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VEGETATION SURVEY

Distribution maps of vegetation alliances in Europe

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Abstract

Aim: The first comprehensive checklist of European phytosociological alliances, orders and classes (EuroVegChecklist) was published by Mucina et al. (2016, *Applied Vegetation Science*, 19 (Suppl. 1), 3–264). However, this checklist did not contain detailed information on the distribution of individual vegetation types. Here we provide the first maps of all alliances in Europe.

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Location: Europe, Greenland, Canary Islands, Madeira, Azores, Cyprus and the Caucasus countries.

Methods: We collected data on the occurrence of phytosociological alliances in European countries and regions from literature and vegetation-plot databases. We interpreted and complemented these data using the expert knowledge of an international team of vegetation scientists and matched all the previously reported alliance names and concepts with those of the EuroVegChecklist. We then mapped the occurrence of the EuroVegChecklist alliances in 82 territorial units corresponding to countries, large islands, archipelagos and peninsulas. We subdivided the mainland parts of large or biogeographically heterogeneous countries based on the European biogeographical regions. Specialized alliances of coastal habitats were mapped only for the coastal section of each territorial unit.

Results: Distribution maps were prepared for 1,105 alliances of vascular-plant dominated vegetation reported in the EuroVegChecklist. For each territorial unit, three levels of occurrence probability were plotted on the maps: (a) verified occurrence; (b) uncertain occurrence; and (c) absence. The maps of individual alliances were complemented by summary maps of the number of alliances and the alliance–area relationship. Distribution data are also provided in a spreadsheet.

Conclusions: The new map series represents the first attempt to characterize the distribution of all vegetation types at the alliance level across Europe. There are still many knowledge gaps, partly due to a lack of data for some regions and partly due to uncertainties in the definition of some alliances. The maps presented here provide a basis for future research aimed at filling these gaps.

KEYWORDS
alliance, distribution, Europe, EuroVegChecklist, map, phytosociology, syntaxon, vegetation survey, vegetation type

1 | INTRODUCTION

Information on the distribution of vegetation types and related habitat types is critical for effective habitat conservation (Janssen et al., 2016; Rodwell et al., 2018). It is also essential for basic ecological and biogeographical research. Surprisingly, such information is sparse and incomplete, even for Europe, where vegetation surveys have a longer and stronger tradition than on other continents.

Vegetation maps that use a consistent approach and legend across the continent are few, and each has some limitations. The most detailed pan-European vegetation map that uses phytosociological units is the Map of the Natural Vegetation of Europe (Bohn et al., 2000–2003). It maps the dominant units of natural vegetation that could prevail in the absence of human land use, but it excludes most types of azonal vegetation that occur in small stands, such as wetlands or rock and scree vegetation. It also excludes vegetation types developed under human influence, although such types are prevalent in today's European landscape and many of them are of high conservation value (Veen et al., 2009). Many vegetation types shown in the Map of the Natural Vegetation of Europe can be considered vegetation complexes rather than single syntaxa. Moreover, this map shows for each site only one vegetation type or vegetation complex that is predominant there, whereas other types are not shown. Consequently, the distribution ranges of almost all vegetation types shown in this map are smaller than their actual distribution ranges.

In the past two decades, habitat mapping projects in several European countries have produced many relevant maps that serve as a basic source of information for nature conservation. However, each national project uses a specific system and methodology to classify and map habitats (Ichter et al., 2014). The European Red List of Habitats (Janssen et al., 2016) provided factsheets with tentative distribution maps compiled from various sources, combining accurate data for some areas with expert estimates for others. These maps were produced only for habitats of conservation concern and did not consider the eastern part of the continent, including Russia, Belarus, Ukraine, Moldova, Turkey-in-Europe and the Caucasus countries. The MAES project (Mapping Europe's Ecosystems) of the European

Environment Agency (EEA, 2018) focused on the same area, excluding much of Eastern Europe. It used land-cover data interpretation based on remote sensing to map 47 terrestrial, freshwater and marine habitats corresponding to hierarchical Level 2 of the European Nature Information System (EUNIS) habitat classification. Chytrý et al. (2020) applied a classification expert system to more than 1.2 million vegetation-plot records from the European Vegetation Archive (Chytrý et al., 2016) to produce point occurrence maps for 199 habitat types at Level 3 of the EUNIS habitat classification (extended to 234 habitat types in 2021; http://doi.org/10.5281/zenodo.4812736). These maps were produced for the whole of Europe but were affected by the scarcity of vegetation-plot data in some areas, particularly in Northern and Eastern Europe.

A recent list of European vegetation types (EuroVegChecklist; Mucina et al., 2016) classified European vegetation dominated by vascular plants into 1,105 alliances. It included all previously recognized types of European vegetation, from natural to those that have developed spontaneously in anthropogenic habitats. It covered the entire European continent and islands, including some adjacent areas with political links to Europe such as Greenland, the Macaronesian archipelagos, Cyprus and the Caucasus countries. Although the EuroVegChecklist provided an excellent basis for a detailed inventory of the diversity of vegetation types and vegetated habitats across the continent, the distribution of many of these vegetation types remains poorly known.

During the preparatory phase of the EuroVegChecklist, Jiménez-Alfaro et al. (2014) compiled a database with information on the occurrence of 753 alliances in 23 European countries. They included those countries that had recent national lists of vegetation types. This was the first attempt to map a large number of vegetation types across Europe, including those that are not part of potential natural vegetation and occur in small patches. Here, we build on this initiative, and aim to extend the previous data set across the whole of Europe and map the distribution of all 1,105 alliances included in the EuroVegChecklist.

