Title: Mapping current and future European potential vegetation to support restoration planning

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Abstract:

The extent and intactness of natural ecosystems is a key factor enabling species populations to thrive. However, the distribution of ecosystems is changing owing to both climatic and anthropogenic factors. Recently negotiated European policy directives, such as the Nature Restoration Law, argue for the restoration of natural ecosystems. Yet to determine what is to be restored the range of possible outcomes should be first explored, also with regards to future climatic conditions. Here the concept of potential natural vegetation (PNV) is applied and mapped in a data-driven manner at European extent, exploring where PNV transitions are most likely to happen under contemporary and future conditions. Specifically, I predict the distribution of current and future potential coverage of six natural vegetation types at 1 km^2 grain using Bayesian machine learning approaches. I find that most current land cover and land use could develop to no single, but multiple PNV states, although options for some types, such as areas suitable for wetlands might become rarer under future climatic conditions. Furthermore, the challenge of transitioning to PNV was found to be particularly high for current intensively cultivated landscapes. Overall data-driven PNV mapping holds considerable promise for assessing land potentials and supporting restoration assessments. Future work should expand the thematic grain of vegetation maps and consider feedback with biotic factors.

Keywords: Potential natural vegetation, Climate change, Restoration, Habitat mapping

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Introduction:

Intact ecosystems are key for the preservation of species and provisioning of nature contributions to people (Betts et al., 2017). The occurrence of natural ecosystems is driven by its dominant vegetation, itself determined by complex interactions of biotic factors, climate, topography, soil and lithology (Jiménez-Alfaro et al., 2014; Jung et al., 2020; Keith et al., 2022; Sayre et al., 2020). Many natural ecosystems are under threat from current and future anthropogenic and climatic factors (Berdugo et al., 2020; Huntley et al., 2021), and restoring them seems to be the most promising way to bring nature on a path towards recovery (Keith et al., 2013; Leclère et al., 2020; Nicholson et al., 2021). The Kunming-Montreal Global Biodiversity Framework explicitly calls for the effective restoration of ecosystems (CBD, 2023), while the European Biodiversity Strategy for 2030 lists the establishment of trees and widespread restoration of ecosystems among its ambitions (European Commission, 2020). However, a key question that influences the success of ecosystem restoration is the probability by which natural vegetation can be established; especially as the range of options available, given current and future environmental constraints, remains often unclear.

The Potential Natural Vegetation (PNV) concept describes a hypothetical scenario of dominant natural vegetation in an area under the assumption that human influence would largely cease (Loidi et al., 2010). The concept of PNV is not a new one and its usefulness has been intensely debated since its conception (Tüxen, 1956). Common critiques are that successional pathways are highly uncertain given historical human legacies (Chiarucci et al., 2010; Loidi and Fernández-González, 2012). Furthermore, the creation - or in some cases re-establishment - of habitats does take time and success is far from guaranteed (Crouzeilles et al., 2016; Prach et al., 2016). Active human interventions, such as through habitat recreation, management practices, or supportive processes such as rewilding (Jepson et al., 2018; Perino et al., 2019; Svenning et al., 2024) are in many cases likely necessary to establish a given ecosystem. Despite these limitations, the PNV concept continues to be useful across scales by qualitatively or quantitatively putting land potentials into context and defining lower and upper boundaries (Figure 1).

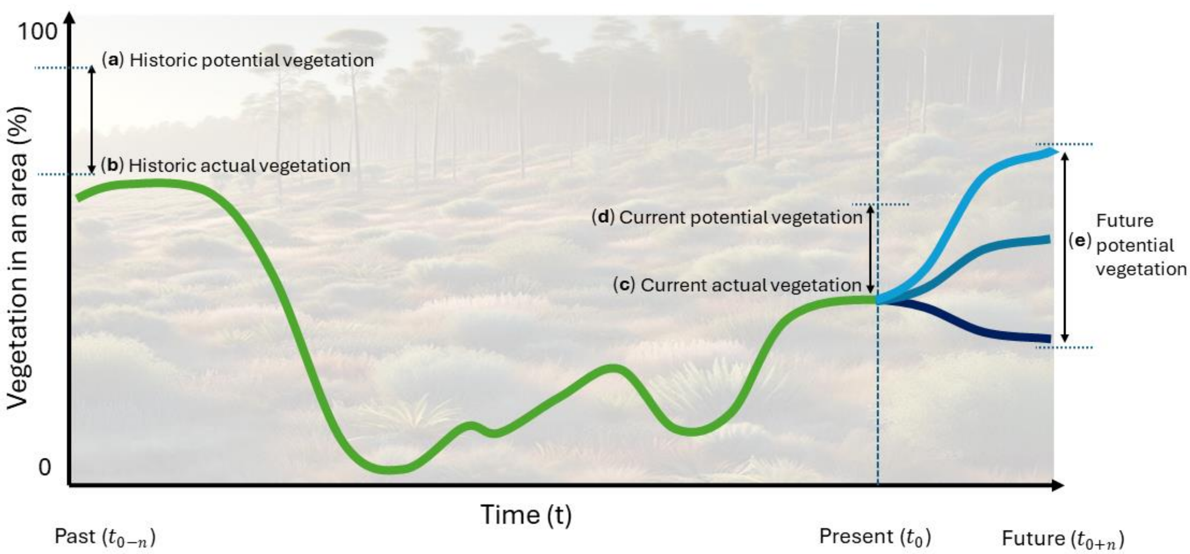

Figure 1: Idealized trajectory of actual and potential natural vegetation from past to future states. Highlighted are historic potential (a) and actual (b) vegetation levels and their corresponding states (c, d) in the present. Depending on the future trajectory different future potential vegetation levels (e) might be possible. Transparent background image generated by DALL-E 3.

PNV has been estimated in different ways across scales and temporal baselines (Hengl et al., 2018). At local scales, ecological fieldwork and experimental studies use PNV concepts to highlight the plausibility of local vegetation successions, taking historical legacies and local contexts into account (Johnson and Miyanishi, 2008; Walker et al., 2010). Other work have used soil cores and archaeological approaches to infer a historic PNV state based on what has been lost (Courtney Mustaphi et al., 2021; Finsinger et al., 2021). Bohn and Gollup used botanical knowledge and phyto-socioecological techniques to make an expert-based assessment of European PNV (Bohn and Gollub, 2006). Although these European maps remain unrivalled in terms of thematic detail, their spatial resolution can be coarse, and they do not account for anticipated changes in future climatic conditions.

