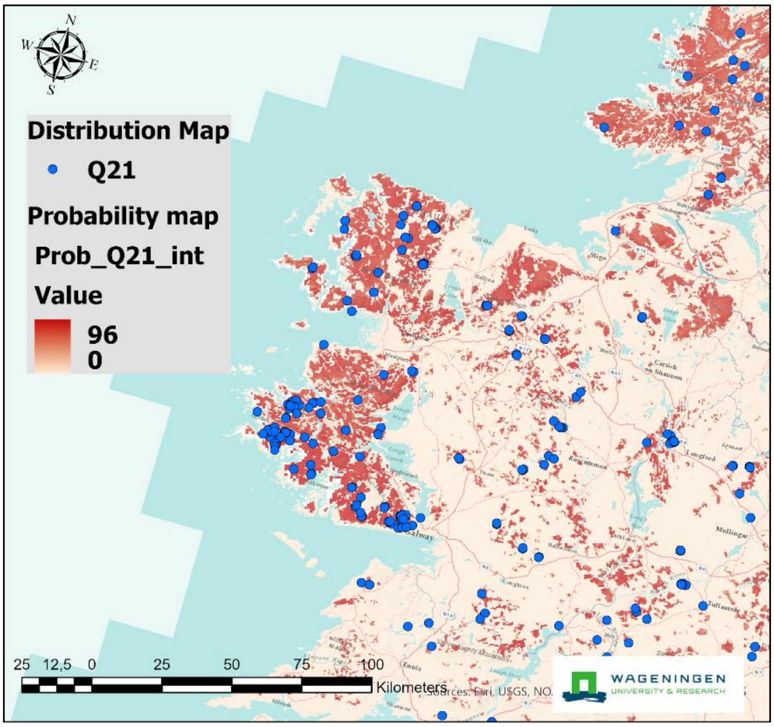
Q11 'Raised bog'. The mire surface and underlying peat of highly oligotrophic, strongly acidic peatlands with a raised centre from which water drains towards the edges. The peat is composed mainly of sphagnum remains. Raised bogs form on nearly flat ground and are ombrotrophic, i.e. derive moisture and nutrients only from rainfall. Raised bog complexes include larger and smaller bog pools, lawns, elevated hummocks and their associated vegetation. Raised bogs form only in cool climates with high rainfall, and they are most widespread in the boreal zone and in the mountains and hills of the temperate zone; they also occur locally in the lowlands of the temperate zone. They are characteristic of lowlands and hills of northwestern and northern Europe, the adjacent Hercynian ranges, the Jura, the Alps and the Carpathians. Bogs harbour, in addition to sphagna (Sphagnum fuscum, S. magellanicum aggr., S. majus), which are often abundant, a small number of dwarf shrubs such as Andromeda polifolia, Rhododendron tomentosum, Vaccinium oxycoccos, and sedges such as Carex magellanica, Carex pauciflora, Eriophorum vaginatum and Trichophorum cespitosum, non-sphagnaceous bryophytes and lichens.



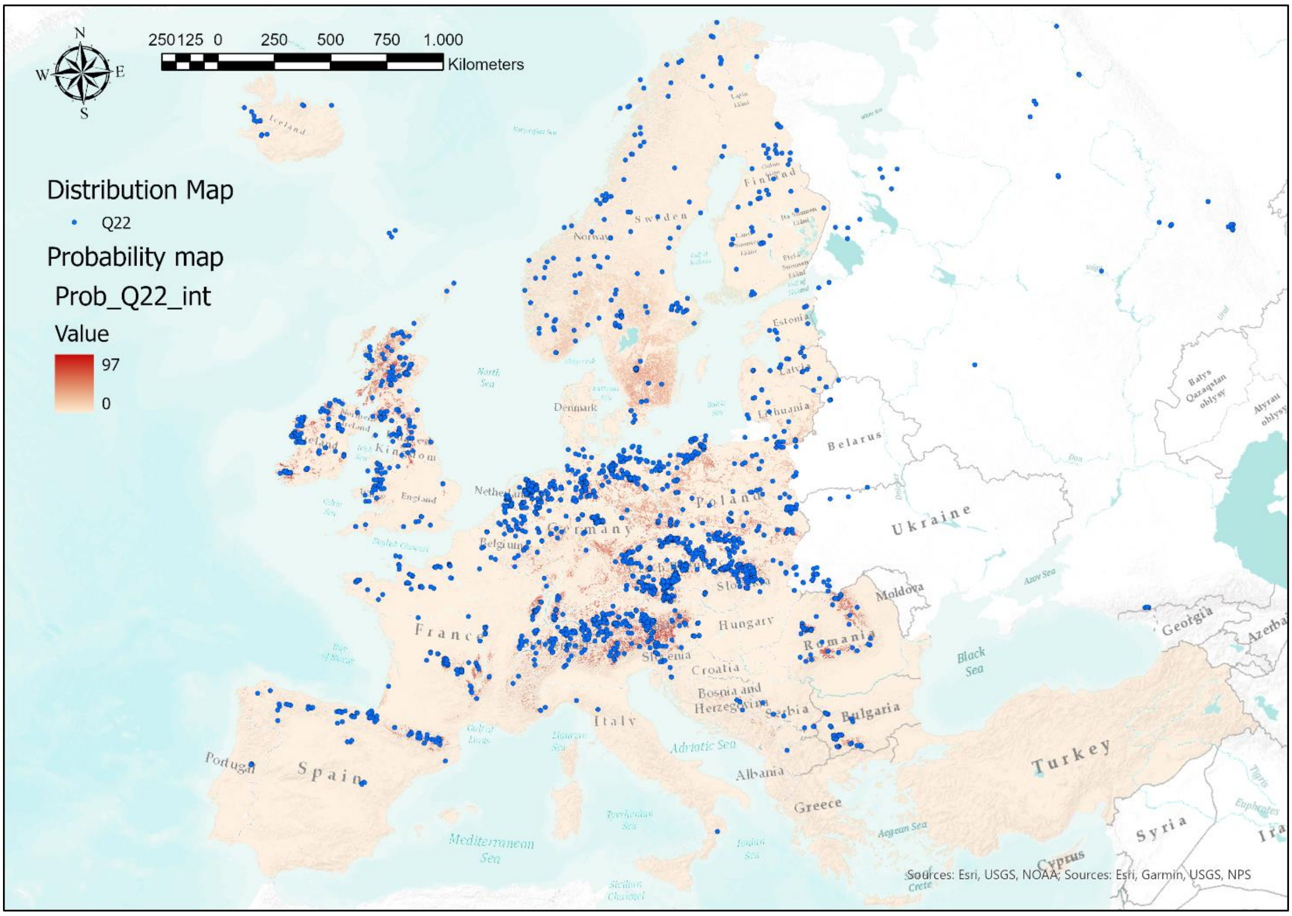


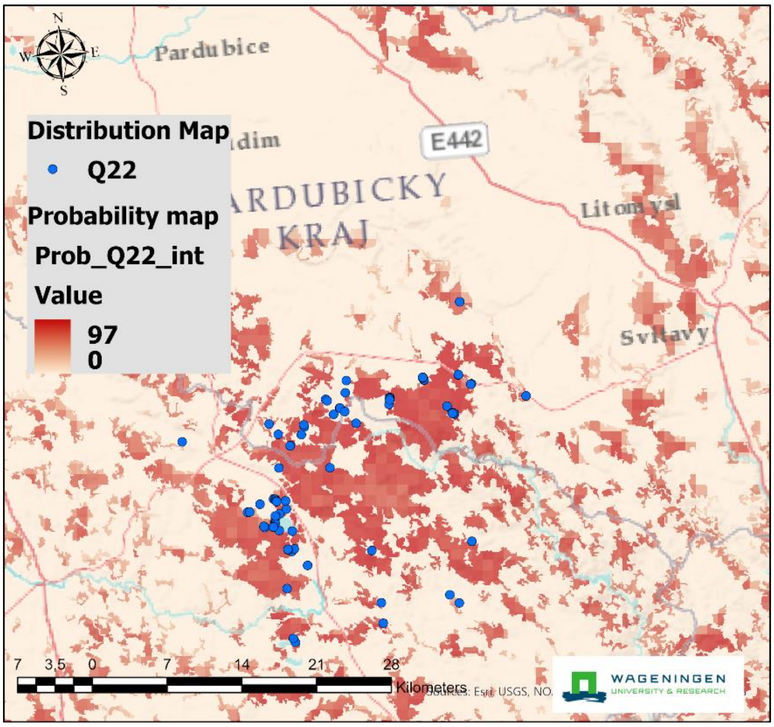
Q12 'Blanket bog'. The mire surface and underlying peat of ombrotrophic peatlands, formed on flat or gently sloping ground with poor surface drainage, in oceanic climates with high rainfall. The mire surface may on flatter ground be very similar to that of a raised bog, with a complex of small pools and terrestrial hummocks. Blanket bogs are a habitat of northwestern Europe, characteristic of the western and northern British Isles, the Faeroe Islands and the western seaboard of Scandinavia with small outliers in France, Portugal and Spain. They often cover extensive areas with local topographic features supporting distinct communities. Sphagna (Sphagnum compactum, Sphagnum papillosum, Sphagnum rubellum, Sphagnum tenellum) play an important role in all of them, accompanied by Calluna vulgaris, Eriophorum angustifolium, Eriophorum vaginatum, Molinia caerulea, Narthecium ossifragum, Schoenus nigricans and Trichophorum cespitosum. Blanket bog complexes include dystrophic pools and acidic flushes as well as the mire surface.