2 | METHODS

We mapped all 1,105 alliances of vegetation dominated by vascular plants as defined in the EuroVegChecklist (Mucina et al., 2016). The number of alliances is smaller than the figure of 1,108 given in the EuroVegChecklist article because the actual number of alliances included in the EuroVegChecklist was 1,107 (and not 1,108 as given in the article), one alliance (*Campanulo herminii-Nardion strictae*) was erroneously included twice, and one alliance (*Ormenido multicaulis-Malcolmion broussonetii*) probably occurs in Morocco but not in Europe. We used the alphabetically sortable alliance codes following the EuroVegChecklist website (www.synbiosys.alterra.nl/evc).

The geographical scope was the same as for the EuroVegChecklist, i.e. geographically defined European continent and islands, supplemented by Greenland, the Azores, Madeira, the Canary Islands, Cyprus and the Caucasus countries. Because point distribution data for many alliances are sparse and uncertain, we mapped the occurrence of alliances within politically or (bio)geographically defined territorial mapping units. The units were defined as countries, large islands, archipelagos and large peninsulas, as well as biogeographical subdivisions for the mainland portions of some countries. These subdivisions were based on the intersection of national borders with the boundaries of European biogeographical regions (EEA, 2016). Only large or biogeographically heterogeneous countries were subdivided if there was enough information to assign all alliances to the subdivisions. For Turkey and Russia, only their European parts were considered. Gibraltar and the smallest countries (Andorra, Liechtenstein, Monaco, San Marino and Vatican) were not considered.

We mapped the distribution of alliances in 45 countries. We used 82 territorial mapping units (Figure 1), of which 69 were whole countries or territorial subdivisions of the mainland parts of some countries, and 13 were islands, archipelagos and peninsulas. For 54 of these 82 territorial mapping units, we added their coastal section as a separate unit. In the coastal sections, we recorded only the specialized alliances of coastal environments (mainly saltmarsh, beach, dune and cliff vegetation) that do not occur in the interior part of the respective territorial unit. Each alliance was recorded only once for each territorial unit, i.e. either for the entire unit or for its coastal section. These coastal occurrences were mapped by colouring only the coastline rather than the entire area of the territorial unit. The 54 territorial units with a coastal section were Albania, Azerbaijan, Azores, Belgium, Bosnia and Herzegovina, Bulgaria, Canaries, Corsica, Crete, Crimea, Croatia, Cyprus, Denmark, Estonia, Faroe Islands, Finland, France Extra-Mediterranean, France Mediterranean, Georgia, Germany Atlantic, Germany Continental, Great Britain, Greece, Greenland, Iceland, Ireland, Italy Continental, Italy Mediterranean, Latvia, Lithuania, Madeira, Malta, Montenegro, Netherlands, Northern Ireland, Norway, Poland Lowlands, Portugal Atlantic, Portugal Mediterranean, Romania Extra-Carpathians, Russia Arctic, Russia Boreal, Russia Caucasus, Russia Kaliningrad, Russia Steppic, Sardinia, Sicily, Slovenia, Spain Atlantic, Spain Mediterranean, Svalbard, Sweden, Turkey European and Ukraine Steppic.

Owing to the lack of data, many occurrences had to be decided based on expert judgements. Therefore, we carried out this work with a team of experts from most European countries. As a starting point, we used the existing database with the distribution of 753 alliances in 23 European countries (Jiménez-Alfaro et al., 2014), linked it to the EuroVegChecklist alliances and added new territorial mapping units. In the second step, we reviewed national vegetation monographs, habitat catalogues, checklists of vegetation units and international synthetic studies on selected vegetation types to complement and correct the alliance distribution data (see Appendix S2 in Mucina et al., 2016, for the overview up to that year, and further, especially Didukh, 2016; Fayvush & Aleksanyan, 2016; Brullo et al., 2017, 2020; Guarino et al., 2017; Peterka et al., 2017; Reymann et al., 2017; Škvorc et al., 2017; Marcenò et al., 2018, 2019; Dubyna et al., 2019; Bergmeier, 2020; Chytrý et al., 2020; Landucci et al., 2020; Bonari et al., 2021;