As an alternative to expert-based assessments, data-driven tools such as machine learning or simulation models can provide an alternative way to estimate PNV under current and future conditions, often considering both climate and anthropogenic effects. Previous work have mapped the potential distribution of biomes (Bonannella et al., 2023; Hengl et al., 2018), species habitats (Jung, 2020), plant functional traits (Boonman et al., 2020; Joshi et al., 2022), actual and potential photosynthetic activity (Hackländer et al., 2024) or the potential distribution of land cover and vegetation types (Bastin et al., 2019; Hengl et al., 2020; Jiménez-Alfaro et al., 2014). The impact of anticipated future climate change on PNV can also be simulated or projected, which can be particular useful for assessing land potentials (Bonannella et al., 2023; Hickler et al., 2012; Huntley et al., 2021; Zabel et al., 2014). For Europe however, no PNV estimates exist for different functional vegetation types at a resolution useful for regional planning.

Maps of current PNV have been used for spatial planning studies (Kowarik, 2016), offering alternative points of departures that, instead of looking backwards to restore a (pre-)historic state of vegetation (Keane et al., 2009), can be forward looking also taking into account broad-scale changes such as climate change. Most importantly PNV estimates can be useful to delineate the upper restoration potential for biodiversity and climate mitigation (Chapman et al., 2023; Hackländer et al., 2024; Roebroek et al., 2023; Strassburg et al., 2020). For example, previous studies have used potential current vegetation estimates to quantify benefits of restoring land to biodiversity while maximizing carbon sequestration benefits (Chapman et al., 2023; Strassburg et al., 2020), while Roebroek et al., 2023 estimated that existing forests could increase their carbon contributions by up to 16% if released from anthropogenic management. Although such scenarios are likely implausible, they can help to draw some first boundaries for narrowing the potential benefits of such actions.

In this work a quantitative broad-scale assessment of the current and future potential natural vegetation (PNV) is made for the European continent, specifically the EU27 countries plus Switzerland, the United Kingdom and the western Balkan countries. Integrating considerable amounts of natural vegetation and habitat observations from different vegetation and land-cover datasets Bayesian machine learning frameworks are used to predict current and future PNV under different climate scenarios. Furthermore, using contemporary land-use data, opportunities, but also potential challenges for different restoration pathways are investigated through a comparison with existing European vegetation. Posterior predictions are made openly available to support future efforts in identifying potential pathways towards restoring natural vegetation in Europe.

Methods:

The aim of this work is to create a series of vegetation-type specific PNV predictions for the European continent, quantify its contemporary and future extent and evaluate options for different landscapes. Thematically I rely on the natural vegetation types described by the MAES ecosystem classification scheme, the most commonly applied legend for ecosystem accounting by European member states (Maes et al., 2014). For natural vegetation at level 1 it distinguishes between Grassland, Forest and woodland, Heathland and shrub, sparsely vegetated land, Inland wetlands and marine inlets and transitional waters (Rivers and lakes are ignored for this exercise). Given the unpredictability of future PNV trends each vegetation type was modelled separately opposed to estimating the exclusive (e.g. either or) probability of PNV (but see predictive modelling).

Input training data and covariates

The aim of the predictive modelling is to characterize current as well as potential future PNV for a set of natural vegetation types according to MAES. To parametrize the models a range of different data sources on the distribution of MAES vegetation types was acquired, focussing primarily on contemporary vegetation cover that can be related to climatic, soil and topographic covariates. The vegetation data originated not from a single, but multiple openly available data sources. Specifically, data originated from the repeated Land Use/Cover Area survey (J. R. C. European Commission, 2020), European Article 17 reporting data (EEA, 2020), EUNIS habitat distribution plots (Hennekens, 2019), Natura 2000 reporting data (EEA, 2023) as well as vegetation occurrence information from the Global Biodiversity Information Facility (GBIF.Org User, 2024). For GBIF all vegetation occurrences were spatially aggregated to a centre of a 1km^2 grid cell. The grid cells in which – based on a European expert-based crosswalk (Chytrý et al., 2020), more than 5 typically descriptive species for a MAES habitat type have been observed, were then further used as indicative vegetation type by extracting the centroid of the grid cell. All vegetation cover data was thematically harmonized to the MAES legend, geographically aggregated to a 1km^2 grid and reprojected to a Lamberts-equal area grid (Appendix S1).

The selection of covariates is a critical choice for any PNV modelling, and generally speaking any covariates directly linked to land cover, land use or actual photosynthetic activity are to be avoided (Hackländer et al., 2024; Hengl et al., 2018). Predictions were informed by previous PNV estimates (Bohn and Gollub, 2006; Hengl et al., 2020) and a set of both static and dynamic covariates. Static variables include altitude and derivates such as slope, aspect, roughness, northness and eastness, and the topographic position index (TPI) as a characterization of the relief, all of which were calculated in R and based on the Copernicus EU DEM (European Space Agency and Airbus, 2022). Estimates of European Lithology were taken from predicted Pan-European lithology estimates and harmonized to the same grid as other variables (Isik et al., 2024). For predicting wetland PNV data on topographic wetness was included to consider areas that are likely regularly flooded or could potentially be wetlands (Tootchi et al., 2019). For predicting potential marine inlets and transitional waters the distance of each grid cell to the coast was calculated (in meters). With regards to dynamic variables current and future downscaled climatologies were obtained from CHELSA (Karger et al., 2017). For the future, data on three Shared Socioeconomic Pathways (SSPs) relying on SSP1-2.6, SSP3-7.0 and SSP5-8.5 respectively. All projections were calculated for the period 2020 to 2100 and the GFDL-ESM4 General Circulation Model. All covariates were aggregated (arithmetic mean for continuous, mode for categorical) to a common 1km^2 grain size, reprojected to a Lamberts Equal-Area projection and for the predictive modelling rescaled (subtraction of mean and division by standard deviation) to facilitate model convergence and extrapolation.