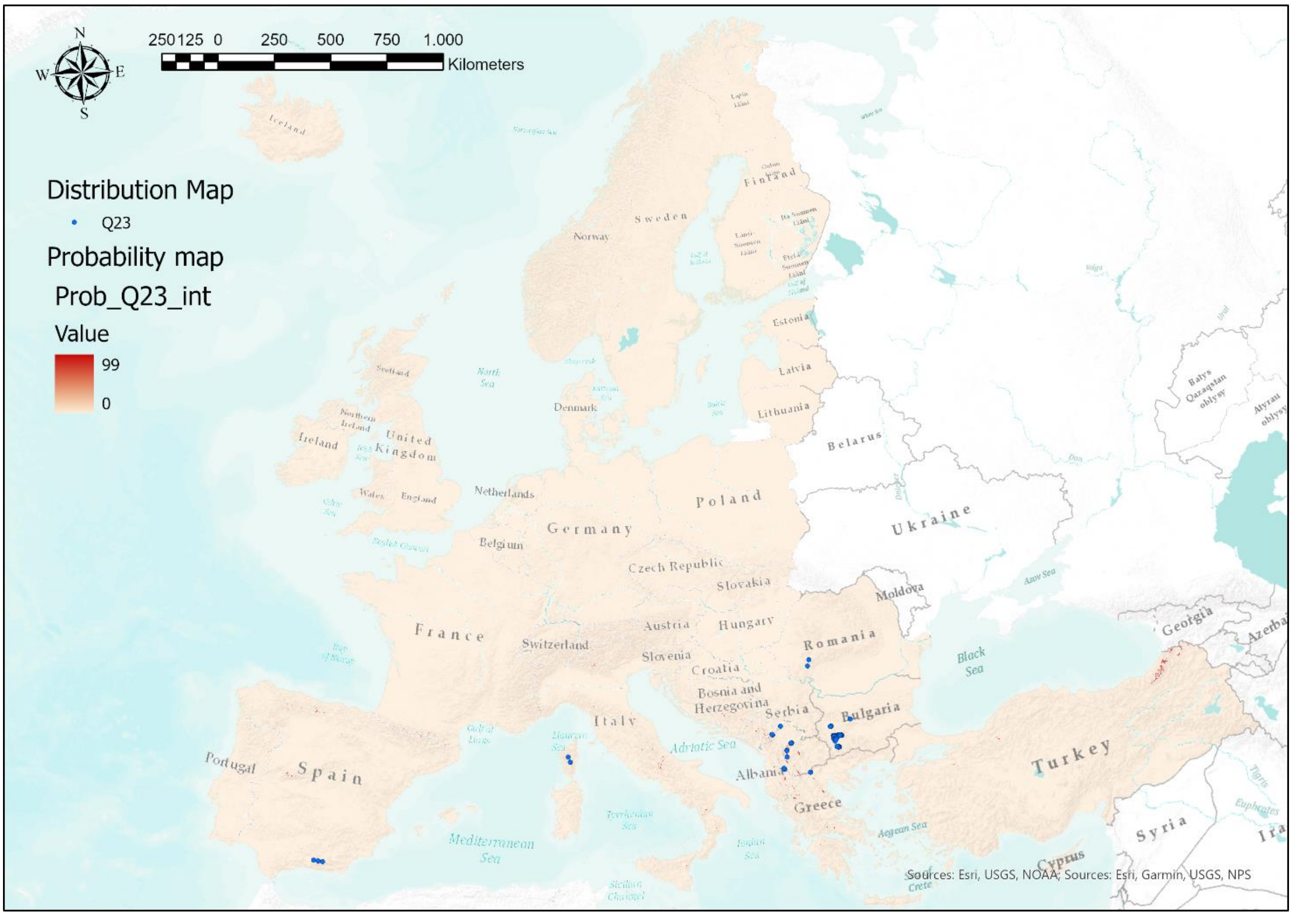


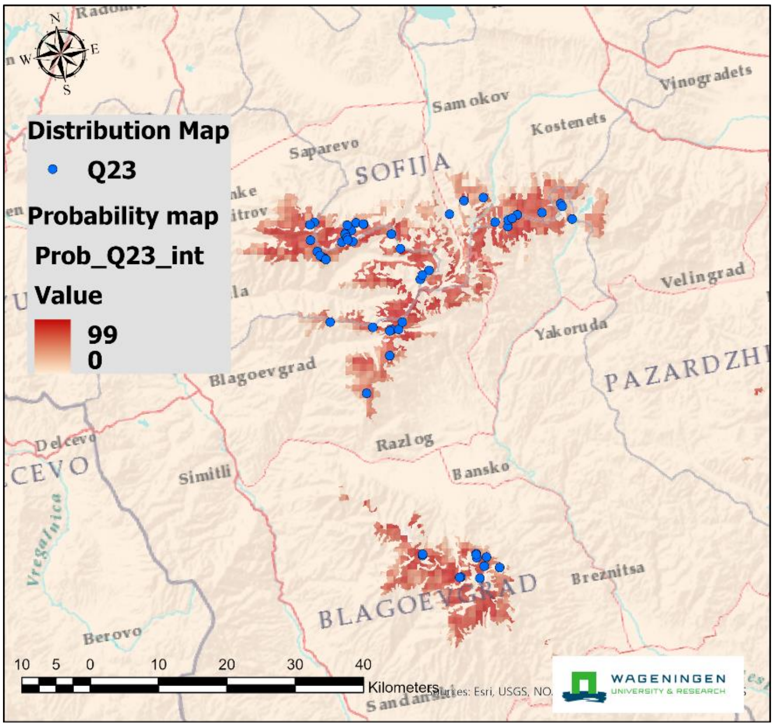
Q21 'Oceanic valley mire'. Topogenous wetlands in which the peat-forming vegetation depends on water draining from the surrounding landscape. Most valley mires are habitat complexes including poor fens, transition mires and pools. Acid valley mires often have vegetation resembling that of bogs, especially in those parts relatively distant from flowing water. Basic and neutral valley mires support mainly poor-fen vegetation, but in large mire systems, this is accompanied by acid wet grassland, large sedges and reeds. Sphagnum hummocks form locally, and transition mires or littoral and spring communities colonize small depressions. Excluded are rich-fen valley mires.





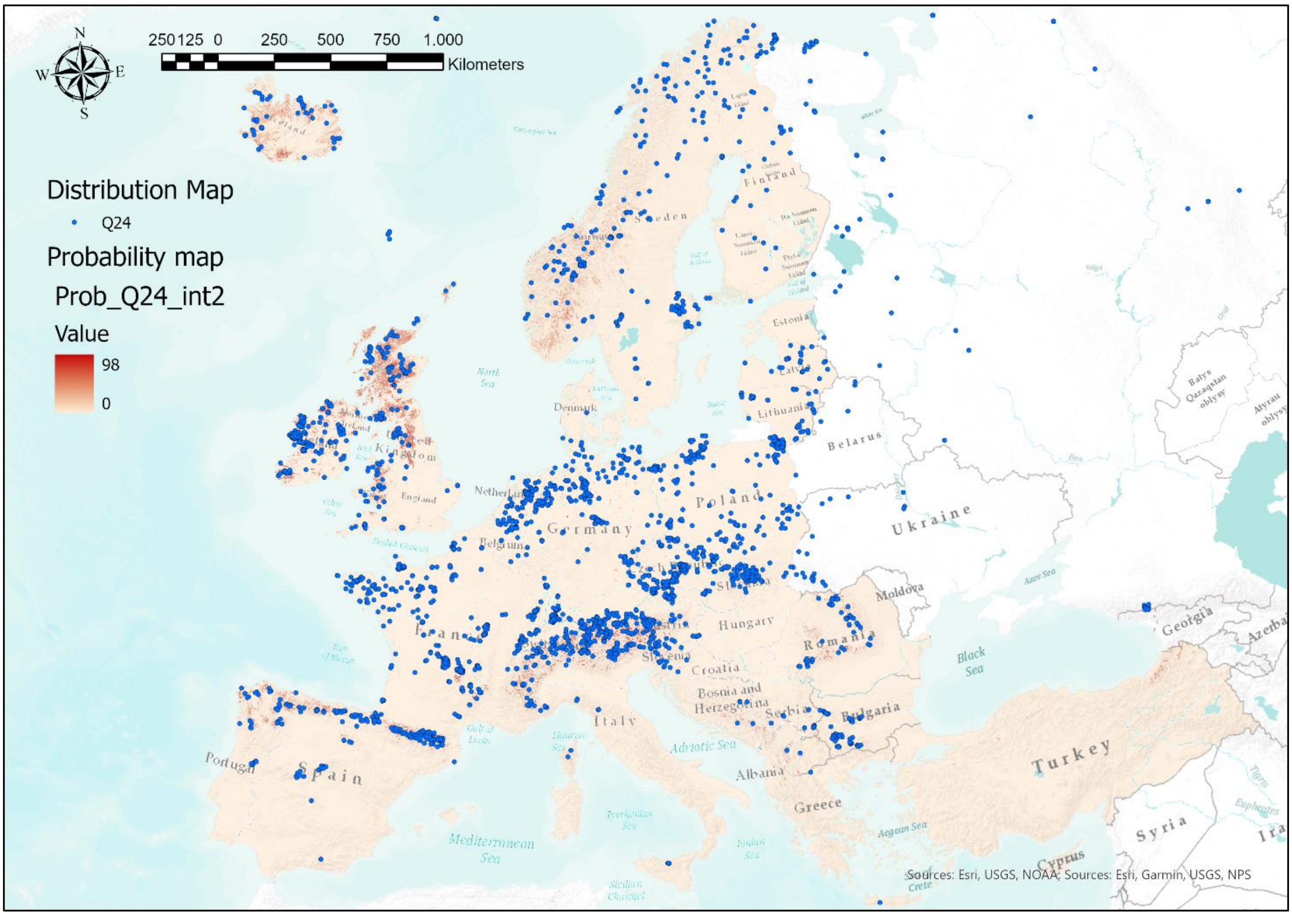
Q22 'Poor fen'. This type of mire, fed by a throughput of acid, nutrient-poor groundwater occurs in a variety of topographic situations (around upland springs, in the laggs of raised bogs, in forest hollows and among infertile fen-grassland complexes) throughout the siliceous landscapes of temperate Europe, particularly in the north. There is a continuous surface carpet of oligotrophic sphagna and small sedges and an associated flora of mire generalists characteristic of less minerotrophic situations. Surface patterning is usually very limited but, towards the boreal regions, there can be a gentle hummock-hollow pattern with scattered trees in drier areas.

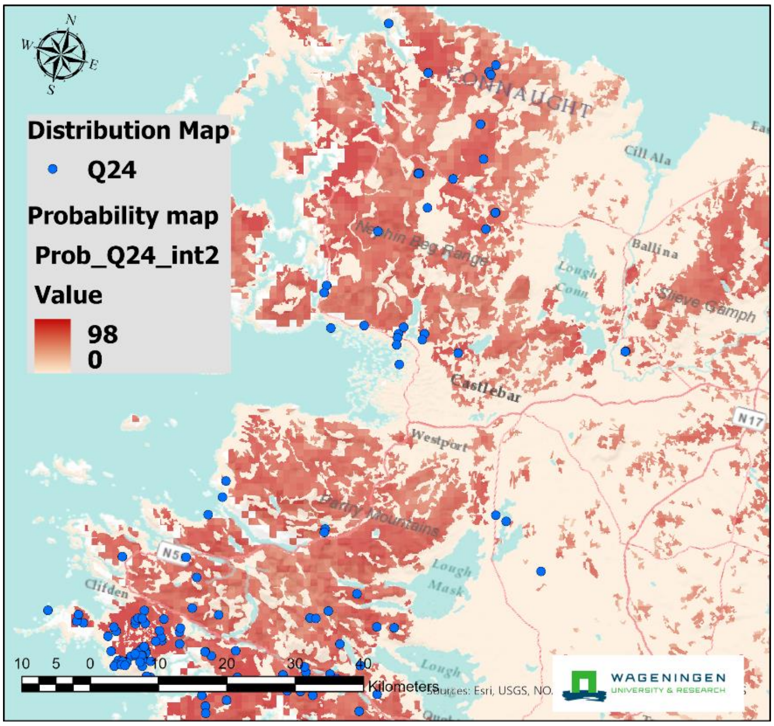




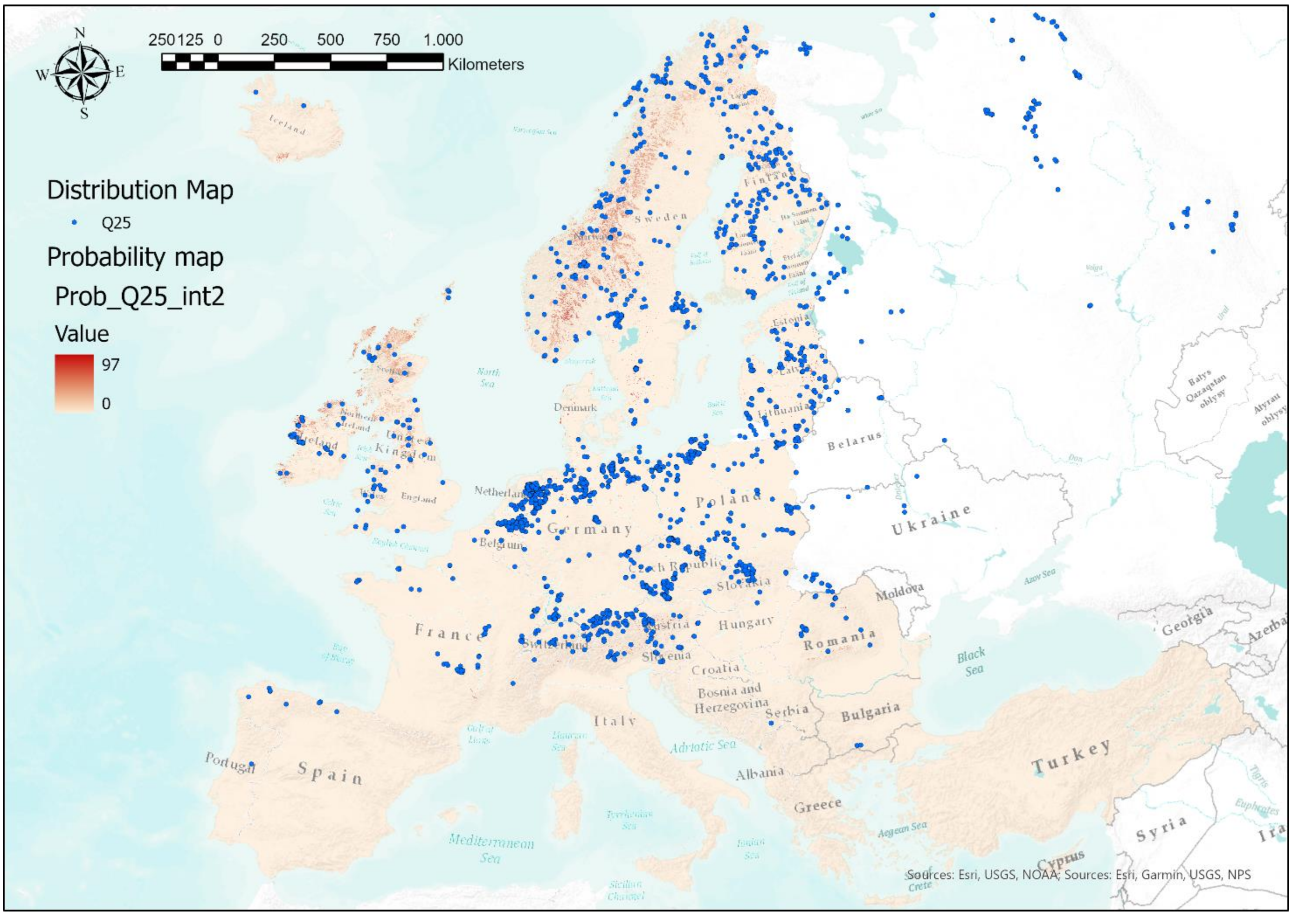
Q23 'Relict mire of Mediterranean mountains'. Oligo- to mesotrophic mire occurring on the waterlogged margins of glacial lakes and around streams in the montane and subalpine belts of the