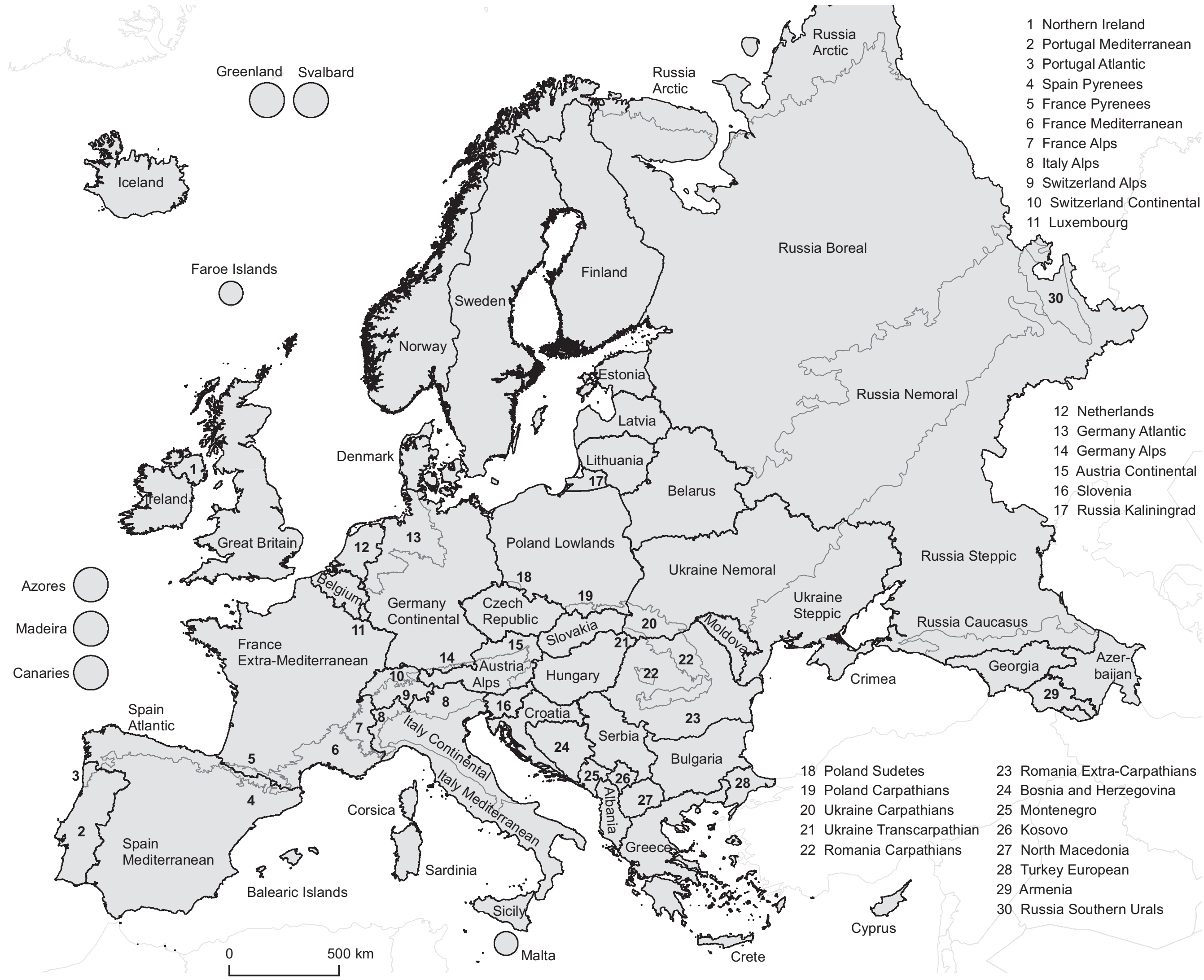

FIGURE 1 Territorial units used for distribution mapping of European alliances. These units are based on countries. Some islands, archipelagos and peninsulas are mapped separately. The mainland parts of some countries are subdivided based on the borders between European biogeographical regions. The Azores, Madeira, the Canary Islands, Greenland and Svalbard are shown as circles at the edges of the map. The Faroe Islands and Malta are shown as circles at their actual position

Kalníková et al., 2021). We took special care to correctly interpret the names and concepts of each alliance to match those of the EuroVegChecklist. We encountered several alliances that were either newly described or newly recorded in Europe since publication of the EuroVegChecklist. However, we did not map them in this study. They can be added to the current set of maps after being evaluated and accepted by the European Vegetation Classification Committee (http://euroveg.org/evc-committee; Biurrun & Willner, 2020). In the third step, we produced preliminary distribution maps and involved a larger group of vegetation and habitat experts from most European countries to revise and complement these maps.

It was found that, in many cases, there is a high degree of uncertainty about the occurrence of a particular alliance in a particular territorial unit. The main cause of this uncertainty was the lack of data. However, in many cases, there was also uncertainty about the definition and delimitation of some alliances, which made their mapping difficult. Therefore, we used a three-level scale in the maps to account for the uncertainties: (a) verified occurrence, including very likely occurrence (green colour); (b) uncertain occurrence (yellow); and (c) absence (white). In a few cases, we received information that an alliance was present in the territorial unit in the past, but currently is undoubtedly absent due to habitat destruction. We recorded this information as absence. However, we mapped the presence of those alliances that have likely disappeared but whose habitats still exist in the territorial unit.

In addition to the maps for individual alliances, we also created summary maps showing the number of all alliances (including those with uncertain occurrence) and rare alliances in the territorial mapping units. Because the number of alliances depends on the area of the territorial mapping unit, we accounted for the area effect by dividing the number of alliances by the log area of each territorial unit. A shapefile of the base map for alliance distribution mapping was created in ArcGIS (version 10.6). Distribution maps were created in R version 4.1.0 (R Foundation for Statistical Computing, Vienna, AT) using the *raster* (version 3.3-13) and *rgdal* (version 1.5-12) packages. We also plotted the number of alliances in each territorial unit against the logarithm of its area in km^2 using the R packages *ggplot2* (Wickham, 2016) and *ggrepel* (version 0.9.1) and fitted a robust linear model using the M estimator, employing function *rlm* from the package MASS (Venables & Ripley, 2002).

3 | RESULTS

Maps for the 1,105 EuroVegChecklist alliances are shown in Appendix S1, and the associated database can be found in Appendix S2. These maps do not show the exact distribution ranges. They show occurrences in territorial units, and in many cases, a relatively large territorial unit is shown in colour even though it contains a single or few occurrences of the alliance. Therefore, the actual distribution ranges of each alliance are smaller than shown on the maps.

The territorial units with the highest number of alliances were concentrated in Southern Europe, but relatively high numbers of alliances were also found in the mountainous areas of Central Europe (Figure 2a). After correcting for area (Figure 2b), the differences between rich Southern Europe and moderately rich Central Europe increased. Moreover, the differences between the richer Central Europe and the poorer Northern and Eastern Europe also increased.

Considering the number of all alliances, the richest territorial units (excluding coastal alliances) were Spain Mediterranean (267), Bulgaria (235), Italy Continental (221), Albania (211), Greece (211), Montenegro (207), Serbia (206), Italy Mediterranean (204), Bosnia and Herzegovina (203), Croatia (203) and Italy Alps (203) (Appendix S2). The patterns found for all alliances (including those with uncertain occurrence; Figure 2a,b) and those for verified alliances (not shown) were similar. The lowest numbers of alliances were found in all coastal mapping units and, in addition, in Svalbard (22), the Faroe Islands (28), Russia Arctic (34), Cyprus (37), Greenland (38), the Azores (43), Iceland (45) and Malta (49).

Of the entire countries, the most alliances were found in Spain (446), Italy (424), France (420), the European part of Russia (287), Ukraine (270), Greece (258) and Portugal (250). The smallest numbers of alliances were reported from Cyprus (54), Iceland (58), Malta (71), Armenia (72), Azerbaijan (75), Georgia (82) and the European part of Turkey (93) (Table 1).

