Biological Conservation 293 (2024) 110568

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Assessing the national red lists of European vascular plants: Disparities and implications

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ARTICLE INFO

Keywords:
Conservation gaps
Europe
Plant conservation
Red lists
Threatened taxa
Vascular plants

ABSTRACT

The diversity of vascular plant taxa in Europe is threatened. National red lists are valuable biodiversity conservation tools that provide us with information on the proximity of a taxon to extinction. However, there are still differences in the methods and implementation of these assessments across European countries, indicating gaps in conservation efforts at national and regional levels. To address these disparities, we conducted a study in which we compiled data from the most recent national red lists of vascular plants in European countries, including some countries from the eastern part of the Mediterranean biodiversity hotspot. Our results confirm concerns that the conservation status of European vascular flora is not fully mapped. We also found that this knowledge is not evenly distributed across European regions. There were differences in the availability of red lists, the regularity of updates, and the implementation of assessment methods. Countries that assessed their entire flora had a higher proportion of threatened taxa than countries that assessed only a portion of the flora. This highlights the risk of overlooking the conservation status of less known taxa when assessments are limited to specific taxa. Financial capacity was found to be a critical factor influencing the extent of these shortcomings. Our study has shown that countries that assess their entire flora have, on average, higher national spending on environmental protection within their overall economies. This information is critical for developing effective biodiversity conservation strategies across Europe and for addressing the threats faced by vascular plants in the region.

1. Introduction

Major threats to the world's biodiversity are escalating at an unprecedented rate, affecting the fitness and distribution of organisms, leading to the rapid decline and extinction, sometimes even before they are discovered. This is mainly due to the anthropogenic climate change, habitat loss, urban development, agricultural intensification, abandonment of traditional practices of land use, unsustainable livestock ranching, overexploitation of natural resources (e.g., unsustainable forest management, overharvesting) and biological invasion (Hochkirch et al., 2023; Maxwell et al., 2016; Tedesco et al., 2014). Of the worlds' flora, 45 % of the known species and three in four undescribed species are at a risk of extinction (Antonelli et al., 2023). The response of European vascular flora is not an exception and is heavily

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https://doi.org/10.1016/j.biocon.2024.110568
Received 7 October 2023; Received in revised form 22 March 2024; Accepted 29 March 2024
Available online 10 April 2024

affected by the ongoing global biodiversity crisis. Of the 20 thousand species of vascular plants native to Europe, almost 45 % are estimated to be threatened with extinction and this estimate matches with global level predictions (Holz et al., 2022; Bilz et al., 2011). To tackle the global challenge for stopping or reversing biodiversity loss, enforcing conservation strategies has become a global, continental, and national priority (CBD (Convention on Biological Diversity), 2010) and implementing action plans at local level was essential. Consequently, gathering information on the status and trends of biodiversity by assessing the extinction risk of taxa at national level through monitoring programs has become increasingly important to support decision makers in setting conservation actions and policies.

Several documents address the conservation status of vascular plants, outlining appropriate conservation policies in reference to national and European Union legislation (e.g., The Habitat Directives) and international agreements (e.g., Bern Convention, Convention on International Trade in Endangered Species of Wild Fauna and Flora or CITES). Concerns about the risk of extinction of the European and global flora were clearly articulated in the various targets of the Global Strategy for Plant Conservation (GSPC) under the Convention on Biodiversity (CBD, 2010). Despite ambitious plans to halt biodiversity loss by 2020, we ultimately failed to meet this deadline (Bachman et al., 2018). Subsequently, new deadlines have been proposed for the near future (CBD, 2022, 2021). However, the lack of coherence in plant conservation actions and policies is a constant but rarely addressed problem in Europe (Fišer et al., 2021). There are significant differences between European regions in terms of financial resources allocated to biodiversity conservation actions (Adamo et al., 2022) and a clear correlation between the number of threatened or declining species and various indices of economic inequality (Mikkelson et al., 2007). In Europe, the southern European peninsulas (Iberian, Apennine, and Balkans) harbour most of Europe's plant diversity, with the broader Mediterranean basin representing one of the global biodiversity hotspots (Myers et al., 2000). However, inadequacies have been identified in the provision of appropriate conservation measures and policies in regions recognised as hotspots of plant diversity and endemism, such as the Balkan Peninsula (Vasilijevic et al., 2018). Therefore, closer look at the state of the art in these areas is essential in comparison to other regions and hotspots.