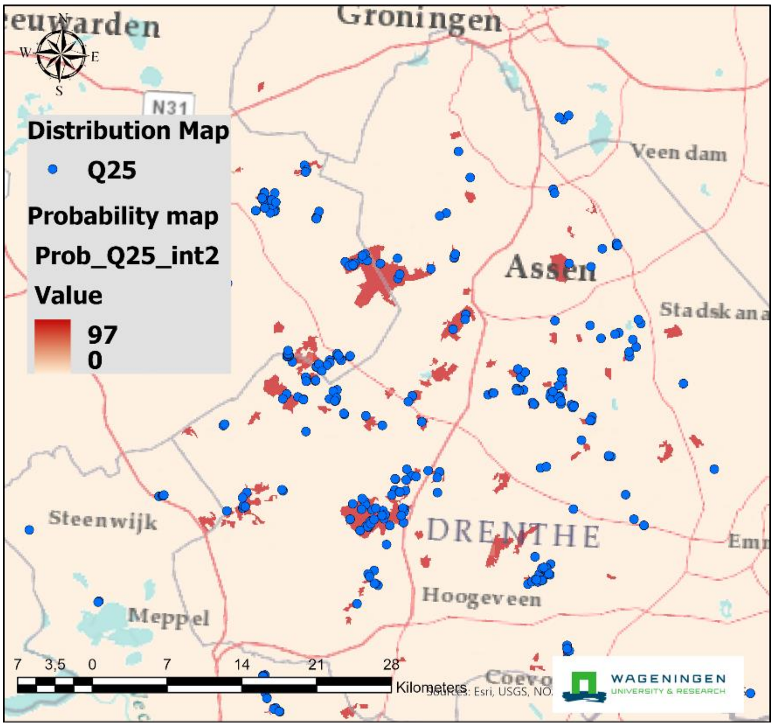
Spanish Sierra Nevada, Corsica, and the western Balkan Peninsula (and also the High Atlas of Morocco). It develops on blankets of thin peat over siliceous bedrocks, kept constantly wet and cool (covered by snow in the high Balkan mountains for much of the year) and providing a splash of green in prevailingly dry landscapes. The vegetation is dominated by small sedges or graminoids often with distinctive endemic and relict species.



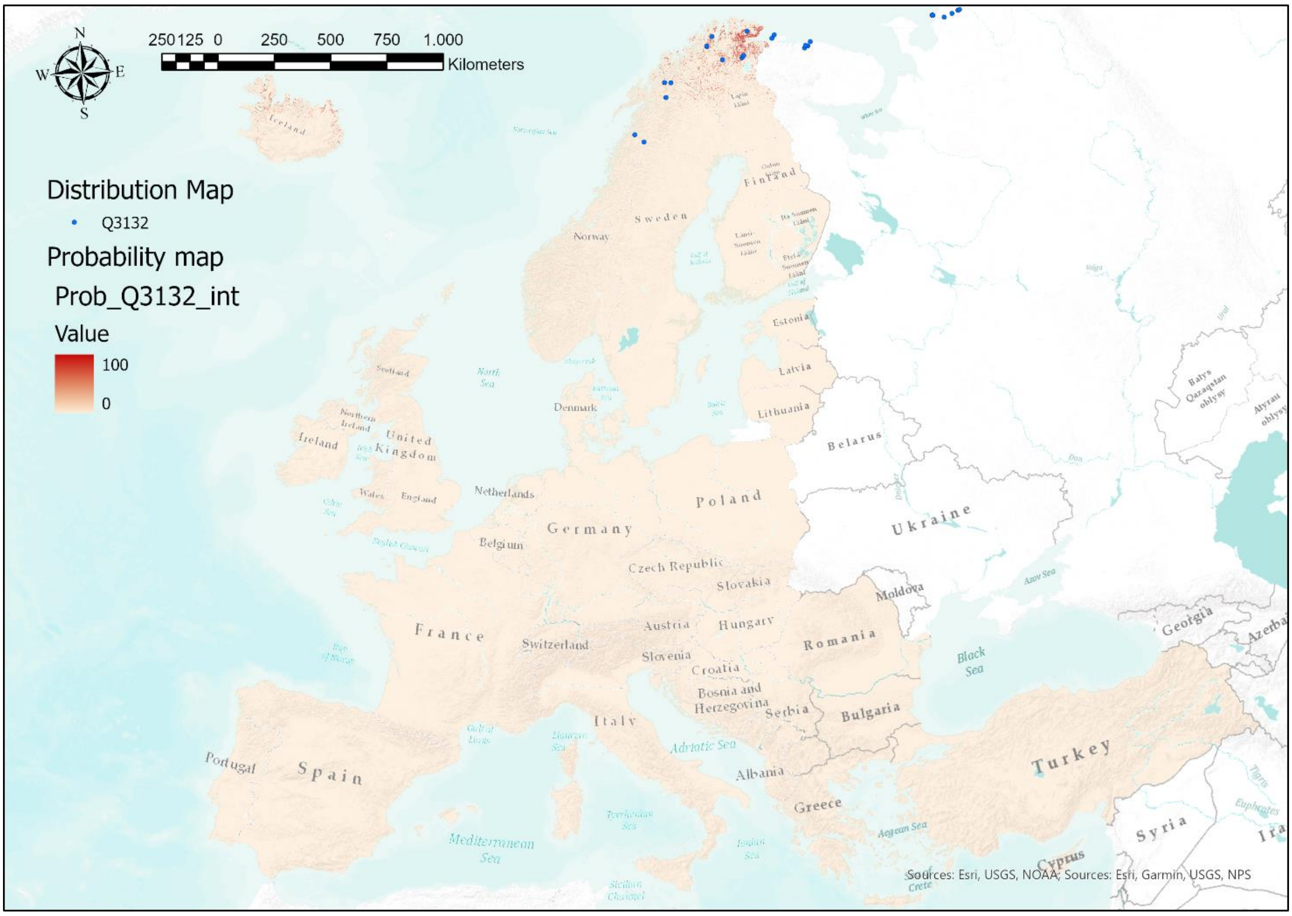


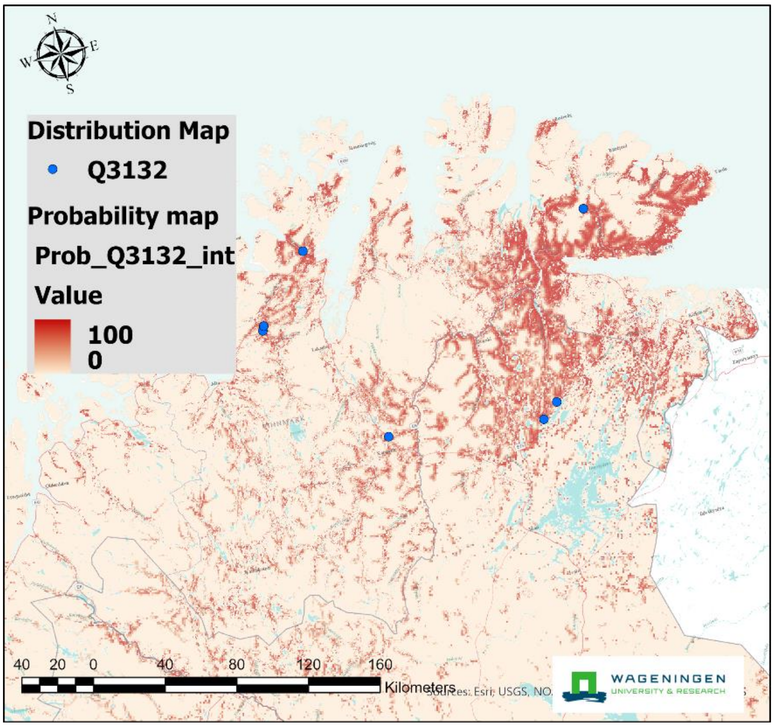
Q24 Intermediate fen and soft-water spring mire These weakly acidic minerotrophic mires occur on peat fed from upper catchments by diffuse seepage of non-calcareous groundwater discharged via springs. They occur widely throughout temperate Europe, though at higher altitudes in the warmer south. The vegetation is typically dominated by a carpet of brown mosses and minerotrophic sphagna, small sedges and associated herbs, though generally without rich-fen indicators, and sometimes with drier hummocks on which sub-shrubs and occasional trees can be found.





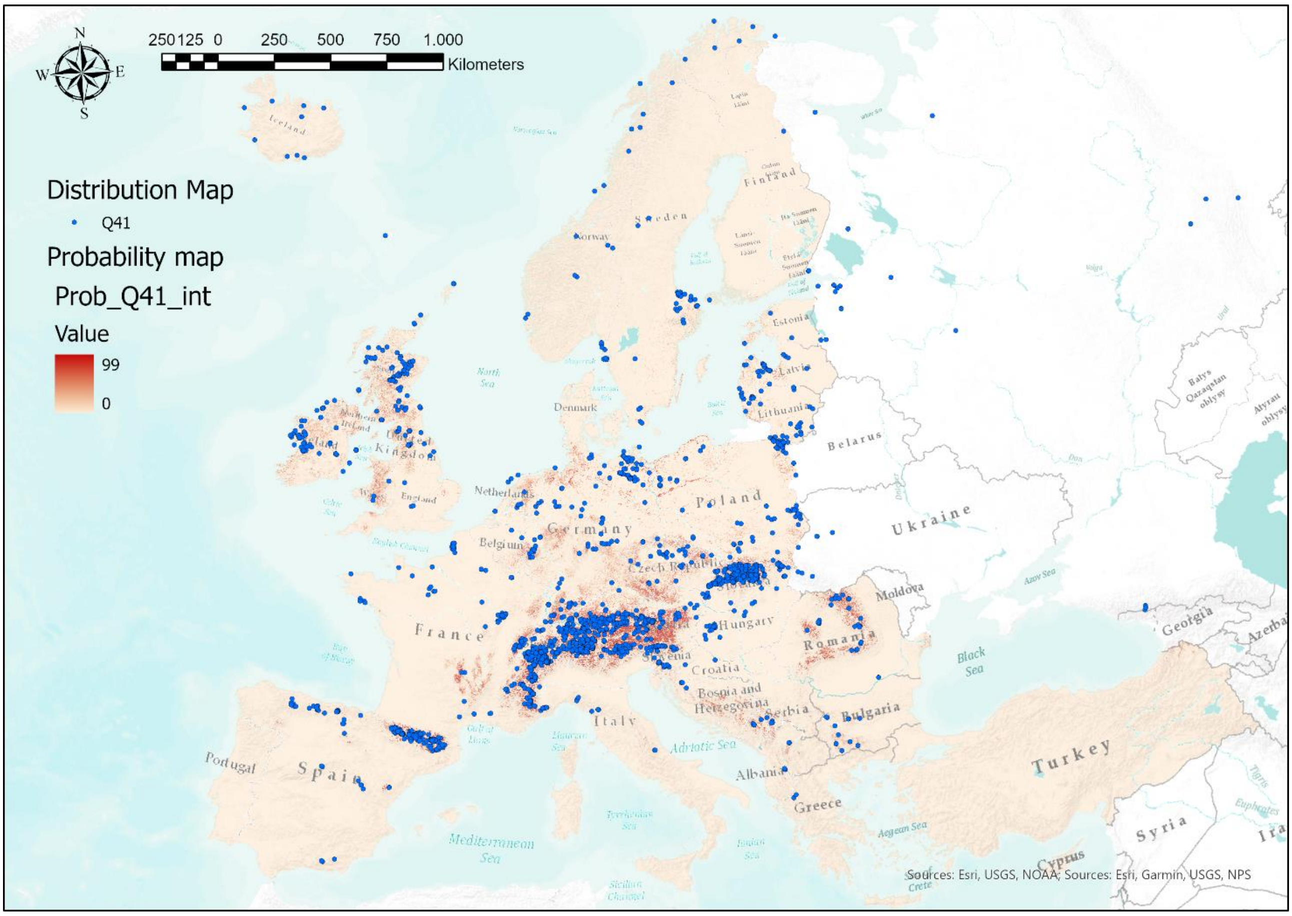
***Q25 Non-calcareous quaking mire*.** This habitat develops by terrestrialisation of open water through the outgrowth of sodden floating rafts of vegetation and accumulating peat from the margins of acidic lakes and ponds, the whole forming a flat quaking surface. It is widely distributed through Europe, though usually highly localised, with the largest areas reported from the Nordic countries. On the matted carpets of sedges and other vascular plants typical of minerotrophic situations, sphagna, other mosses and often abundant liverworts develop, thicker stretches sometimes forming irregular ombrotrophic hummocks. The main threat for such mires is drainage, leading quickly and often irreversibly to the development of other habitats, like poor fens. Quaking areas in percolation mires (which have a much higher species richness) need a very long time to regenerate after rewetting if the regulatory mechanism of the peat body has been destroyed by drainage.