By far the largest number of rare alliances in territorial units were concentrated in Spain Mediterranean. Large numbers of rare alliances also occurred in Italy Mediterranean, Portugal Mediterranean, Russia Steppic, Italy Continental and Greece (Figure 2c,d).

The highest proportions of uncertain occurrences of all (verified plus uncertain) occurrences were in the coastal parts of Azerbaijan (100%), Faroe Islands (90%), Georgia (57%), Northern Ireland (56%), Russia Steppic (50%) and Russia Caucasus (50%), and in the mainlands of Luxembourg (48%), Russia Kaliningrad (48%), Turkey European (46%), Kosovo (41%), Moldova (41%) and Northern Ireland (41%) (Appendix S2). Of entire countries or their European parts, the highest proportions of uncertain occurrences were found in Luxembourg (48%), Turkey European (44%), Kosovo (41%), Moldova (41%), Azerbaijan (40%), Albania (36%), Armenia (36%) and Cyprus (35%) (Table 1).

Alliances reported in most territorial units (including their uncertain occurrences) were those of aquatic or wetland vegetation: NB01A *Potamogetonion* (79), NA01A *Lemnion minoris* (77), OD01A *Phragmition communis* (77), OD04A *Magnocaricion elatae* (77), OD05A *Glycerio-Sparganion* (76), NB02A *Batrachion fluitantis* (72), NB02B *Ranunculion aquatilis* (72), NB01B *Nymphaeion albae* (71), QI01A *Bidention tripartitae* (71) and QI01B *Chenopodion rubri* (70). Some alliances of anthropogenic vegetation and livestock pastures also had extensive distribution ranges, e.g. CM10A *Potentillion anserinae* (69), QE01A *Polygono-Coronopodion* (69), QE01C *Saginion procumbentis* (68), CM01C *Cynosurion cristati* (66) and QF01B *Dauco-Melilotion* (66). Some alliances of wet forests were also widespread, e.g. HB01B *Salicion albae* (65), HA02A *Alnion incanae* (63) and IA01A *Alnion glutinosae* (63).

The smallest territorial units always had a small number of alliances but there were large differences in the number of alliances between the largest units (Figure 3). Relatively large and medium-sized territorial units on the Iberian, Italian and Balkan peninsulas, but also Extra-Mediterranean France and Continental Germany had many alliances. By contrast, the territorial units in the Arctic and boreal zones, lowland parts of Russia, the Caucasus region and Cyprus had much lower numbers of alliances than would be expected from their size.

4 | DISCUSSION

We present the first distribution maps of all phytosociological alliances for the whole of Europe and some adjacent areas. These maps complement efforts to map European vegetation and habitat types using a different approach. Previous approaches (Bohn et al., 2000–2003; Jiménez-Alfaro et al., 2014; Janssen et al., 2016; EEA, 2018; Chytrý et al., 2020) mapped a smaller number of vegetation or habitat units. Some of them (Janssen et al., 2016; EEA, 2018) excluded non-European Union countries in Eastern Europe. Here, we produced distribution maps for the most detailed vegetation classification with 1,105 units covering all of Europe (Mucina et al., 2016).

A limitation of our approach is that with such a detailed classification and broad geographical scope, there are many cases in which the occurrence of a particular alliance in a particular territorial unit is uncertain. Some European countries or regions have well-described vegetation that has been surveyed using the phytosociological approach. For some of them, up-to-date lists of alliances have been recently published, following or considering the EuroVegChecklist classification, for example in Croatia (Škvorc et al., 2017), Czech Republic (Chytrý, 2017), Sicily (Guarino et al., 2017), Ukraine