Despites the recognition that the International Union for Conservation of Nature's (IUCN) Red List of Threatened Species (henceforth 'red list') is the most comprehensive resource for providing global level assessments for extinction risks of animals, fungi, and plants, it only covers a small and biased subset of known biodiversity (Bachman et al., 2019; Rodrigues et al., 2006). Using a series of numerical thresholds in conjunction with population parameters of taxon, the assessment evaluates the conservation status at species, subspecies, variety, or subpopulation levels by assigning a red list category. Although red listing process does not involve prioritization of taxa, a complete and more up-to-date red list gives an overview and helps identifying taxa deemed to be priorities for conservation and captured them at early stage of their extinction risk (Bachman et al., 2019). Although the red list is far from perfect and complete, it remains as a critical indicator of the health of the world's biodiversity providing scientifically rigorous evidence to enable decision making in conservation (IUCN, 2023; Rodrigues et al., 2006).

The red list assessment process has been developed over the last two decades, but the real understanding of its advancements has lagged as it is often assumed the red list categories are still based on experts' opinion (Rodrigues et al., 2006). IUCN (2012) has developed guidelines to empower regions and countries in conducting conservation assessments within geographically defined areas, enabling more focused conservation efforts. Although there were similarities of red list categories between global and national conservation assessments for most animals and plants, differences were notable for some species (Brito et al., 2010). For example, taxa that are listed nationally as threatened are not assessed globally or reverse; and taxa that are considered as not threatened globally but are nationally threatened or reverse. Whilst the comparison between global and national assessments remains a priority, the global scale trends may not always correlate with local trends. Therefore, more geographically focussed assessments are required to address conservation needs at local level. Consequently, national red list assessments have become increasingly important alongside global assessments for developing country or sub-country level conservation strategies for species (Zamin et al., 2010), especially among signatory parties of CBD who are agreed to monitor their own progress towards biodiversity targets including those set for the Kunming-Montreal Global Biodiversity Framework (CBD, 2022).

The European Red List of vascular plants is a review of the conservation status of 1.826 selected plant taxa native to the European continent (Bilz et al., 2011). Already a brief review of the assessment reveals a geographical inequality, largely neglecting the species-rich Southeast Europe (Bilz et al., 2011). Consequently, this gap was partially filled by the assessments of the European medicinal plants (Allen et al., 2014), lycopods and ferns (García Criado et al., 2017), trees (Rivers et al., 2019) and selected endemic shrubs (Wilson et al., 2019), which considered all countries in Southeast Europe. Nevertheless, only 16 % of all European vascular plant taxa have been assessed in the IUCN Red List (Holz et al., 2022), which is remarkably lower than the global level, varying between 21 % and 26 % (Bachman et al., 2018).

Red list data meet important political, social and scientific needs in biodiversity conservation and are often used to guide natural resource management at different levels, in the development of national policies and legislation and can make an important contribution to strengthening multilateral agreements (Rodrigues et al., 2006). However, most often red list assessments do not have direct legal implications (Rossi et al., 2016). Although there are well-established guidelines for conducting extinction risk assessments, differences between national red list assessments persist, highlighting gaps in conservation in individual countries and at different levels. Despite increasing efforts to follow IUCN recommendations, some countries still apply their own criteria to create red lists (Maes et al., 2019). The need for expansion of taxonomic, spatial, and temporal coverage through new and repeated assessments has been recognised (Bachman et al., 2019). These updates provide more insight when they contribute new knowledge through detailed evaluation (e.g., especially those previously assessed through expert's judgement or using opportunistic data) and capturing more up-to-date data (e.g., taxonomic concepts, distribution, and population data). There are also notable differences between countries in the frequency of updates. Only regularly updated red lists can provide a valuable warning and monitoring system for rapidly emerging conservation issues (Rodrigues et al., 2006). Finally, although one of the objectives of the IUCN is to progressively assess the extinction risk of all taxa (Rodríguez, 2008), most national red lists still contain a limited and incomplete number of taxa compared to the national flora.