Predictive modelling

For the modelling I used the *ibis.iSDM* R-package (Jung, 2023), which consists of an integrated modelling environment customized to different datasets as well as spatial and temporal projections. Two different Bayesian modelling approaches were used to identify the relative probability of any given ecosystem in space and time, both of which have the capability of estimating a full posterior distribution for current and future suitability, and thus estimates of several statistical moments including a true quantification of lower and upper relative probabilities. First, a linear Bayesian regularized regression model was applied using Spike-and-Slab priors which are particular useful in the regularization of high-dimensional regression problems (Friedman et al., 2010; Scott, 2023). Linear models can be useful for projections beyond observed unit scales as they make fewer assumptions about extrapolation (Norberg et al., 2019). Second, a Bayesian additive regression tree (BART) model was parametrized, which has the advantage that it can represent complex non-linear relationships, and through leaf pruning and regularization is assumed to be more robust to overfitting that other non-linear approaches (Carlson, 2020; Dorie, 2022; Jung, 2023). Both models were parametrized using contemporary vegetation cover and covariates, with different models being trained for each vegetation type (see above) and then projected to future conditions. From each fitted and projected model, the arithmetic mean, median and lower (25%) and upper percentile (75%) was extracted as well as the coefficient of variation and standard deviation of the whole posterior. For final predictions all statistical moments were averaged depending on their cross-validated predictive performance (see below).

To assess the predictive performance of the model a spatial block cross-validation scheme was applied using the ‘spatialsample’ R-Package (Mahoney et al., 2023). For each vegetation type the available vegetation data was split into three randomly selected spatial blocks and two repeats, thus allowing for a training and testing subset. A threshold and validation were calculated on the arithmetic mean by maximizing the F1 score as a measure of predictive performance (SI Table 1). The F1 score was chosen to reduce the effect of class imbalances, although comparisons are made only for each vegetation type and spatial blocks were split to equal ratios, thus ensuring comparable sample sizes. For all further analysis a weighted ensemble of both models calculated from the average F1 score across spatial folds was used.

Posthoc correction and overlays

Although the point of PNV is not to estimate the distribution of potential managed or actual vegetation types (Hengl et al., 2018), an argument can be made that certain transitions from current actual to current or future PNV are highly unlikely and should not be further considered in any ecosystem accounting practices. A typical example includes transitions from highly urbanized anthropic areas to PNV (e.g. forest or wetlands), which is unlikely to happen beyond marginal extents. Similarly, any open-water bodies (larger rivers, lakes) are unlikely to transition to natural vegetation with exception of very marginal changes to wetlands or marine inland vegetation. For this purpose a mask was created from the latest 2018 Corine layer (European Environment Agency, 2019) containing continuous and discontinuous urban land cover as well open water grid cells at 100 m grain size. The resulting mask was fractionally aggregated (% covered) to a 1 km grain and all grid cells containing more than 50% of urban or open water were excluded from all PNV maps.

To estimate a possible restoration challenge and most likely transition from actual to current PNV, several overlays were performed. Here it is assumed that a) areas with greater current land-use intensity as mapped by existing land systems maps provide a greater challenge (Dou et al., 2021), b) distance to nearby natural land cover facilitates the transition and c) transitions from structurally similar types are less of a challenge (e.g. pasture to natural grassland transition, see SI Table 2 for a simplified crosswalk). Notably, this assessment can only serve as illustrative first perspective as active management interventions are not explicitly considered. For each class and grid cell in the land systems map a Challenge score *C* of the transition challenge is then estimated as the minimum across all PNV types as follows: $C_{iv} = \min\left(\frac{s_v}{p(v)_i}\right)$, where *i* is a grid cell, *v* is one of the PNV types, *s* is the cost of transition (SI Table 2) and $p(v)$ is the estimated probability of encountering PNV of a given class *v*. Thus, the lower the probability of encountering PNV and the higher the score s, the more challenging the transition from current to potential natural vegetation. The resulting challenge score (higher is more challenging) was then visualized as quantiles together the with class *v* for which C is the smallest (Figure 3).

Results:

Most land area in Europe can potentially develop into multiple trajectories under contemporary climate conditions (Figure 2). With exception of Marine inlets and transitional waters, which were largely constrained to coastal areas and thus small in potential area extent (median q_{50} = 0.44 million km^2), all vegetation types could potentially occur in less than half of all European land area (q_{50} = 1.82 million km^2 for Heathland and shrubs up to q_{50} = 2.1 million km^2 for Woodland and Forests), although with broad geographic differences (Figure 2). While contemporary potential sparsely vegetated areas and Heathlands and shrubs were mainly concentrated in the mediterranean geographic regions, particular wetland vegetation types could potentially occur mostly in northern Europe including Scandinavia (SI Figure 2). The predictive performance of the various models varied (SI Table 1), with Marine Inlets being most consistently predicted (Average F1

= 0.89), while all other vegetation types had a lower predictive performance ranging between a F1 score of 0.7 and 0.67 (SI Table 1). This indicates that for most vegetation types there is considerable uncertainty in the posterior predictions (see also SI Figure 3).