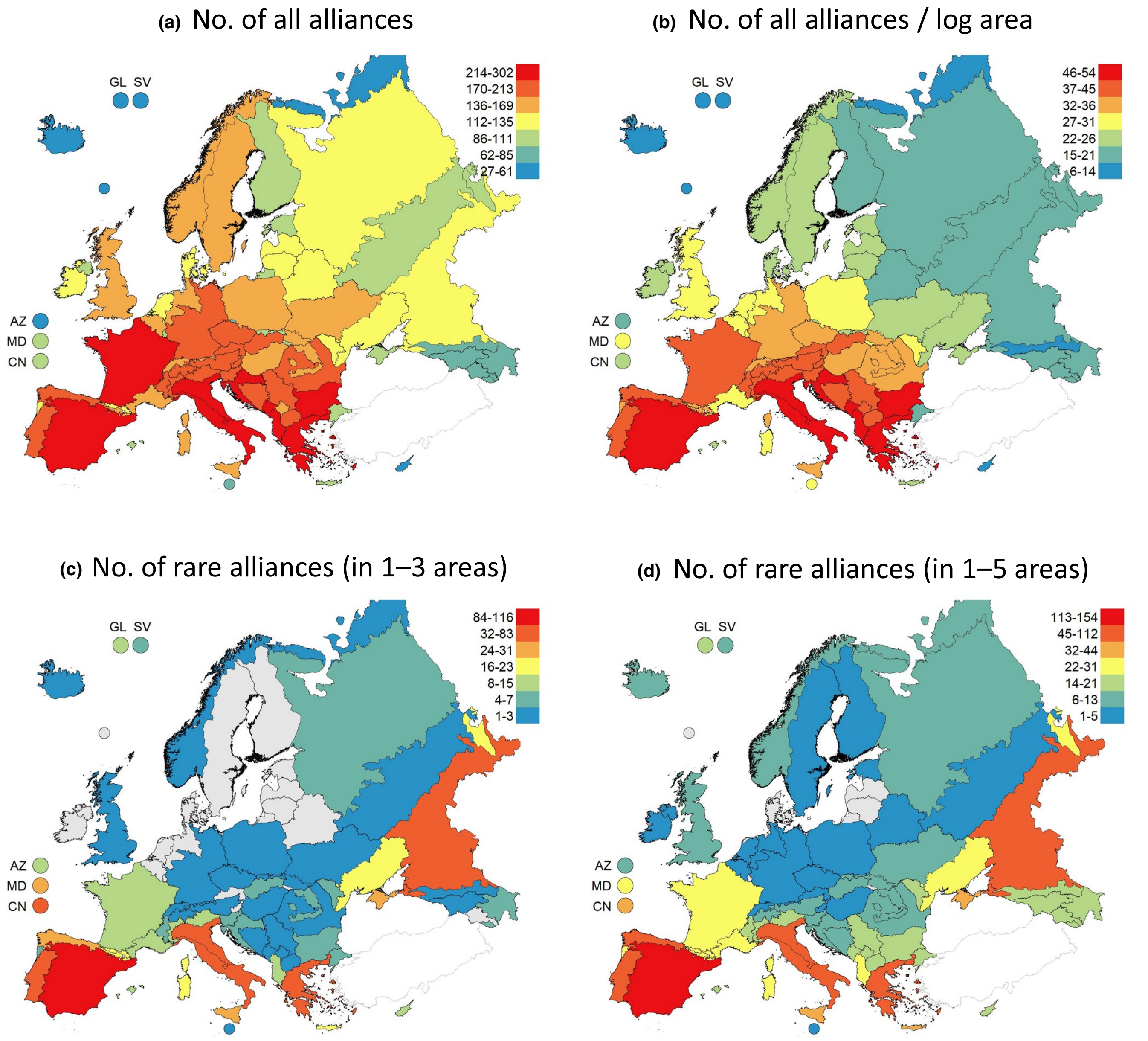

FIGURE 2 The number of alliances in territorial units. (a, b) All alliances (including both verified and uncertain) and (c, d) rare alliances (both verified and uncertain) in 1–3 or 1–5 territorial units, respectively. In (b), the numbers of alliances are divided by the log area to account for the different sizes of the territorial units. Coastal alliances are added to the number of mainland alliances in each territorial unit. The scale is based on natural breaks. The grey colour in (c) and (d) means that there is no rare alliance. See Figure 1 for the key to the territorial units. The Azores (AZ), Madeira (MD), the Canary Islands (CN), Greenland (GL) and Svalbard (SV) are shown as circles at the edges of the map

(Solomakha et al., 2017), Germany (Bergmeier, 2020) and Malta (Brullo et al., 2020). By contrast, modern phytosociological classifications and vegetation-plot data have been scarce in other regions, particularly in Northern and Eastern Europe, as well as in Cyprus and the Caucasus countries (Chytrý et al., 2016, 2020; Mucina et al., 2016). Although the diversity of both plant species and vegetation types decreases towards the north and in topographically homogeneous areas (see also Jiménez-Alfaro et al., 2014), the reported number of alliances (Figure 2, Table 1) shows areas with insufficient data, which often have a strikingly lower number of reported alliances than adjacent territorial units. Such lack of knowledge concerns in particular Belarus, the Caucasus region, Cyprus, Ireland and Northern Ireland, Moldova, the Kaliningrad Region of Russia and the European part of Turkey. The alliance–area relationship also suggests that large areas in Russia and Finland may still be unsatisfactorily studied, although their low number of alliances may also be due to the low diversity in these predominantly flat areas. We expect our database to motivate research filling these gaps. It also provides the first lists of phytosociological alliances for some countries (e.g. Belarus, Finland, Moldova, Sweden and the Caucasus countries). However, future research in the insufficiently studied southern regions could still yield many new alliances, as these areas contain

TABLE 1 Number of alliances in each country, sorted by decreasing number of all occurrences; all occurrences are the sum of verified and uncertain occurrences; the percentage of uncertain occurrences is a measure of the uncertainty of the alliance list for individual countries

	All occurrences	Verified occurrences	Uncertain occurrences	% of uncertain occurrences
Spain	446	427	19	4
Italy	424	400	24	6
France	420	394	26	6
Russia	287	251	36	13
Ukraine	270	252	18	7
Greece	258	208	50	19
Portugal	250	243	7	3
Bulgaria	248	184	64	26
Germany	237	232	5	2
Albania	228	147	81	36
Austria	228	212	16	7
Romania	227	205	22	10
Montenegro	223	159	64	29
Croatia	220	187	33	15
Poland	208	192	16	8
Switzerland	208	191	17	8
Bosnia and Herzegovina	207	165	42	20
Serbia	206	178	28	14
Slovakia	198	183	15	8
Slovenia	196	171	25	13
North Macedonia	192	132	60	31
Czech Republic	179	164	15	8
Kosovo	168	99	69	41
United Kingdom	166	152	14	8
Denmark	165	140	25	15
Hungary	160	136	24	15
Norway	151	132	19	13
Sweden	145	118	27	19
Belgium	140	111	29	21
Moldova	134	79	55	41
Netherlands	128	125	3	2
Lithuania	124	110	14	11
Latvia	123	89	34	28
Ireland	117	95	22	19
Belarus	115	85	30	26
Finland	110	84	26	24
Estonia	109	79	30	28
Luxembourg	100	52	48	48
Turkey	93	52	41	44
Georgia	82	62	20	24
Azerbaijan	75	45	30	40
Armenia	72	46	26	36
Malta	71	68	3	4
Iceland	58	50	8	14
Cyprus	54	35	19	35