Europe's national red lists have already been the subject of research to assess the extinction risk of different groups of organisms at the continental scale, such as threatened plants across Europe in relation with their distribution ranges (Holz et al., 2022), orchids across Europe (Kull et al., 2016), and European butterflies (Maes et al., 2019). Also, European national red lists were used for estimating the Red List Index (RLI) for monitoring trends in the overall extinction risk of a set of taxa overtime (e.g., Finland - Juslén et al., 2013; Spain - Saiz et al., 2015); to identify primary threats for native and also endemic flora (Italy - Orsenigo et al., 2021, 2018); and in predictive modelling at ecosystem scale e.g., to identify main factors shaping plant species assemblages and community diversity in riparian ecosystems (Slovakia - Slezák et al., 2022).

To elucidate their implications on overall biodiversity conservation, there is still a need to assess strengths and shortcomings in the use of red lists as effective conservation tools by reviewing the current progress, exploring the taxonomic, spatial and temporal gaps in assessments, unlocking the variability and highlighting the trends both within and across countries and understanding the likely causes for inherent differences. Therefore, the overall aim of the study was to identify differences in conservation approaches between countries by analysing the national red lists of European and Eastern Mediterranean countries as these are key documents used for nature conservation. We envision our findings to be used as a knowledge base for formulating a roadmap for future red listing in Europe. Specifically, the aim was set to threefold: (i) identify differences in assessment approaches (e.g. the number of taxa assessed or the red list categories used), (ii) investigate whether national red lists that consider only part of countries floras have a weaker conservation significance than those in which the entire flora has been assessed, and (iii) assess what factors (including socio-economic characteristics) may have led some countries to assess only part of the national flora, while others have assessed the entire flora. We retained the focus of the study to Europe, but where necessary specific regions or geographic ranges are included and/or described in relation to the similarities in type of climate and vegetation or their rich biodiversity (e.g., eastern Mediterranean). For example, the Middle East, and Turkey in particular, is considered one of the most species-rich areas in the world in terms of vascular plants. Together with other 14 M-biodiversity rich countries, Turkey comprises 50 % of the world's vascular plant phylogenetic diversity (Tietje et al., 2023). As an area that connects Europe with the wider Mediterranean region and Western Asia, and as a member of European integration, we decided to include it in this analysis together with some neighbouring countries. Also, the comparison of national and sub-national level red lists against the global assessments and technical or methodological differences in assessments were considered out of scope of the current study.

2. Material and methods

2.1. Data compilation

To provide a detailed overview of the current status of national red lists of vascular plants in Europe and to identify differences in their assessment approaches, we compiled data from the most recent national red lists of vascular plants of European countries together with some countries from the eastern part of the Mediterranean biodiversity hotspot, namely Turkey, Lebanon and Israel. Alternatively, in the case that red lists have not been published at the national level for a given country, we have gathered red lists at the regional level where available. The list of complete references is available in supporting information (Appendix A). Compiled data included the country/region to which red list belongs to, taxonomic name and their respective assessment categories, as well as other available meta data (year of publication, format and availability, categories with their definition). In the present study, we have not resolved the taxonomic differences between the compiled lists. We observed that some national red lists included non-native taxa, but often only as NA (Not Applicable) or NE (Not Evaluated). In some red lists, both neophytes and archaeophytes were considered as non-native; in other instances, archaeophytes were treated as autochthonous taxa. However, we have not eliminated non-native taxa provided on red lists. As a result, some red lists may be either over or under-represented with non-native flora.