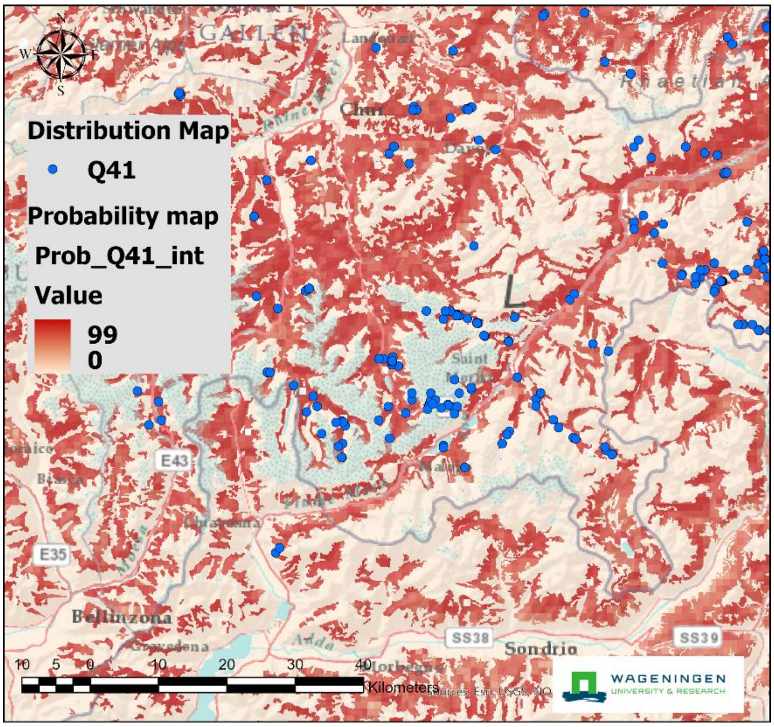




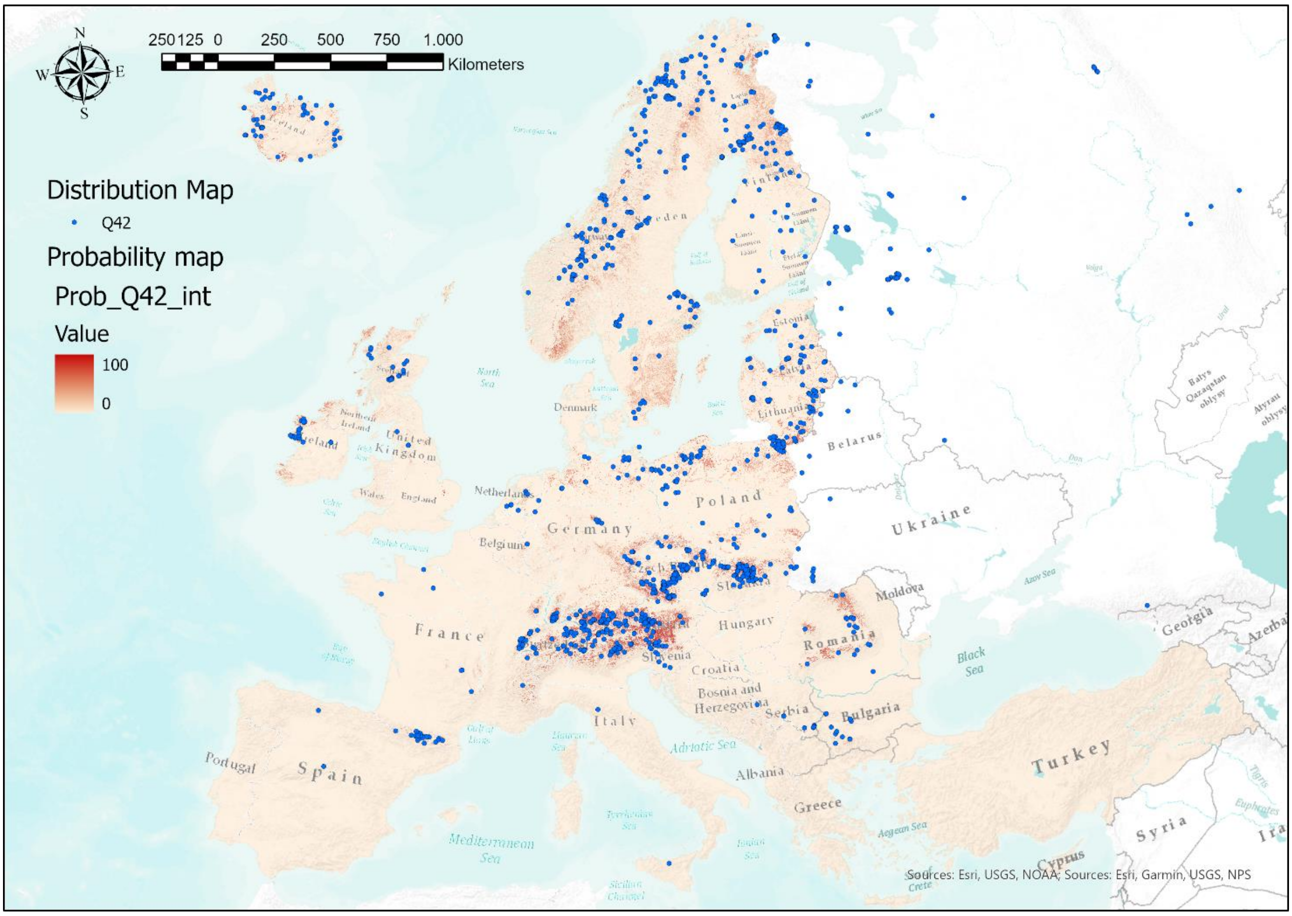
Q31 Palsa mire Palsa mire develops where thick peat is subject to sporadic permafrost in Iceland, northern Fennoscandia and Arctic Russia where there is low precipitation and an annual mean temperature below -1°C. The permafrost dynamics produce a typical patterning with palsa mounds 2–4 m (sometimes 7 m) high, elevated in central thicker areas by permafrost lenses. The carpet of Sphagnum peat limits the penetration of thaw, maintaining a perennially frozen core of peat, silt and ice lenses beneath. Pounikko hummock ridges can be found in marginal areas subject to seasonal freezing, and there are plateau-wide palsas and string mires in the Arctic. Intact palsa mounds show a patterning of weakly minerotrophic vegetation with different assemblages of mosses, herbs and sub-shrubs on their tops and sides. Old palsa mounds can become dry, and erosion may lead to melting and collapse. A complete melting leaves behind thermokarst ponds.

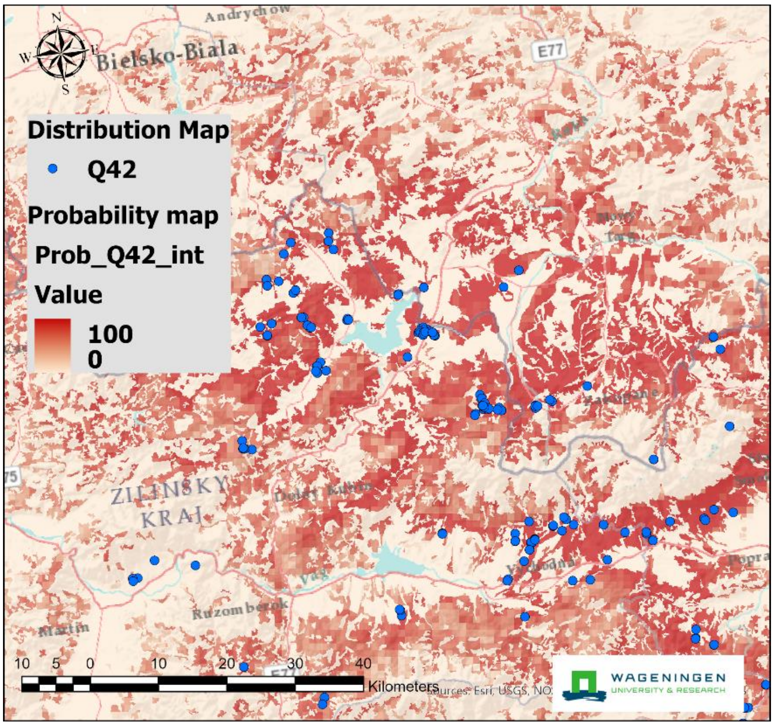
Q32 ***Polygon mire*** Complex mires of the Arctic and subarctic patterned by surface microrelief of large, 10–30 m in diameter, low-centre or high-centre polygons formed by the juxtaposition of dry, 0.3–0.5 m high ridges. The non-sphagnaceous mosses (Dicranum elongatum, Polytrichum strictum) and lichens (Cladonia and Flavocetraria genera) outweigh the sphagna and together with dwarf shrubs occur on the ridges. Wet hollows are occupied by grasses, sedges (Carex rariflora, Eriophorum scheuchzeri) and mosses incl. sphagna. Polygon mires occur rarely in northeastern Europe (Novaya Zemlya, Svalbard and Russian Nenets Autonomous Okrug), in the tundra where the mean annual temperature is below -1°C.



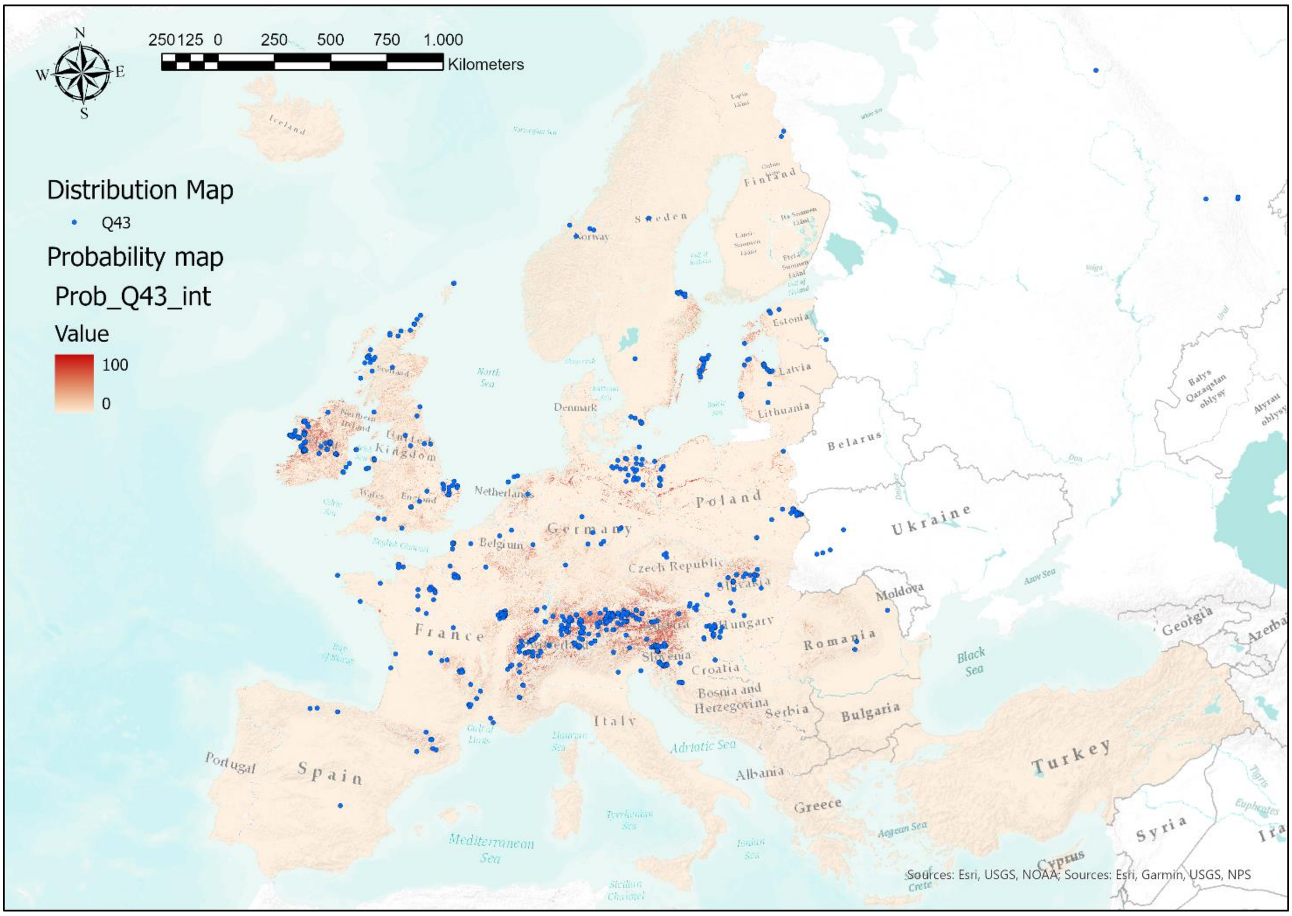


Q41 Alkaline, calcareous, carbonate-rich small-sedge spring fen. Short-sedge fens, spring fens and fen grasslands kept continually wet by base-rich, nutrient-poor waters, occurring through the lowlands and mountains of temperate Europe and more locally in the boreal zone. They are most common, rich and diverse in the limestone massifs of central European mountains, especially the Alps and Carpathians. The soil is rich in organic matter and has high pH, often with precipitation of carbonate or tufa. Small basiphilous sedges dominate the vegetation with rich associated flora and a patchy carpet of fen bryophytes while sphagna are absent.