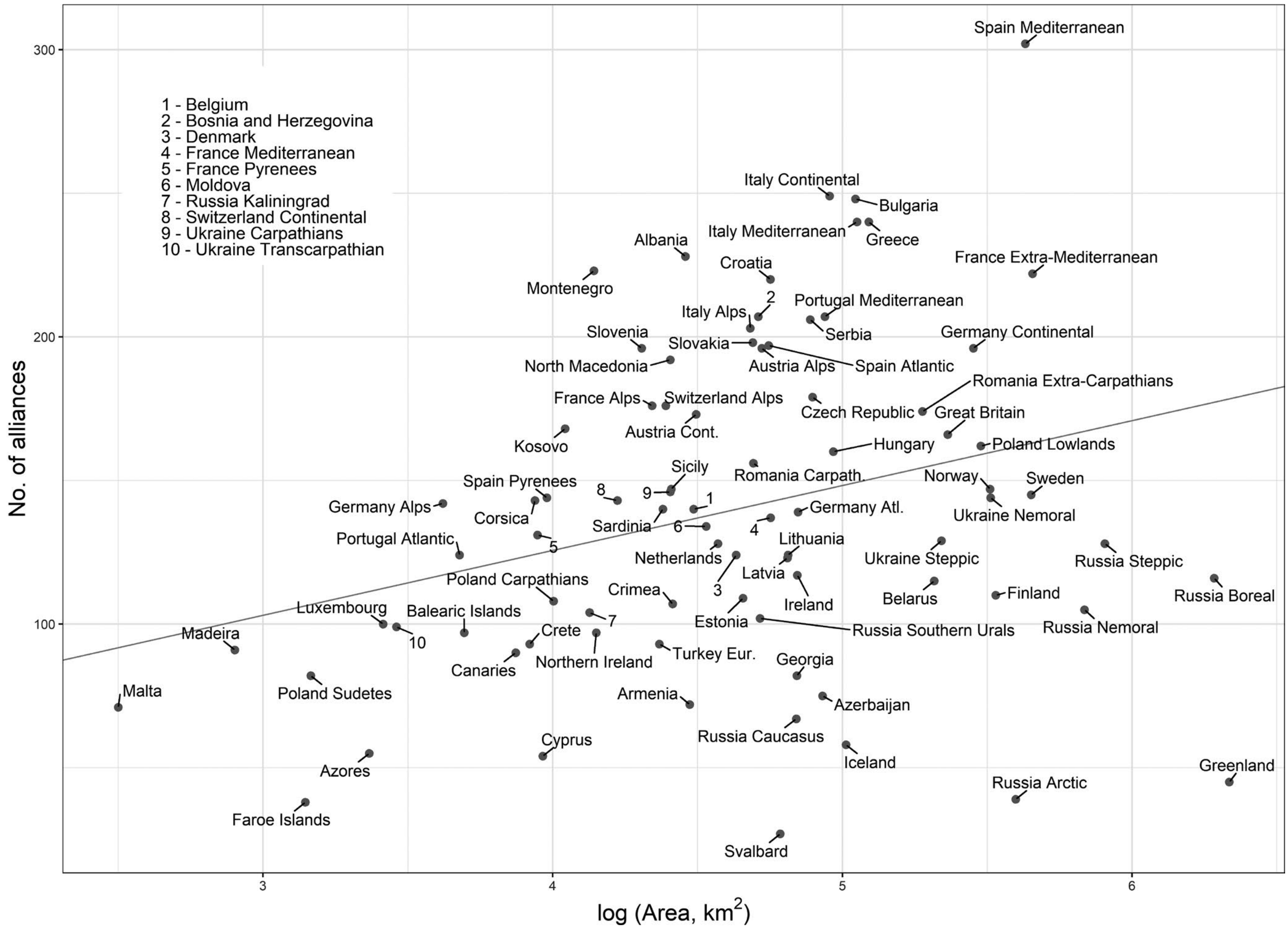

FIGURE 3 Relationship between the number of alliances and the $\log_{10}$-transformed area of territorial units. The grey line corresponds to a robust linear model fitted using the M estimator (intercept = 35.31; slope = 22.59)

many rare alliances (Figure 2c,d), reflecting a high number of species in these regions (Jiménez-Alfaro et al., 2014), glacial refugia (Médail & Diadema, 2009) and the concentration of species with small distribution ranges (Araújo et al., 2005).

Another problem is the unclear delimitation of some alliances. The EuroVegChecklist provides a short textual definition of each alliance, but the exact floristic delimitation has never been defined for most of them. The concepts of many vegetation types were proposed for the first time in the EuroVegChecklist or in related publications (Čarni & Mucina, 2015; Chytrý et al., 2015; Lysenko & Mucina, 2015; Willner et al., 2015), and the links between these concepts and the data published in previous literature have yet to be established. As a result, it is often difficult to decide where the geographical boundaries lie between pairs or groups of similar alliances. Another problem is that the same alliance name can represent very different concepts in different European traditions of vegetation classification (Guarino et al., 2018). In many cases, an alliance name listed in a national vegetation overview may represent a different vegetation type than the same name in the EuroVegChecklist. Different researchers may use different and sometimes contradictory names and concepts for the same vegetation types even in the same country. This is reflected in the highly inconsistent use of names of vegetation types assigned to individual vegetation-plot records in databases (Chytrý et al., 2016). Without critical evaluation, the names used in databases are not suitable for the production of distribution maps of vegetation types.

To overcome these problems, we used a fully expert-based approach. This relied mainly on national overviews of vegetation types and their interpretation by international experts. The experts also added information on occurrence in territorial units for which few data have been published. We tried to respect the concepts of vegetation units defined in the EuroVegChecklist, which often led to the modification or rejection of the concepts used in the previous national literature. However, for several alliances, we also had to reconsider the brief description of their distribution in the EuroVegChecklist. In particular, some alliances seem to have a broader distribution than indicated in these descriptions (e.g. *Aegopodio podagrariae-Sambucion nigrae*, *Archangelicion litoralis*, *Asplenion septentrionalis*, *Calamagrostion pseudophragmitae*, *Cymbalario-Asplenion*, *Epilobion fleischeri*, *Galio valantiae-Parietarion judaicae*, *Juncion trifidi*, *Limonion confusi*, *Nardion strictae*, *Phagnalo saxatilis-Cheilanthion maderensis*, *Rhododendro ferruginei-Vaccinion*, *Salicion pentandrae*, *Seslerion rigidae* and *Taeniathero-Aegilopion geniculatae*).