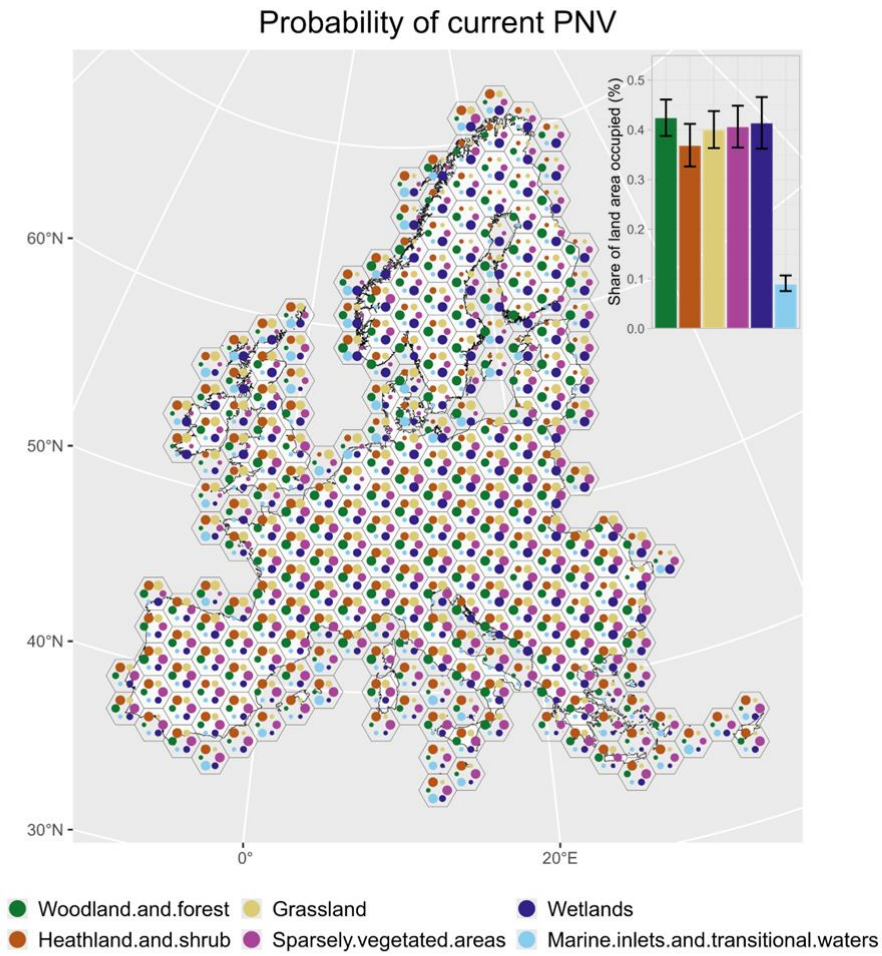

Figure 2: Probability of current PNV for six different vegetation types. Coloured points within hexagons show the average posterior probability of a vegetation class. The size of points within hexagons are rescaled relative to their probability. Inset bargraph show the total share of land relative to the total land area (grey) that could potentially be occupied by each PNV. Individual predictions can be found in SI Figure 2.

Despite the possibility of multiple plausible transitions to PNV (Figure 2), a hypothesis can be made about the most likely transition based on contemporary land use, assuming that it is more challenging for land under more intensive contemporary use to transition to PNV. Across Europe Woodland and Forests are most likely class to transition (40.5% of all land area, Figure 3a), followed by Grassland (27.8%) and sparsely vegetated areas (12.2%). The relative challenge of transition to contemporary PNV is – as perhaps expected – is particularly large in regions with high land-use intensity such as the Po-Valley, Italy (Figure 3b). Some of the lowest challenges of transitioning to PNV can be observed in the Scottish Highlands, UK, and the Pyrenees, Spain. It should be stressed that this assessment is only valid in the context of the mapped land-use intensity classes, the transition scores (SI Table 2) and mapped probabilities (SI Figure 1).

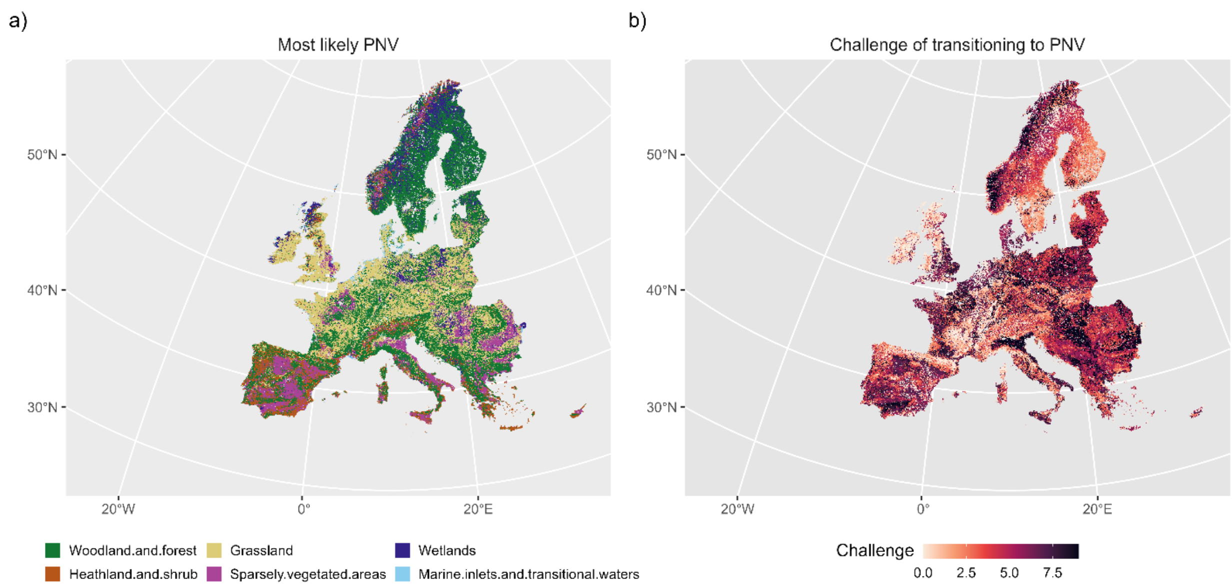

Figure 3: Most likely natural potential vegetation type when transitioning from current land-systems and the challenge (0-10 score) of transitioning to PNV. Based on the coverage of contemporary land systems (Dou et al., 2021) and broad scores of transitioning from transition from land systems to PNV (SI Table 2). Note that the visibility of individual grid cells can be overemphasized in the figure owing to spatial aggregation for the figure.

The extent of PNV can vary depending on the biophysical conditions and this is true especially in future climates. Compared to contemporary climatic conditions (dated up to the year 2010), under future climate scenarios model projections indicate substantial shifts in PNV (Figure 4). Most notably, the total amount of area suitable for forests, grasslands and to a lesser degree marine inlets is projected to increase, while the amount of potentially sparsely vegetated areas and wetlands is projected to decrease (Figure 4). Although there are few differences among future socio-economic pathways (Figure 4), geographically, several relevant trends can be observed in a future climate (SI Figure 4). For example, under future climates it appears as if forest cover in mountainous high-altitude regions such as the alps and southern Spain is more likely to occur. The relatively stable suitable area (± 9 million ha) in heath and shrublands (Figure 4) can be differentiated geographically by increases in western Europe as well as decreases in southern Europe (SI Figure 4). Overall, those results emphasize that PNV is indeed dynamic, and reference periods should be identified for any targeted applications.