Q42 Extremely rich moss-sedge fen. Base-rich fens without calcium carbonate precipitation, neutral, often with calcium-tolerant sphagna (e.g. Sphagnum contortum, S. subfulvum, S. teres and S. warnstorfii) dominated by sedges.



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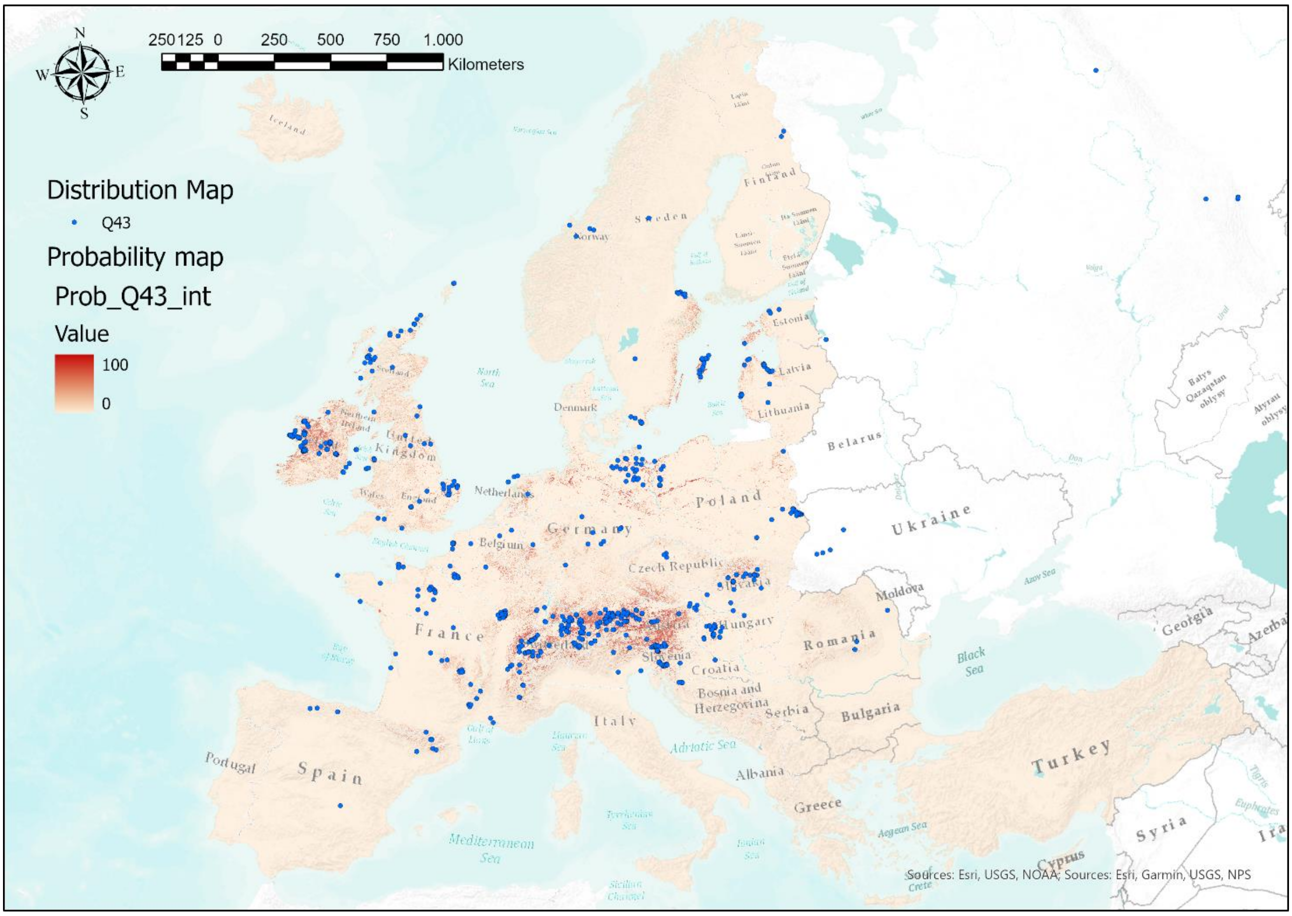
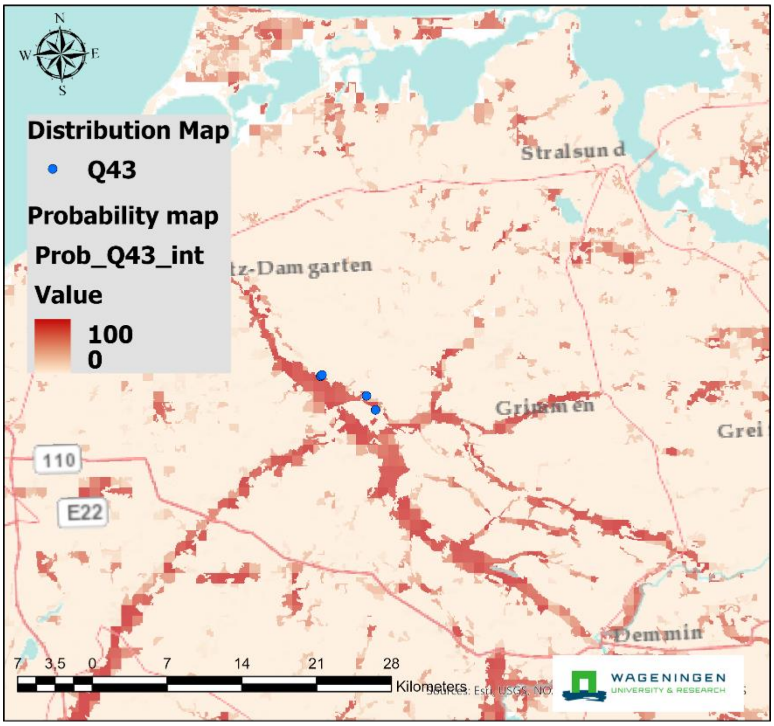
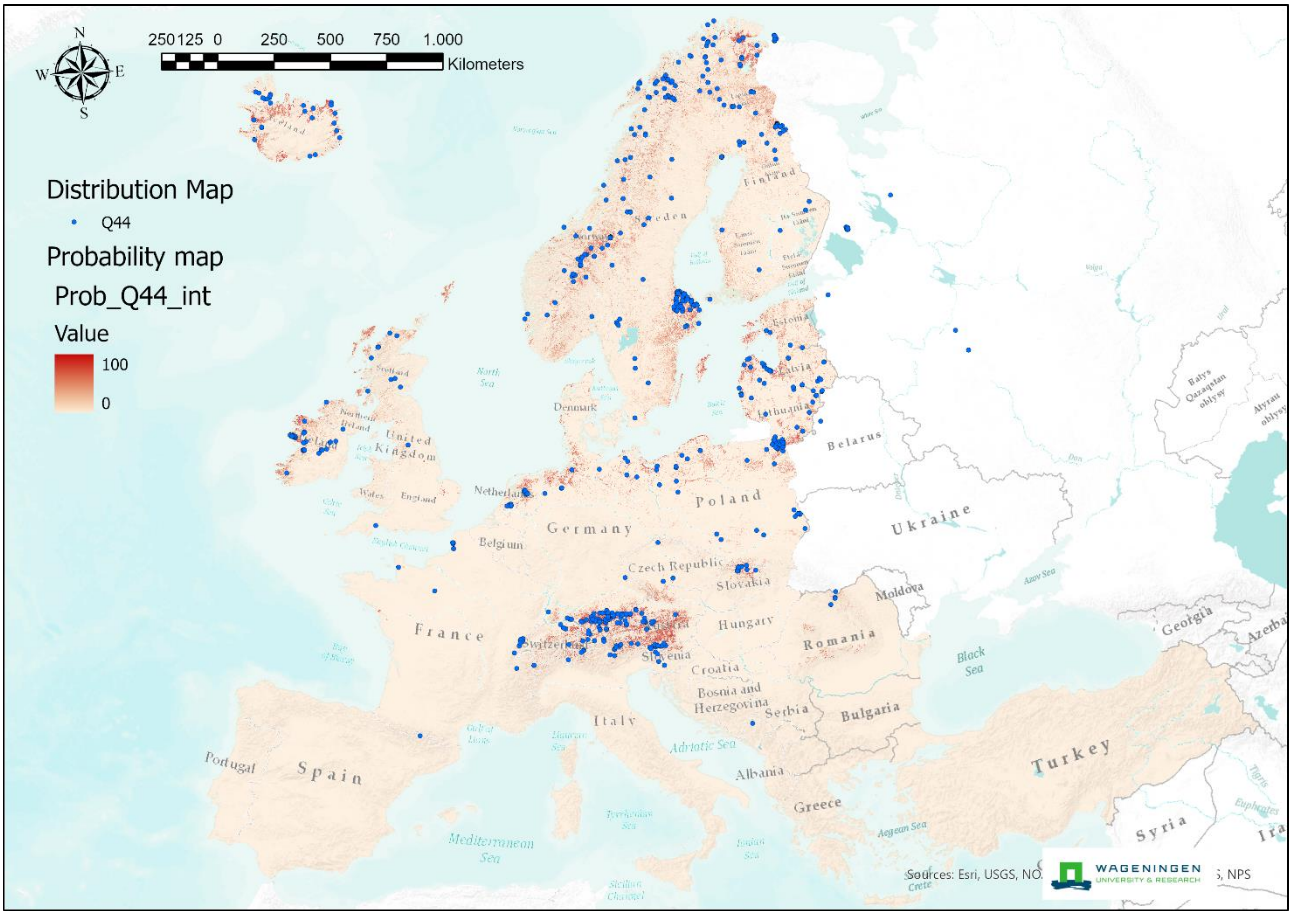
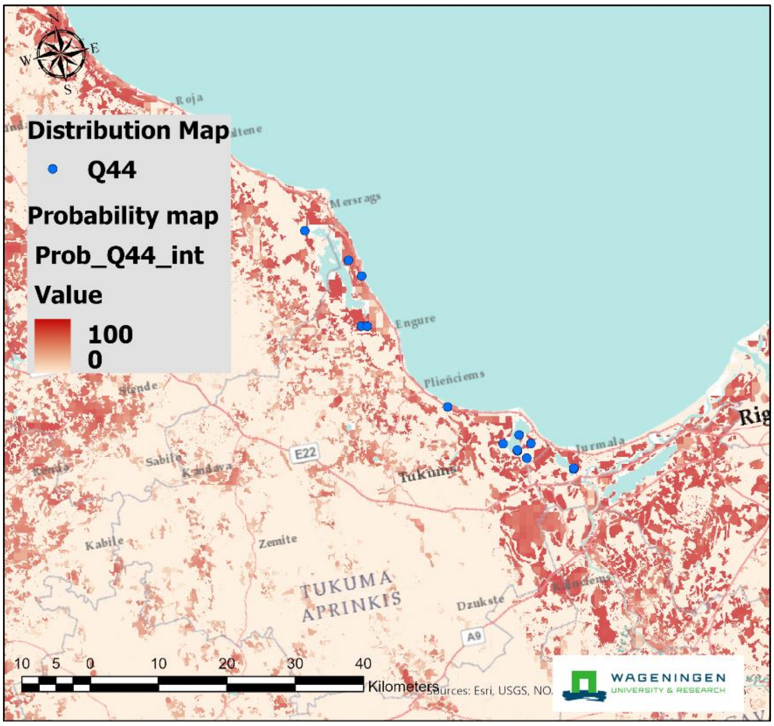