We consider the maps and associated database published in the Supplementary Materials to this article as a baseline that needs to be revised and refined. Their updating will depend on the accumulation of data and, in particular, on international synthetic studies of selected vegetation types that would clearly delineate the individual alliances and map their distribution. In the future, we plan to provide updates of the current maps and database and publish them as numbered versions in a public repository (http://doi.org/10.5281/zenodo.5879676). The current version reflects the vegetation classification system proposed in the EuroVegChecklist, but syntaxonomical research is evolving. The standard European vegetation classification is currently being updated based on the decisions adopted by the European Vegetation Classification Committee (http://euroveg.org/evc-committee; Biurrun & Willner, 2020). Therefore, future versions of the maps will also include the updates to the EuroVegChecklist adopted by this Committee. The ultimate goal is to replace the current country-based maps with maps showing more accurate distribution ranges or comprehensive point occurrence data, but such developments depend critically on the collection of new data in the future.

AUTHOR CONTRIBUTIONS

MC and BJA conceived the idea. BJA, MC and LM created a preliminary version of the database. ZP extended this preliminary version to include all EuroVegChecklist alliances and new territorial units; she also reviewed national and international literature to populate the expanded database. CB, EB, FB, GB, JD, BJA, AK, FL, CM, TMH, PN, DV and WW prepared data for selected territorial units. MVe wrote an R script to draw the distribution maps and prepared Figure 1. TMH prepared Figure 3. ZP and MC revised the preliminary maps based on comments from co-authors. MC coordinated the study, summarized the data and wrote the text. All authors commented on the distribution maps and the draft manuscript.

DATA AVAILABILITY STATEMENT

The database of occurrence records of European vegetation alliances created for this article is available in Appendix S2 and in the Zenodo repository (http://doi.org/10.5281/zenodo.5879676).

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REFERENCES

Araújo, M.B., Thuiller, W., Williams, P.H. & Reginster, I. (2005) Downscaling European species atlas distributions to a finer resolution: implications for conservation planning. *Global Ecology and Biogeography*, 14, 17–30. https://doi.org/10.1111/j.1466-822X.2004.00128.x

Bergmeier, E. (2020) Die Vegetation Deutschlands – eine vergleichende Übersicht der Klassen, Ordnungen und Verbände auf Grundlage der EuroVegChecklist. *Tuexenia*, 40, 19–32 https://doi.org/10.14471/2020.40.024

Biurrun, I. & Willner, W. (2020) First report of the European Vegetation Classification Committee (EVCC). *Vegetation Classification and Survey*, 1, 145–147. https://doi.org/10.3897/VCS/2020/60352

Bohn, U., Neuhäusl, R., Gollub, G., Hettwer, C., Neuhäuslová, Z. & Schlüter, H. (Eds) (2000–2003) *Map of the Natural Vegetation of Europe*. Scale 1:2,500,000. Münster: Landwirtschaftsverlag.

Bonari, G., Fernández-González, F., Çoban, S., Monteiro-Henriques, T., Bergmeier, E., Didukh, Y.P. et al. (2021) Classification of the Mediterranean lowland to submontane pine forest vegetation. *Applied Vegetation Science*, 24, e12544. https://doi.org/10.1111/avsc.12544

Brullo, S., Brullo, C., Cambria, S., Giusso del Galdo, G. & Minissale, P. (2017) Phytosociological investigation on the class *Crithmo maritimi-Limonietea* in Greece. *Plant Sociology*, 54, 3–57. https://doi.org/10.7338/pls2017541/01

Brullo, S., Brullo, C., Cambria, S. & Giusso del Galdo, G. (2020) *The Vegetation of the Maltese Islands*. Cham: Springer Nature. https://doi.org/10.1007/978-3-030-34525-9

Čarni, A. & Mucina, L. (2015) Validations and typifications of some South European syntaxa. *Hacquetia*, 14, 289–299.

Chytrý, M. (2017) Current vegetation of the Czech Republic. In: Chytrý, M., Danihelka, J., Kaplan, Z. & Pyšek, P. (Eds.) *Flora and Vegetation of the Czech Republic*. Cham: Springer. pp. 229–337. https://doi.org/10.1007/978-3-319-63181-3_7

Chytrý, M., Daniëls, F.J.A., Di Pietro, R., Koroleva, N. & Mucina, L. (2015) Nomenclature adjustments and new syntaxa of the Arctic, alpine and oro-mediterranean vegetation. *Hacquetia*, 14, 277–288.

Chytrý, M., Hennekens, S.M., Jiménez-Alfaro, B., Knollová, I., Dengler, J., Jansen, F. et al. (2016) European Vegetation Archive (EVA): an integrated database of European vegetation plots. *Applied Vegetation Science*, 19, 173–180. https://doi.org/10.1111/avsc.12191

Chytrý, M., Tichý, L., Hennekens, S.M., Knollová, I., Janssen, J.A.M., Rodwell, J.S. et al. (2020) EUNIS Habitat Classification: expert system, characteristic species combinations and distribution maps of European habitats. *Applied Vegetation Science*, 23, 648–675. https://doi.org/10.1111/avsc.12519

Didukh, Y.P. (Ed.) (2016) *Biotopes of the Crimean Mountains*. (in Ukrainian). Kyiv: TOV NVP Interservis.

Dubyna, D., Dziuba, T.P., Iemelianova, S.M., Bagrikova, N.O., Borysova, O.V., Borsukevych, L.M. et al. (2019) *Prodromus of the Vegetation of Ukraine*. (in Ukrainian). Kyiv: Naukova Dumka.