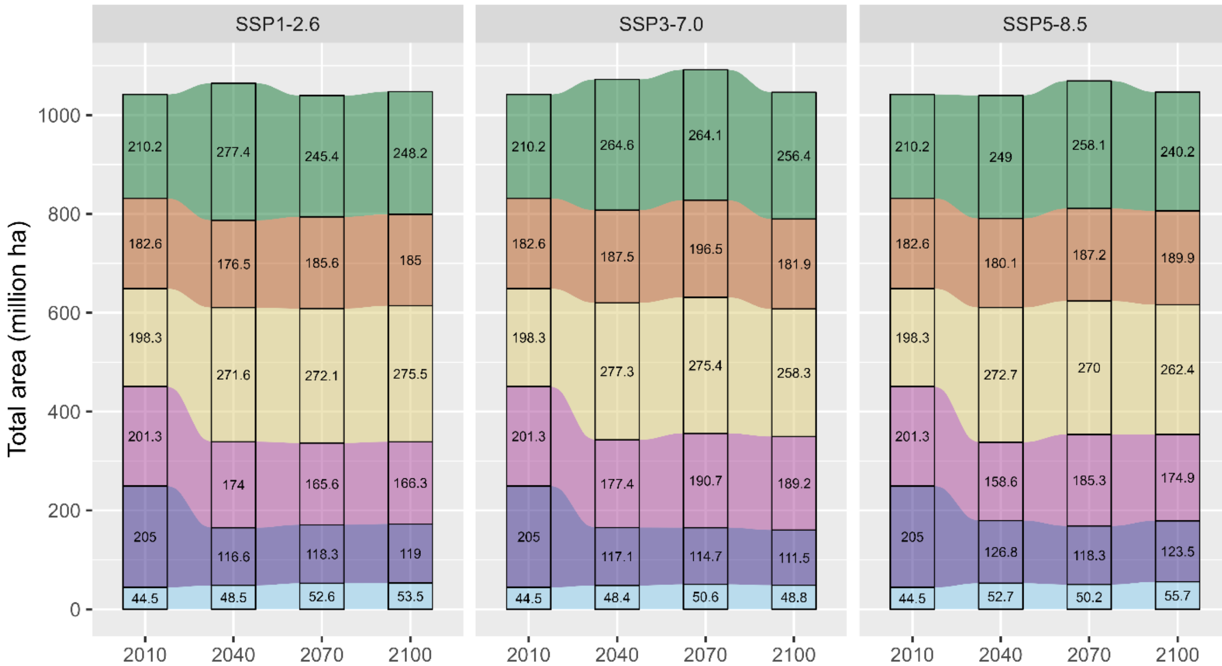

Figure 4: Total amount of predicted suitable area per PNV type, time period and future scenario. The year 2010 shows the total summed area (in million ha) for the current PNV, while facets indicate climate scenarios for 3 different socio-economic development pathways. Colours as in Figure 2 and 3.

Discussion:

How land develops in the future is not predetermined. In this work an attempt is made to provide a data-driven potential natural vegetation (PNV) estimate across Europe for contemporary and future conditions. The results show that most areas in Europe can naturally develop into multiple trajectories (Figure 2), although the most likely transitions are met with considerable challenges by existing land use (Figure 3). Furthermore, future climates affect the PNV in many areas with the establishment of forests and grasslands becoming regionally more likely and sparse vegetation and wetlands less likely (Figure 4). The purpose of this work is to provide a macroecological lens of the distribution of vegetation (Santini et al., 2021), so that possible landscape trajectories could be identified. Ultimately, the PNV layers created in this work could for example be used to constrain spatial prioritizations (Chapman et al., 2023), or inform integrated assessment and other land-use models in estimating nature-positive scenarios such as through the Nature-Futures Framework (Dou et al., 2023).

The goal of this work was not to map the historical potential distribution of vegetation, but the potential vegetation under contemporary and future climate conditions (Hengl et al., 2018). Although PNV maps can be useful for spatial planning exercises, they should not be taken as a normative outcome and how vegetation might develop ultimately depends on local actions and implementation (Loidi and Fernández-González, 2012). For this reason, I also report habitat class specific probabilities are reported (Figure 2, SI Figure 2), highlighting that many different future trajectories might be possible even for the same area. Yet, according to the most likely transition (Figure 3), and perhaps contrary to expectations from ecoregional maps (Olson et al., 2001), much of European land found to have high potential of transitioning to grassland and other non-forested habitats, especially when departing from current land systems. Notably, there is evidence that historic (not contemporary or future) European PNV prior to human modification might have been composed of more non-forest vegetation types than previously assumed (Pearce et al., 2023). It could be that at least some of the historic PNV signal is still contained within contemporary climatic and lithological conditions. Yet overall, the PNV maps presented are but one of many perspectives and should thus be interpreted with care.

The mapping of PNV through data-driven predictive algorithms is a rather novel approach and there is certainly room for further developments and methodological improvements. Machine learning based approaches can provide reproducible and high-resolution assessments of PNV (Bonannella et al., 2023; Hengl et al., 2018), but can suffer from data biases and assume that contemporary conditions can be extrapolated to novel climatic states. Dynamic vegetation models on the other hand can provide a more mechanistic understanding of future vegetation change (Hickler et al., 2012), however they usually are more limited in the types of vegetation and spatial resolution they can represent. A promising future approach could be the development of “hybrid” predictive modelling approaches, such as physics informed machine learning (Shen et al., 2023). Other future work could consider also microclimatic conditions which have been shown to be locally important (Conradi et al., 2024), or include specific biotic interactions such as trophic rewilding through large megafauna to facilitate the creation of natural vegetation (Svenning et al., 2024). Previous studies of natural reforestation in temperate forests have found that natural recolonization tends to occur within the fringe of existing forests up to 200 m and a 20 year period (Bauld et al., 2023), although biotic processes such as seed dispersal by flying animals could further aid this process. Another useful extension could be the expansion of the thematic legend, using for example the indicative descriptions of the IUCN Ecosystem RedList (Keith et al., 2022).

Data availability:

All created data has been made openly available on a data repository in cloud-optimized geoTIFF format for the most-likely transition and current PNV (10.5281/zenodo.13686776) as well as on the EBV data portal in a standardized netCDF format (Quoß et al., 2022) as Essential biodiversity variable (https://portal.geobon.org/). All data is made available under a CC-BY 4.0 License.