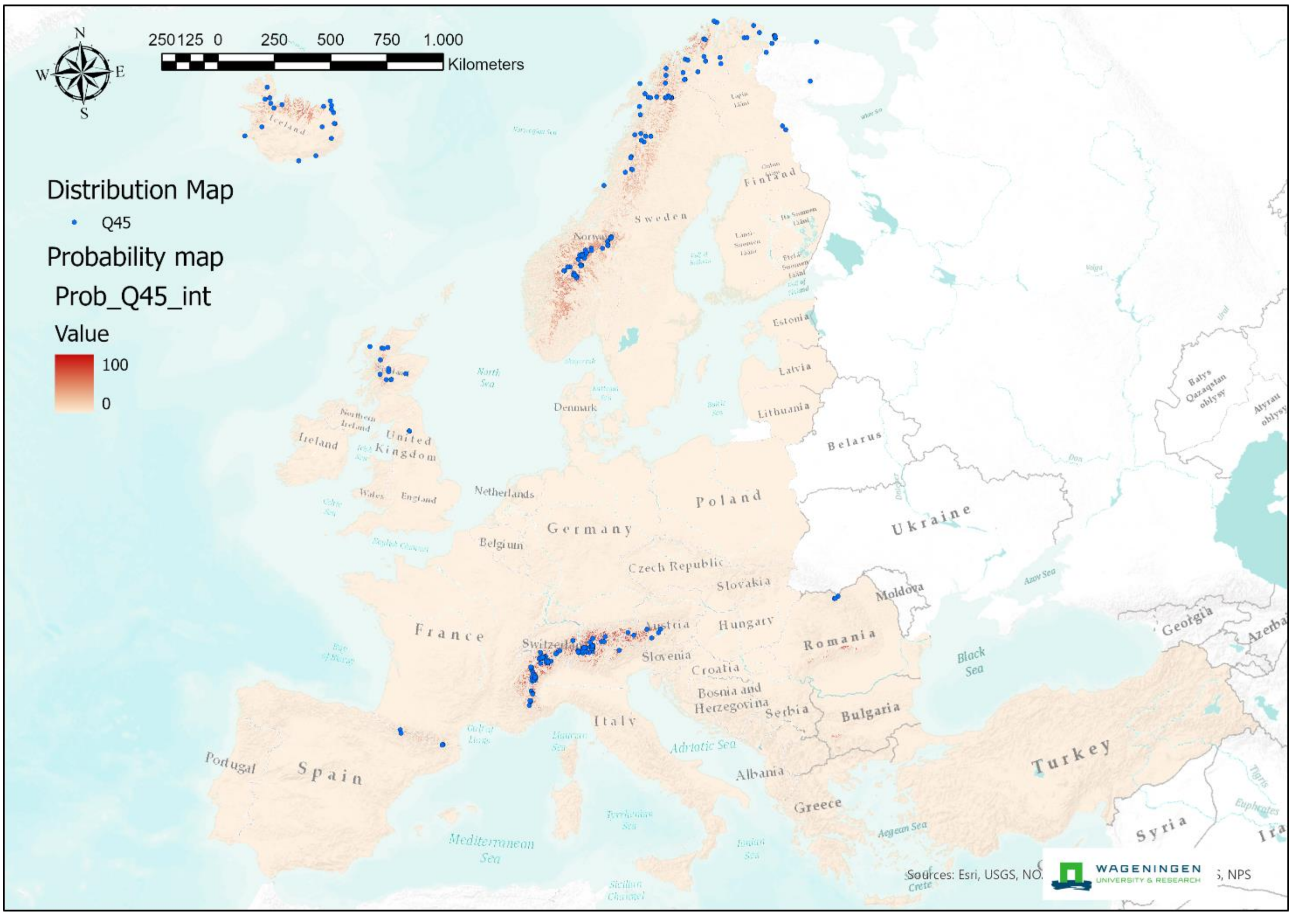


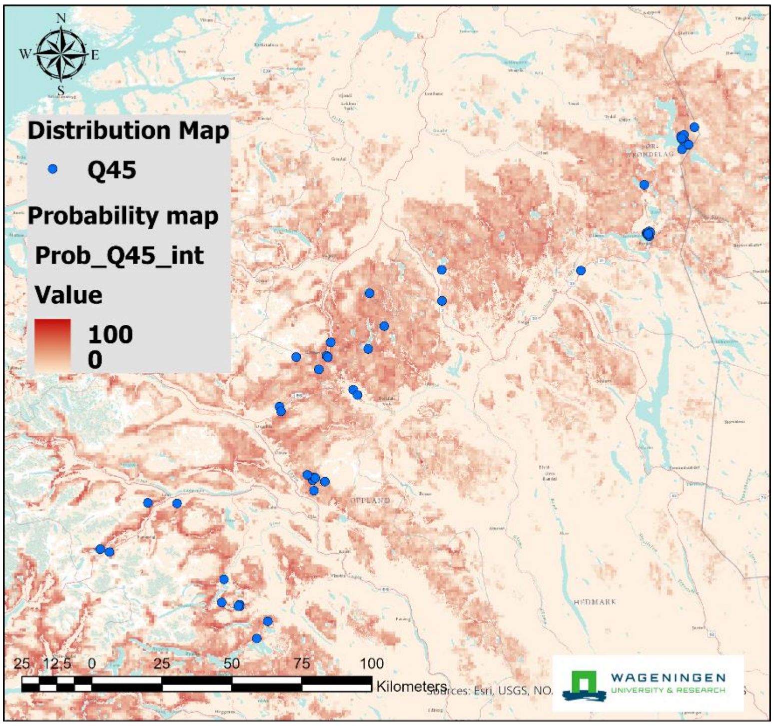
Q43 'Tall-sedge base-rich fen'. Tall-sedge fens are dominated by medium to tall graminoids and tall herbs, along with a patchier tier of low plants, and a ground carpet of rich-fen bryophytes. They are limited to flat landforms where base-rich, nutrient-poor groundwater from springs and seepage lines keep the surface very wet, even in summer. They occur throughout Europe, particularly in the Atlantic and central European lowlands, becoming transitional in species composition northwards to quaking calcareous fens, though sometimes covering large areas in Fennoscandia.





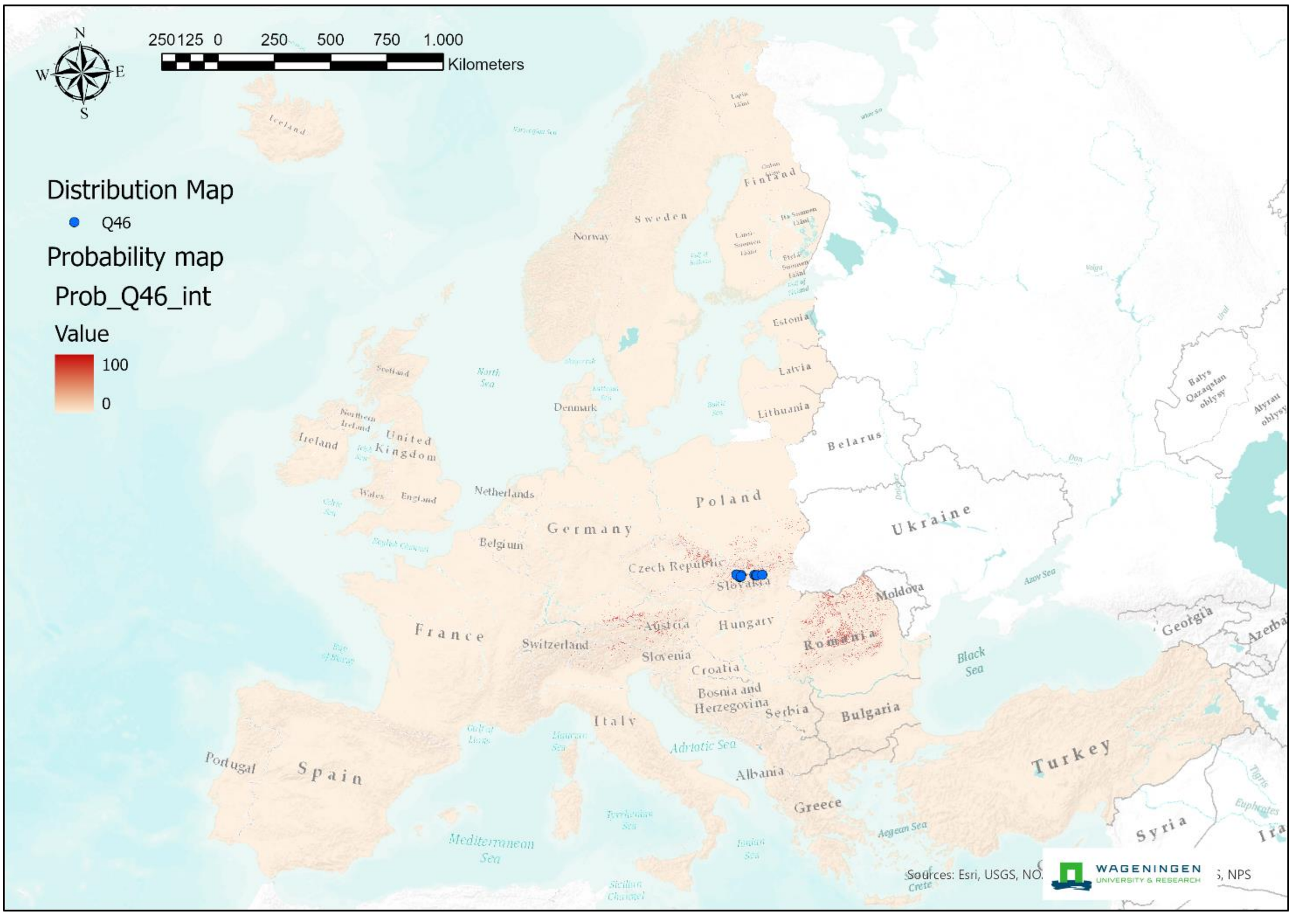
Q44 'Calcareous quaking mire' Calcareous quaking mire develops in as a topogenic mire in basins fed by very calcareous, nutrient-poor groundwater, with generally thin peat, less than 2 m thick. It occurs widely throughout Europe but is most widespread in Finland and Sweden. The surface is kept permanently very wet and covered by an extensive moss carpet with only sparse vascular plants, sometimes disposed over irregular patterns of flarks and hollows. Calcium precipitation can occur on the surface, and the carpet is often interrupted by stretches of open water.