EEA (2016) *Biogeographical Regions in Europe*. Copenhagen: European Environment Agency. https://www.eea.europa.eu/data-and-maps/figures/biogeographical-regions-in-europe-2

EEA (2018) *Mapping Europe's Ecosystems*. Copenhagen: European Environment Agency. https://doi.org/10.2800/850732

Fayvush, G.M. & Aleksanyan, A.S. (2016) *Habitats of Armenia* (in Russian). Yerevan: National Academy of Sciences of the Republic of Armenia, Institute of Botany.

Guarino, R., Cusimano, D., Ilardi, V. & Pasta, S. (2017) Syntaxonomic list of vegetation units. In: Guarino, R. & Pasta, S. (Eds.) *Botanical Excursions in Central and Western Sicily. Field Guide for the 60th IAVS Symposium*. Palermo: Palermo University Press, pp. 281–370.

Guarino, R., Willner, W., Pignatti, S., Attorre, F. & Loidi, J.J. (2018) Spatio-temporal variations in the application of the Braun-Blanquet approach in Europe. *Phytocoenologia*, 48, 239–250. https://doi.org/10.1127/phyto/2017/0181

Ichter, J., Evans, D. & Richard, D. (Eds) (2014) *Terrestrial Habitat Mapping in Europe: an Overview*. Luxembourg: Publications Office of the European Union. https://doi.org/10.2800/11055

Janssen, J.A.M., Rodwell, J.S., García Criado, M., Gubbay, S., Haynes, T., Nieto, A. et al. (2016) *European Red List of Habitats – Part 2. Terrestrial and freshwater habitats*. Luxembourg: Publications Office of the European Union.

Jiménez-Alfaro, B., Chytrý, M., Rejmánek, M. & Mucina, L. (2014) The number of vegetation types in European countries: major determinants and extrapolation to other regions. *Journal of Vegetation Science*, 25, 863–872. https://doi.org/10.1111/jvs.12145

Kalníková, V., Chytrý, K., Biţa-Nicolae, C., Bracco, F., Font, X., Iakushenko, D. et al. (2021) Vegetation of the European mountain river gravel bars: a formalized classification. *Applied Vegetation Science*, 24, e12542. https://doi.org/10.1111/avsc.12542

Landucci, F., Šumberová, K., Tichý, L., Hennekens, S., Aunina, L., Biţă-Nicolae, C. et al. (2020) Classification of the European marsh vegetation (*Phragmito-Magnocaricetea*) to the association level. *Applied Vegetation Science*, 23, 297–316. https://doi.org/10.1111/avsc.12484

Lysenko, T. & Mucina, L. (2015) Nomenclatural notes on some alliances of the halophytic vegetation of Bashkortostan and the Caspian Lowlands. *Hacquetia*, 14, 301–306.

Marcenò, C., Guarino, R., Loidi, J., Herrera, M., Isermann, M., Knollová, I. et al. (2018) Classification of European and Mediterranean coastal dune vegetation. *Applied Vegetation Science*, 21, 533–559. https://doi.org/10.1111/avsc.12379

Marcenò, C., Guarino, R., Mucina, L., Biurrun, I., Deil, U., Shaltout, K. et al. (2019) A formal classification of the Lygeum spartum vegetation of the Mediterranean Region. *Applied Vegetation Science*, 22, 593–608.

Médail, F. & Diadema, K. (2009) Glacial refugia influence plant diversity patterns in the Mediterranean Basin. *Journal of Biogeography*, 36, 1333–1345. https://doi.org/10.1111/j.1365-2699.2008.02051.x

Mucina, L., Bültmann, H., Dierßen, K., Theurillat, J.-P., Raus, T., Čarni, A. et al. (2016) Vegetation of Europe: hierarchical floristic classification system of vascular plant, bryophyte, lichen, and algal communities. *Applied Vegetation Science*, 19(Suppl. 1), 3–264. https://doi.org/10.1111/avsc.12257

Peterka, T., Hájek, M., Jiroušek, M., Jiménez-Alfaro, B., Aunina, L., Bergamini, A. et al. (2017) Formalized classification of European fen vegetation at the alliance level. *Applied Vegetation Science*, 20, 124–142. https://doi.org/10.1111/avsc.12271

Reymann, J., Panaïotis, C., Bioret, F., Bacchetta, G., Delage, A., Delbosc, P. et al. (2017) Prodrome des végétations de Corse. *Documents Phytosociologiques, Ser, 3e*, 4, 1–175.

Rodwell, J.S., Evans, D. & Schaminée, J.H.J. (2018) Phytosociological relationships in European Union policy-related habitat classifications. *Rendiconti Lincei, Scienze Fisiche e Naturali*, 29, 237–249. https://doi.org/10.1007/s12210-018-0690-y

Škvorc, Ž., Jasprica, N., Alegro, A., Kovačić, S., Franjić, J., Krstonošić, D. et al. (2017) Vegetation of Croatia: Phytosociological classification of the high-rank syntaxa. *Acta Botanica Croatica*, 76, 200–224. https://doi.org/10.1515/botcro-2017-0014

Solomakha, I.V., Shevchyk, V.L. & Solomakha, V.A. (2017) *Review of the Higher Vegetation Units and Diagnostic Species of Ukraine according to the Braun-Blanquet Approach*. (in Ukrainian). Kyiv: Taras Shevchenko National University.

Veen, P., Jefferson, R., de Smidt, J. & van der Straaten, J. (Eds) (2009) *Grasslands in Europe of High Nature Value*. Zeist: KNNV Publishing.
Venables, W.N. & Ripley, B.D. (2002) *Modern Applied Statistics with S*, 4th edition. New York, NY: Springer.
Wickham, H. (2016) *ggplot2: Elegant Graphics for Data Analysis*. New York, NY: Springer.
Willner, W., Theurillat, J.-P., Pallas, J. & Mucina, L. (2015) On the nomenclature of some high-rank syntaxa of European forest vegetation. *Phytocoenologia*, 45, 175–181.

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

Appendix S1. Distribution maps of European vegetation alliances
Appendix S2. Distribution data for the European vegetation alliances in a spreadsheet format

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