Code availability:

The analytical code has been made publicly available at (https://github.com/Martin-Jung/EUPNVMapping/).

Acknowledgement:

The author acknowledges funding from the European Union Biodiversity and Climate Strategies Assessment (EU BIOCLIMA, Service Contract 07.0202/2020/836131/SER/ENV.D.2) as well as the 'NaturaConnect' project. NaturaConnect receives funding under the European Union's Horizon Europe research and innovation programme under grant agreement number 101060429.

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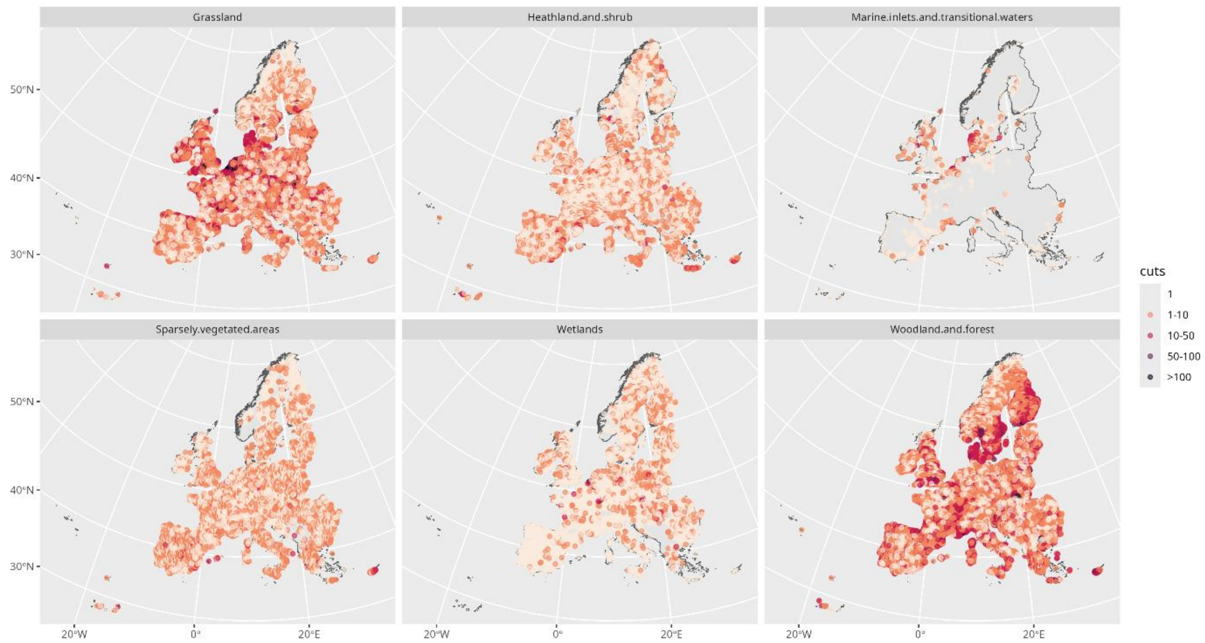
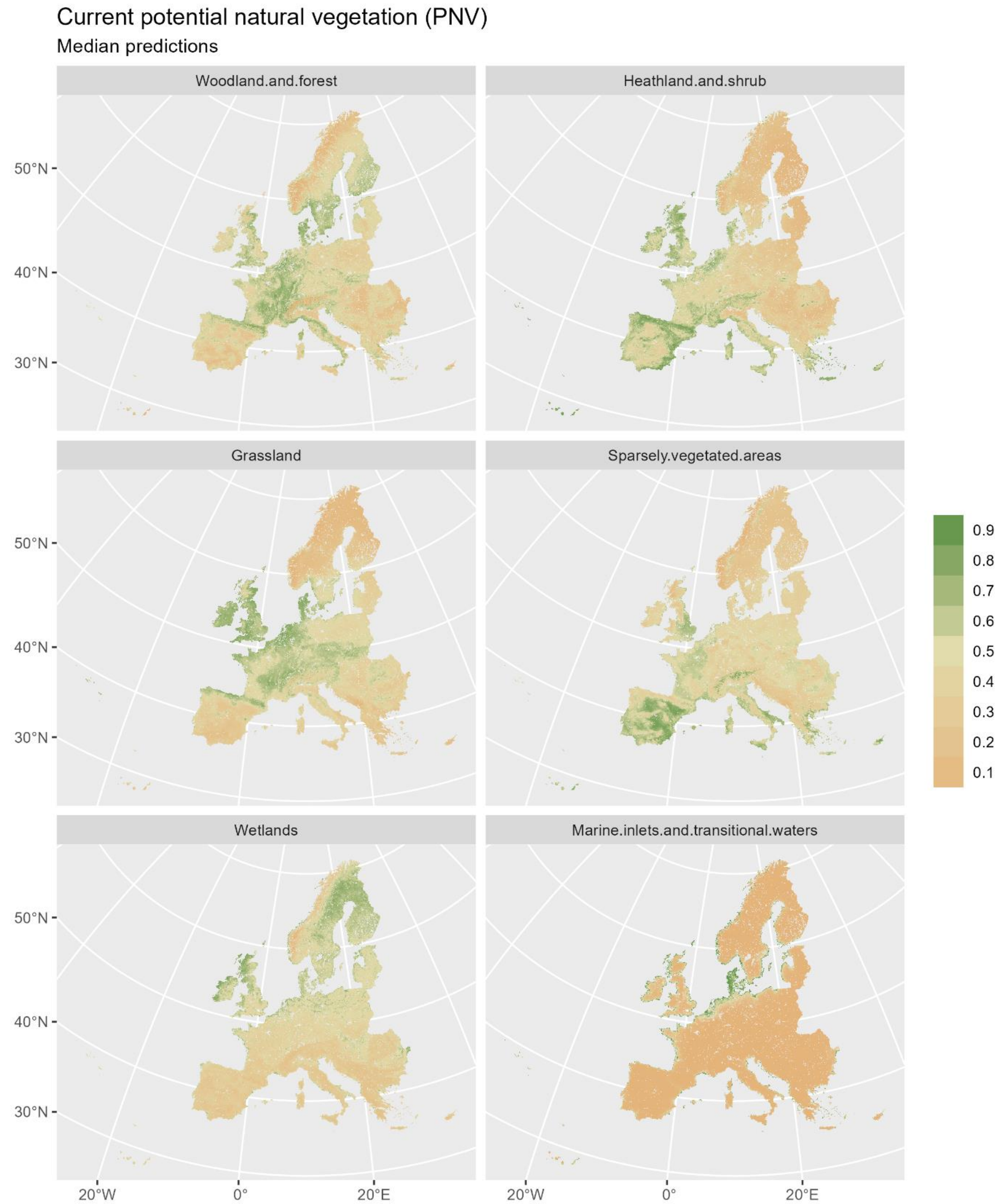
Supplementary Materials