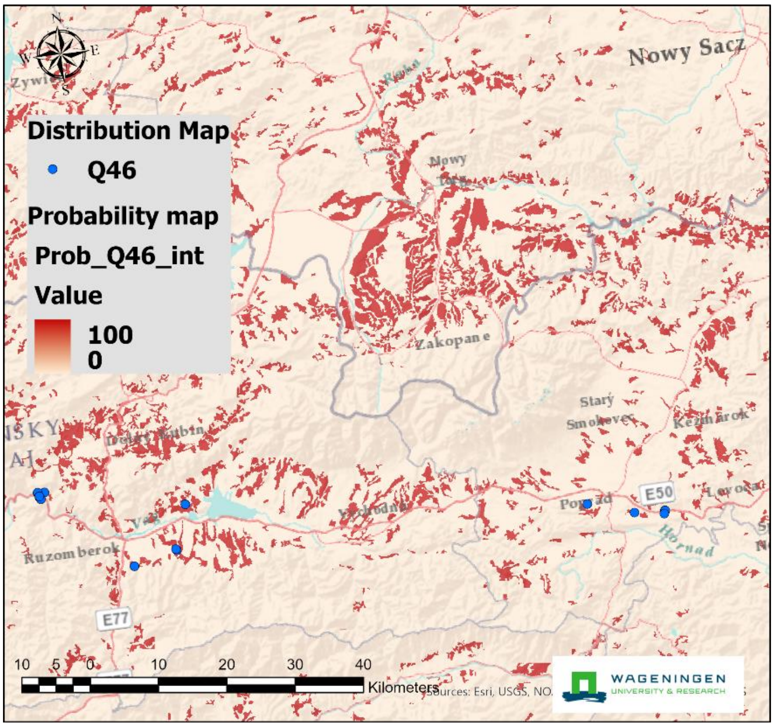




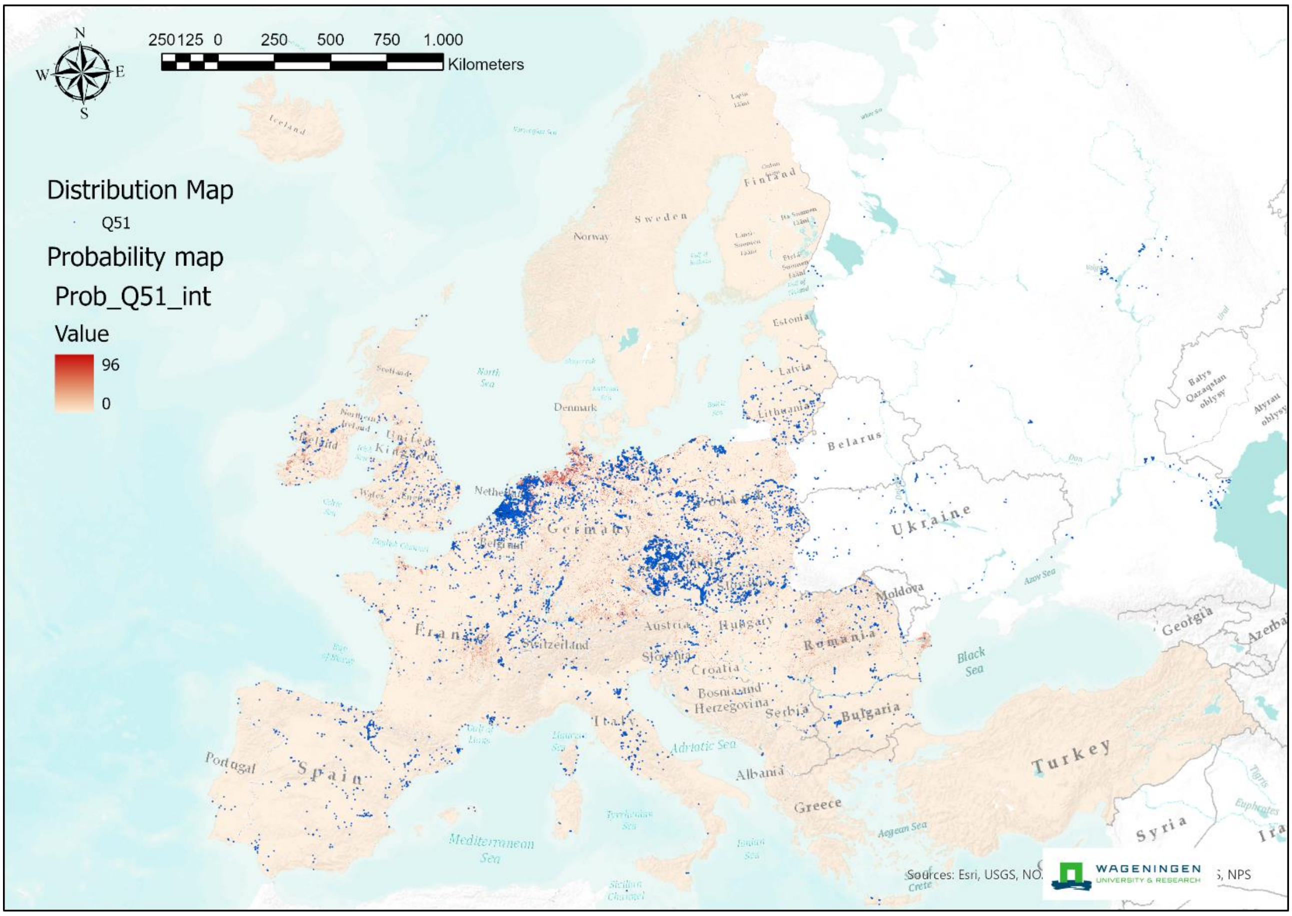
Q45 'Arctic-alpine rich fen'. Fens developed on open substrates constantly flushed by icy, base-rich water alongside small rivers, springs or glaciers in the alpine belt of European mountains and in the

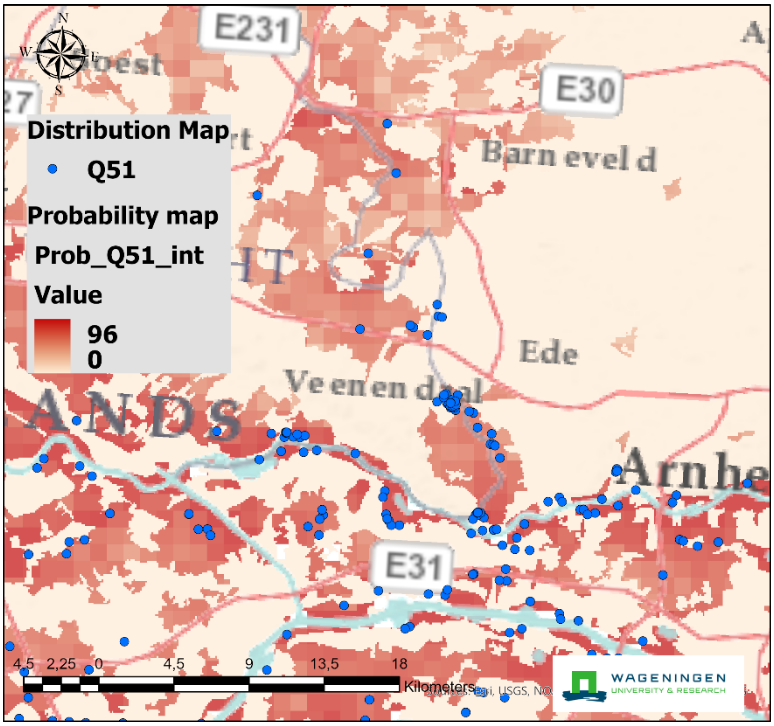
Arctic. Constant disturbance by moving water and freeze-thaw, aeration with turbulent flow and low productivity prevent peat accumulation. Consequently, this fen typically occurs as small unstable patches colonising bare ground. The vegetation consists of small basiphilous sedges, rushes and herbs, brown mosses and liverworts, and can include endemic species that are perhaps glacial relics such as Carex atrofusca, Carex microglochin and Juncus triglumis.



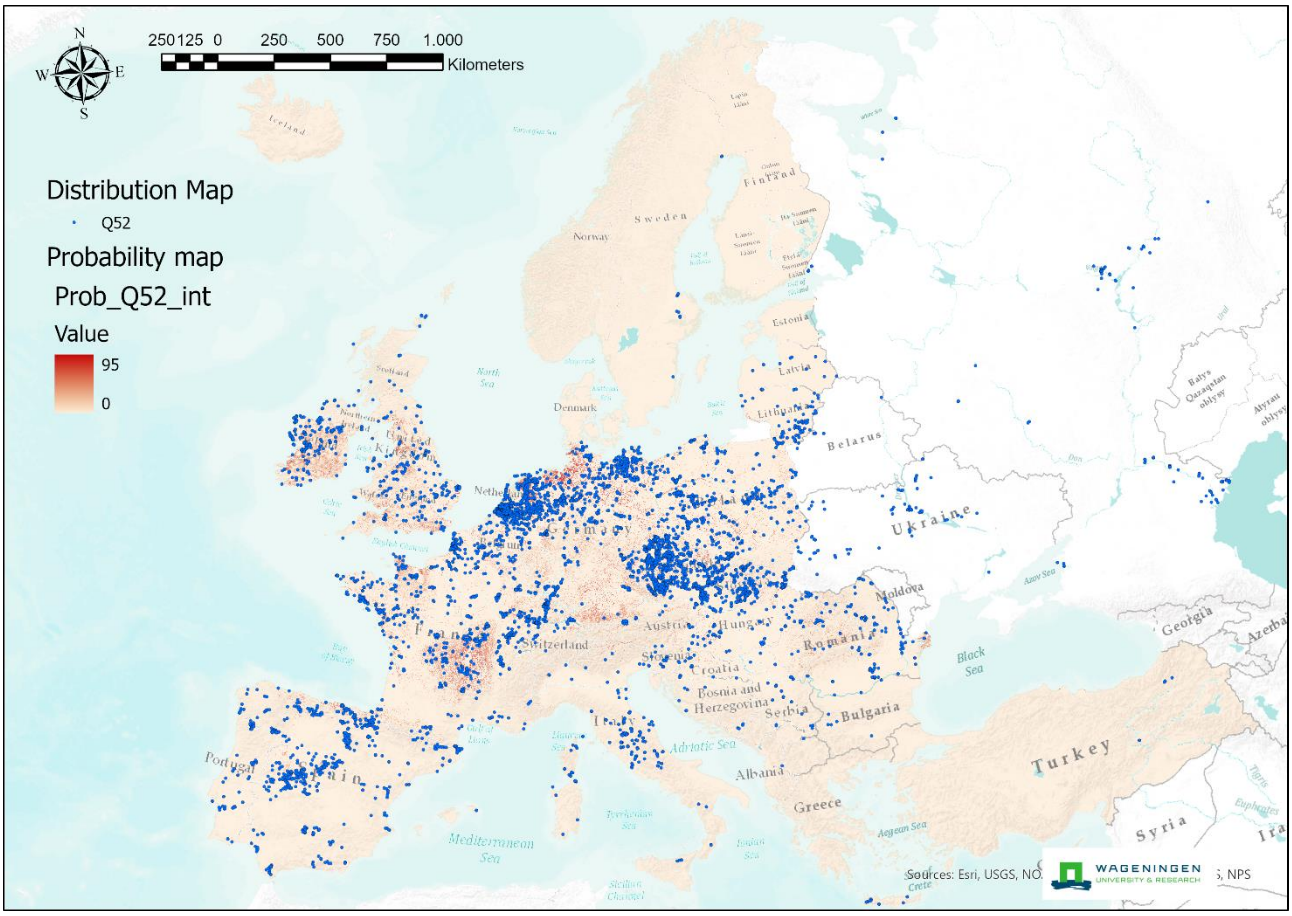


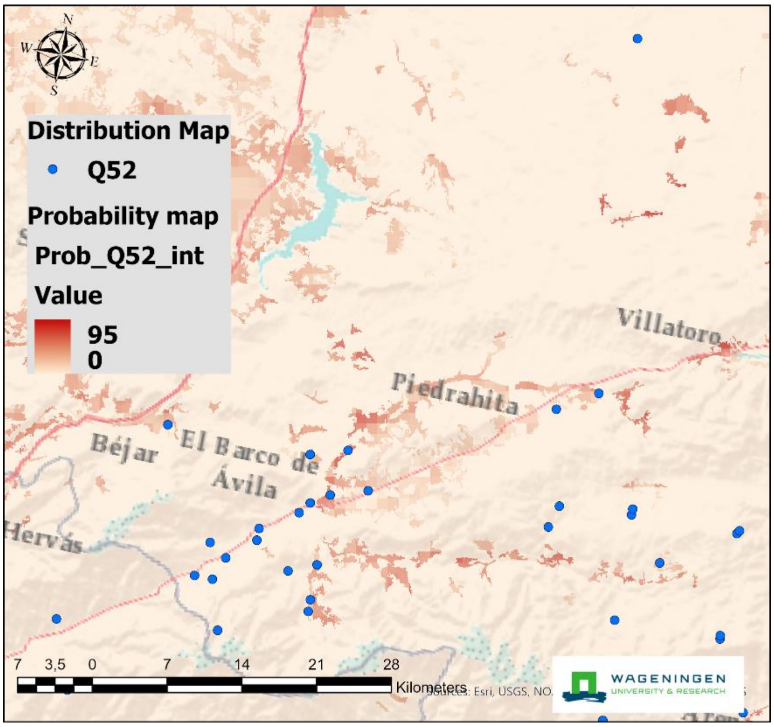
Q46 'Carpathian travertine fen with halophytes'. Short-sedge fens developed on active travertine springs fed by extremely mineral-rich groundwater coming from deep aquifers upwards along Tertiary faults. They have conserved ancient species composition that combines plant and animal (e.g. snails and ostracods) specialists dwelling in short-sedge calcareous fens of temperate Europe (Eleocharis quinqueflora, Parnassia palustris, Pinguicula vulgaris, Primula farinosa, Schoenus ferrugineus and Pupilla alpicola) with halophytic species (Centaurium littorale subsp. uliginosum, Glaux maritima, Plantago maritima subsp. salsa, Scorzonera parviflora and Triglochin maritima) and Trichophorum pumilum, a rare glacial relict of low-productive tundra, fen and salt marsh habitats. Many of these species have isolated relict populations in this habitat. Their species composition is similar to halophytic fens of the southern Siberian high-mountain regions which are climatically analogous to the European full glacial period. The habitat is endemic to the Inner Western Carpathian basins. Most of the localities were destroyed in the past.