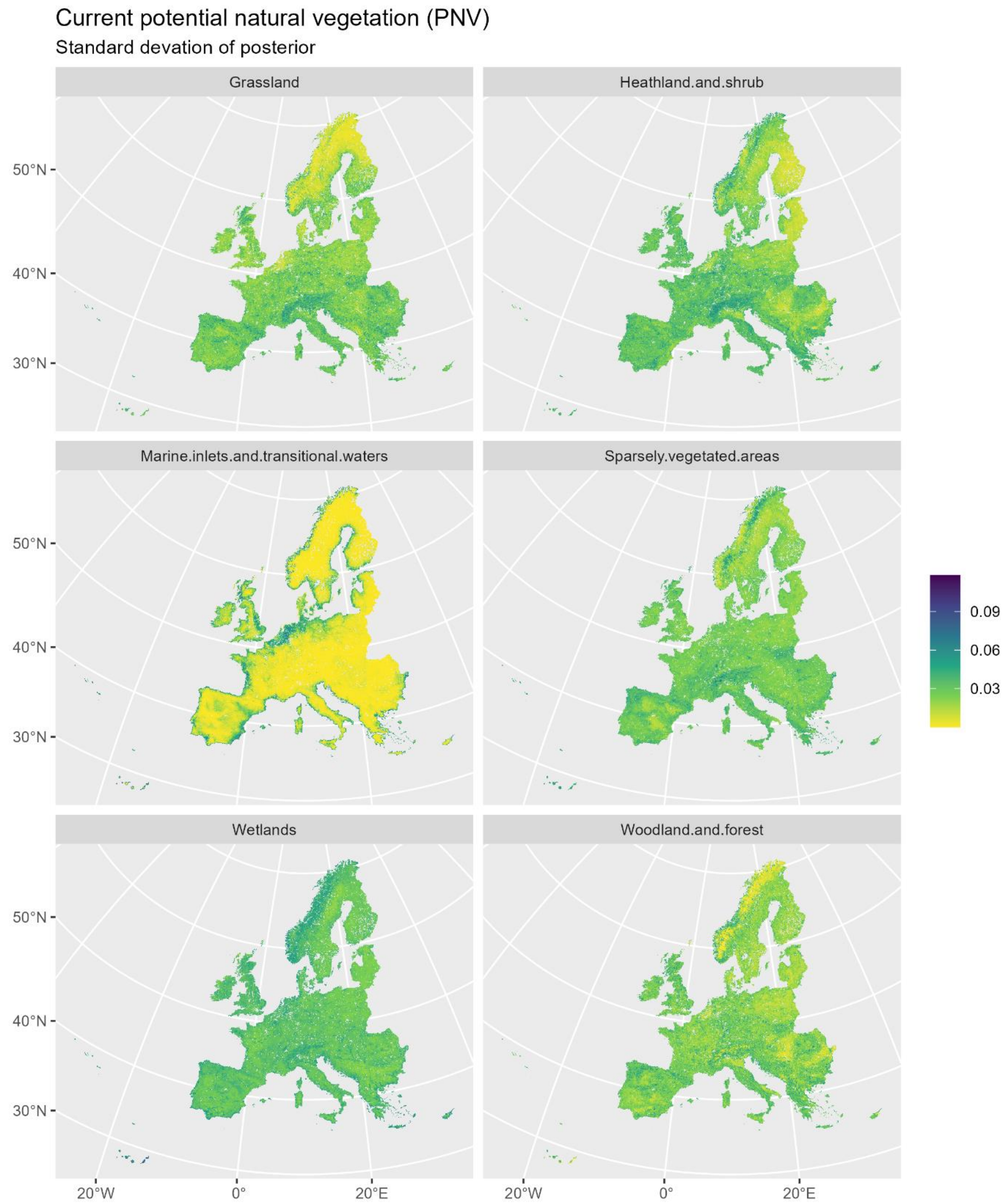
Mapping current and future European potential vegetation in support of restoration planning



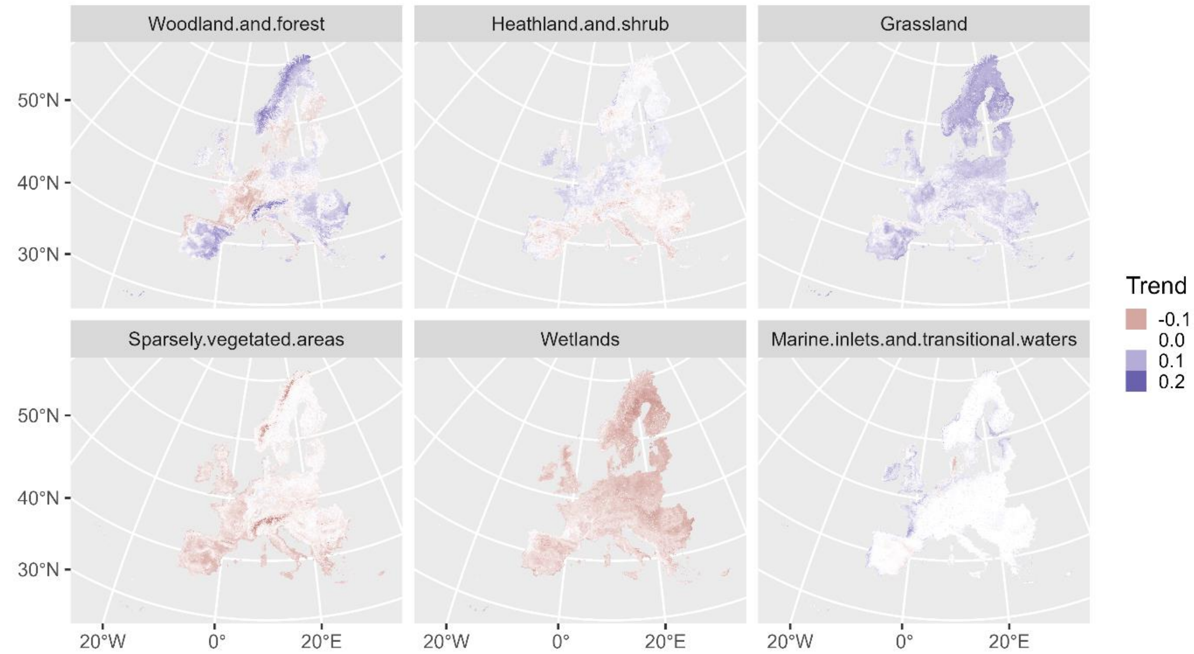
SI Figure 1: Vegetation cover training data used for delineation of European potential natural vegetation. Note that for visual display the background grid (grey landmass) has been aggregated to a 10 km² grain size. The colour of the points indicate the number of occurrences within each 10 km² grid cell. During inference not more than one training point for each covered 1 km² grid cell (the grain of prediction) was considered.



SI Figure 2: Posterior predictions (median) of current potential natural vegetation (PNV) for Europe from Bayesian Additive Regression Trees (BART). Predictions were made for each individual vegetation class.



SI Figure 3: Predictive uncertainty, quantified as standard deviation (SD) from the ensemble posterior. Darker colours indicate areas with greater predictive uncertainty.



SI Figure 4: Shows the relative trend in probability of occurrence from 2010 to 2100. Estimated from an ordinary linear regression at the grid cell level with the slope visualized as negative (red) or positive (blue) trends.

SI Table 1: Table with estimated prediction performance of the models. Performance was evaluated using a spatial block cross-validation design with three blocks and two repeat each. Shown are the average and standard deviation of F1 score and True Skill Statistic (TSS) for each predicted vegetation class.

Metric	Average	Standard deviation
Woodland.and.forest		
f1	0.69	0.04
Heathland.and.shrub		
f1	0.70	0.04
Grassland		
f1	0.68	0.03
Sparsely.vegetated.areas		
f1	0.68	0.04
Wetlands		
f1	0.67	0.04
Marine.inlets.and.transitional.waters		
f1	0.89	0.04

SI Table 2: Expert-based assessment with regards to the challenge of transitioning from current land use and use intensity to a potential natural vegetation state. Scores for each PNV class were specified on a scale from relatively less challenging (1) to very challenging (3). Scores were used to assemble the most likely transition (Figure 3).

code	dou_1	dou_2	dou_description	pnv_forest	pnv_heath	pnv_grass	pnv_sparse	pnv_wetland	pnv_marine
21	1. Settlement systems	1.1 Low-intensity settlement	Low-medium density, far away from urban cores	2	2	2	2	3	3
22		1.2 Medium-intensity settlement	Medium density or adjacent to urban core	3	3	3	3	3	3
23		1.3 High-intensity settlement	High imperviousness	3	3	3	3	3	3
41	2. Forest systems	2.1 Low-intensity forest	High probability as primary forest and low/medium wood production	1	2	3	3	3	3
42		2.2 Medium-intensity forest	Low probability as primary forest and medium wood production	1	3	3	3	3	3
43		2.3 High-intensity forest	Low probability as primary forest and high wood production	1	3	3	3	3	3
61	3. Cropland systems	3.1 Low-intensity arable land	Low inorganic fertilizer input, small field size	2	1	1	1	3	3

62		3.2 Medium-intensity arable land	Medium inorganic fertilizer input, medium field size	3	3	2	3	3	3
63		3.3 High-intensity arable land	High inorganic fertilizer input, large field size	3	3	3	3	3	3
31		3.4 Low-intensity permanent crops	Vineyards, olive graves, fruit gardens, with understory vegetation, this class also has mixed annual and permanent crops	2	2	3	3	3	3
32		3.5 High-intensity permanent crops	Vineyards, olive graves, fruit gardens, without understory	3	3	3	3	3	3
51	4. Grassland systems	4.1 Low-intensity grassland	Low density of livestock, low inorganic fertilizer input, and low mowing frequency	3	2	1	2	2	3

52		4.2 Medium-intensity grassland	Medium density of livestock, medium use of inorganic fertilizer, and medium mowing frequency	3	3	1	2	3	3
53		4.3 High-intensity grassland	High density of livestock, high inorganic fertilizer input, and/or high mowing frequency	3	3	1	2	3	3
80	5. Shrub		Areas dominated by shrub land cover or similar	1	1	3	2	3	3
90	6. Rocks and bare soil		Areas dominated by rocks, bare soil, or similar	3	3	2	1	3	3
71	7. Mosaic systems	7.1 Forest/shrub and cropland mosaics	Areas with small parcels of forest/shrubs and cropland	1	1	1	2	2	2
72		7.2 Forest/shrub and grassland mosaic	Areas with small parcels of forest/shrubs and grassland	1	1	1	2	2	2

74		7.3 Forest/shrubs and bare mosaics	Areas with small parcels of forest/shrubs and bare land	1	1	1	2	2	2
75		7.4 Forest/shrubs and mixed agriculture mosaics	Areas with small parcels of forest/shrubs and mixed areas of cropland and grassland	1	1	1	2	2	2
731		7.5.1 Low-intensity agricultural mosaic (cropland and grassland)	Low density of inorganic fertilizer input, small field size, and low livestock density	3	2	2	2	3	3
732		7.5.2 Medium-intensity agricultural mosaic (cropland and grassland)	Medium use of inorganic fertilizer, medium field size, and medium livestock density	3	3	2	3	3	3
733		7.5.3 High-intensity agricultural mosaic (cropland and grassland)	High inorganic fertilizer input, large field size, and/or large livestock density	3	3	2	3	3	3
13	8. Snow, water,	8.1 Glaciers	Areas dominated by	3	3	3	1	3	3

11	wetland systems	8.2 Water body	glaciers, wetland, or water body	3	3	3	3	1	1
12		8.3 Wetland		3	3	1	2	1	1