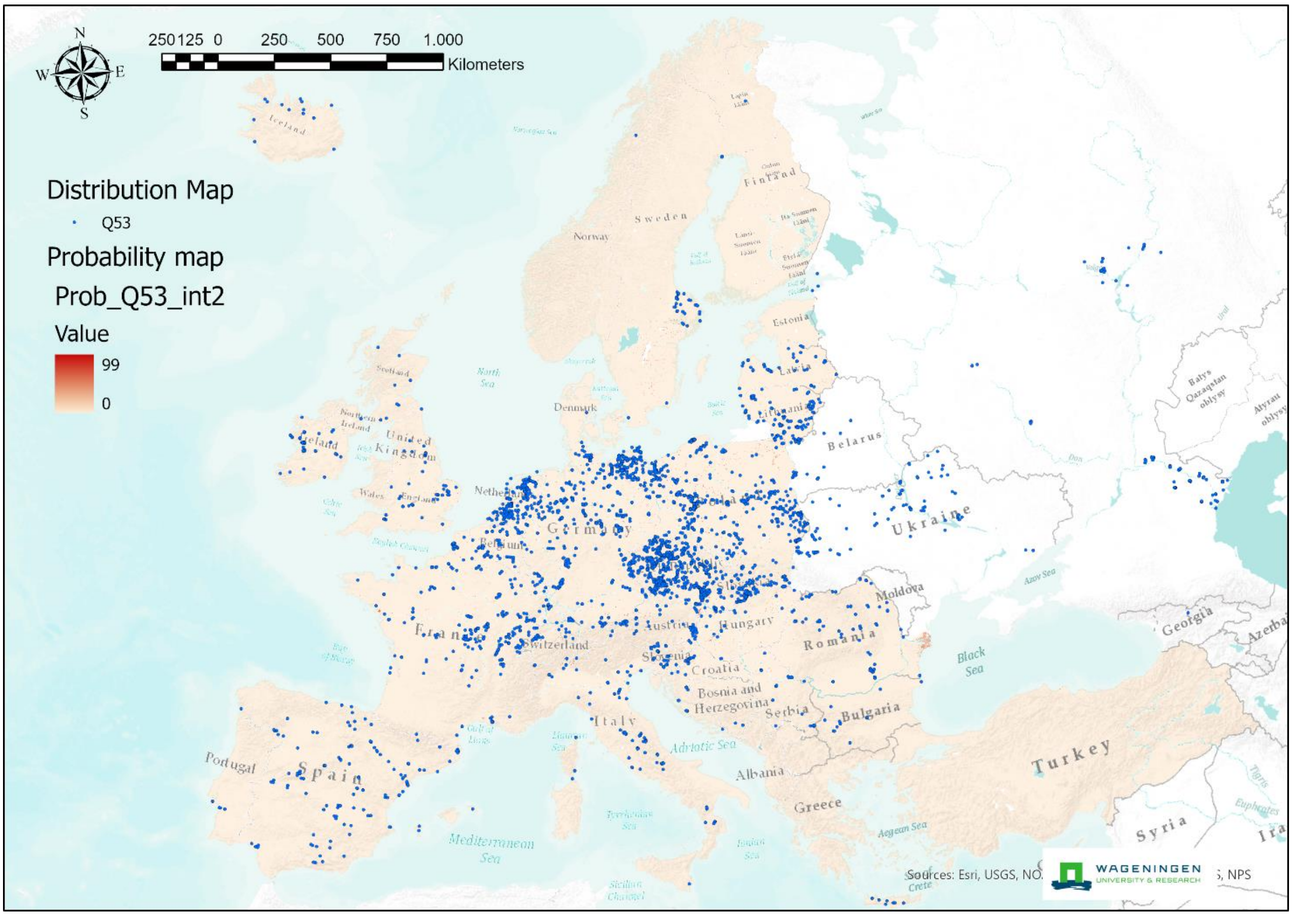


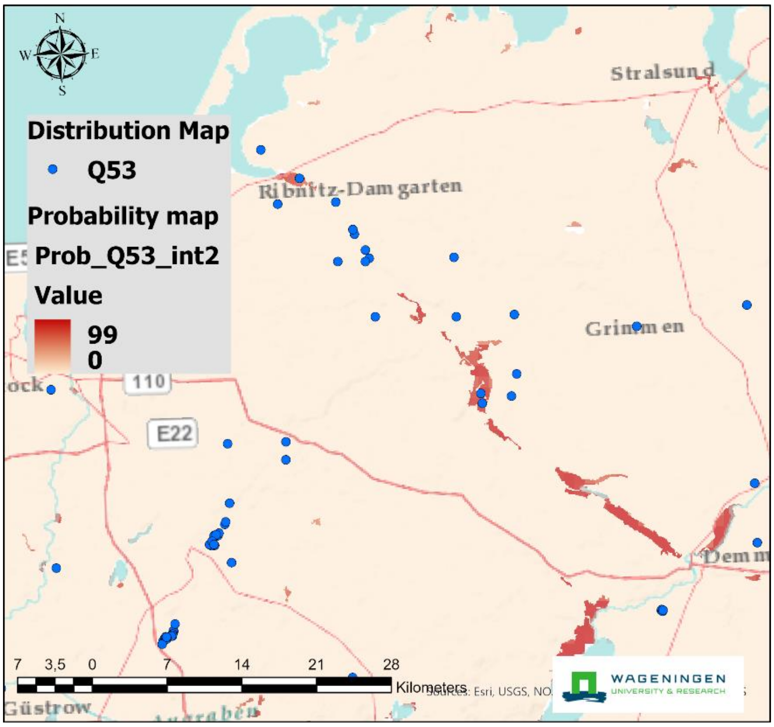
Q51 'Tall-helophyte bed' This habitat of tall helophytes characteristically occupies a zone from shallow to moderately deep mesotrophic to eutrophic fresh or slightly brackish water along the banks of rivers and lakes, in artificial water bodies and at nutrient-rich terrestrial sites on waterlogged ground. It is a very widespread, but naturally fragmented habitat, throughout the European lowlands. The occurrence of different dominant species depends on water depth, duration of flooding, substratum, trophic level, disturbance by waves or current, herbivory and human influence, some of the plants being cut for fodder or thatching. Because of the competitive ability and clonal growth of tall helophytes, the stands are usually species-poor and often dominated by one or a few co-dominants. The habitat is vulnerable to drainage and pollution, land reclamation for agricultural and urban development, and the decline of marshland exploitation for renewable crops.



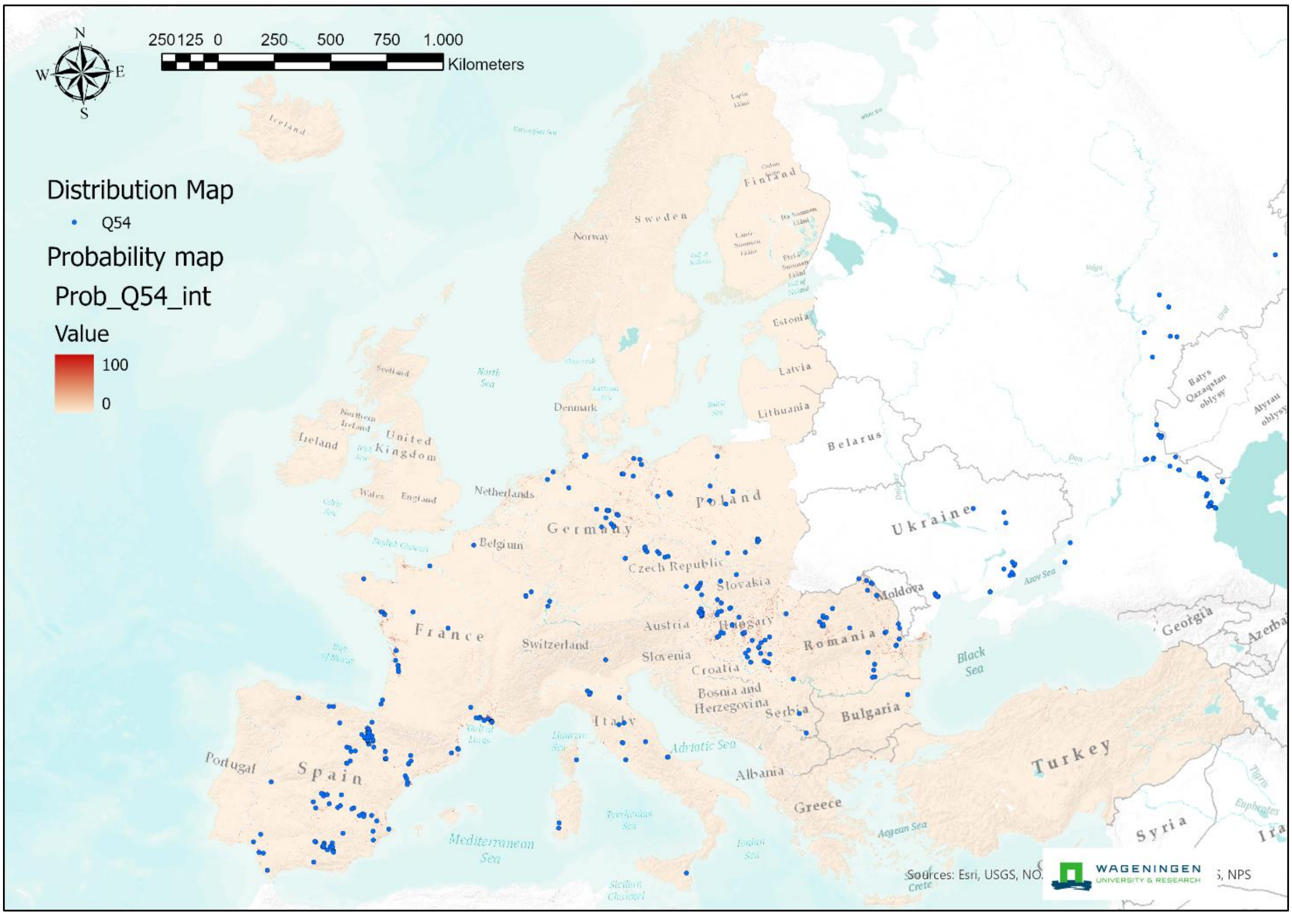


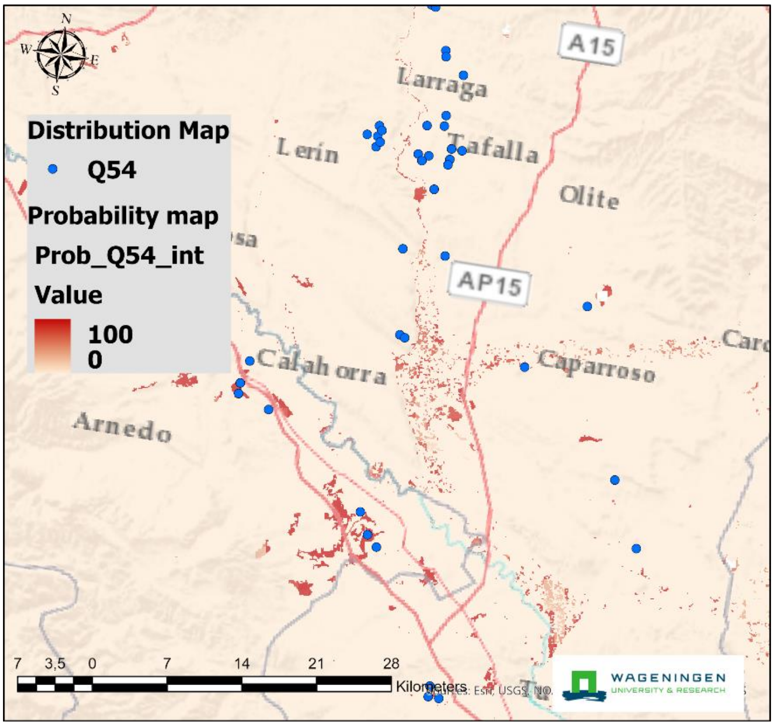
Q52 'Small-helophyte bed'. Small and amphibious helophyte-dominated freshwater vegetation is a widespread, very common but fragmented habitat throughout the European lowlands, occurring in the shallow littoral zones of lakes, ponds and rivers subject to periodic and repeated variation in water levels. It is characterised by amphibious plants and provides an important habitat for benthic invertebrates, fish, amphibians and several species of birds, by offering shelter and food. Like other wetland types, this habitat has suffered much from the intensification of agricultural land use, including drainage, modification of flooding and reclamation, and expansion of urban areas.





Q53 'Tall-sedge bed'. This habitat develops throughout the European lowlands, though less commonly to the warmer south, on the margins of standing and slow-moving fresh waters just above the mean water level, but subject to periodic flooding, and on year-round water-saturated soils. Tall-sedge communities are usually species-poor, often dominated by one productive plant, often of densely tussock habit, and accompanied by few characteristic species, often disposed in mosaics on and between the tussocks. The particular dominant depends on climate, substrate, hydrology and trophic level of the habitat and, now usually in the past, on management by grazing or cutting. The main threats are the expansion of agricultural, industrial and urban areas and changes in the level of groundwater and its pollution. Often the habitat is totally transformed without the possibility of natural recovery, and strong intervention is usually needed for recovery.





Q54 'Inland saline or brackish helophyte bed'. This habitat includes helophyte beds developing in and around inland saline or brackish lakes, ponds and other standing or slowly flowing waters such as saline Mediterranean rivers that are subject to summer drying. The habitat may include, depending on the particular hydrological regime, emergent communities dominated by a variety of tall or tussocky species tolerant of brackish or saline conditions. It is distributed in both the continental part of Europe and the arid Mediterranean region, where it can dry out completely in the summer and become hyper-saline. Threats include land reclamation for agricultural and urban expansion, anthropogenic changes in hydrology, and the input of freshwater to serve waterfowl hunting or ecotourism in dry areas. Safeguarding the distinctive hydrology and controlling the spread of helophytes by grazing are the main conservation actions.