Most of the information utilized in this study was sourced directly from the original red list references. However, to gain a comprehensive understanding of the implication of national red lists on conservation practices in each country, we sought the assistance of national participants involved in the COST action ConservePlants: An integrated approach to conservation of threatened plants for the 21st century (Fišer et al., 2021). ConservePlants is a European network of scientists and other stakeholders actively involved in various aspects of plant conservation. Using a structured questionnaire, we conducted a survey and asked participants in the COST action to answer three multiple choice questions about the publication of the red list of vascular plants in their country: How often is the red list of vascular plants published? What are the legal implications of the publication of the red list of vascular plants? What are the financial implications of the publication of the red list of vascular plants? By exploring these key issues, we aimed to improve our understanding of the broader implications and practical applications of red list assessments for plant conservation efforts. The complete set of questions can be accessed in Supporting Information (Appendix B).

In addition, for each country we have described the level of conservation efforts from the financial perspective by collecting four different descriptors, namely (i) the mean value in millions of euros of national expenditure on environmental protection, (ii) the mean value in millions of euros of investments on environmental protection, (iii) the mean value of the percentage (calculated on gross domestic product (GDP)) of national expenditure on environmental protection and (iv) the mean value of the percentage (calculated on gross domestic product (GDP)) of investments on environmental protection in the total economy, calculated using available data from 2014 to 2021. According to Eurostat (https://ec.europa.eu/eurostat/cache/metadata/en/env_ac_epea_esms.htm; accessed 06 January 2024), national expenditure on environmental protection measures the resources used by resident units to protect the natural environment in a given period. It is calculated as the sum of expenditure on environmental protection activities and investment for environmental protection activities, including net transfers to the rest of the world. Moreover, investments of total economy (general governments and corporations) specifically refer to investments in the provision of environmental protection services. Investments made by corporations to manage their own environmental impacts are also included. The data were retrieved from https://ec.europa.eu/eurostat/data/database (accessed 06 January 2024). The selected descriptors cover expenditure and investments on the protection of various natural assets across nine identified categories including biodiversity and landscapes.

2.2. Data harmonization

Because not all countries use the IUCN (2019) recommended categories or use modified IUCN categories (Fig. 1D), we harmonized the categories based on available definitions and expert opinion, to match those used by the IUCN guidelines (Appendix C). Although one of the main aims was to analyse the differences, the harmonization process was essential to identify patterns in red listing among counties against their entire flora. After harmonization, we considered the following categories: extinct (EX), extinct in the wild (EW), regionally extinct (REX), critically endangered (CR), endangered (EN), vulnerable (VU), near threatened (NT), least concern (LC), data deficient (DD). For the purposes of this analysis, the category rare (R), although an old IUCN category, was analysed on its own, not joint under any other currently valid IUCN categories. The categories not evaluated (NE) and not applicable (NA) contributed to the total flora in countries where this has been assessed, so we decided to keep them in the analysis. A final category, "undefined", was used when harmonization was not possible. To determine the proportion of national flora assessed, we collected data on the total flora of countries from various national sources or alternatively according to expert opinion (Appendix D). According to IUCN guidelines, taxa in CR, EN and VU categories are considered as 'Threatened' with a high risk of extinction.

2.3. Data analysis

To recognize geographical patterns arising from information collected we created cartographic visualization per country or region using the spatial tools of ESRI ArcGIS, ver.10.7. To describe the differences at the geographical level, we utilized descriptive statistics for both individual countries or regions analysed and major geopolitical divisions, namely EU and non-EU countries. For specific information regarding the categorization of individual countries within each group, refer to Appendix E.

To understand how red lists listed with the entire flora differ from red lists that assessed only part of the flora, particularly those referred as threatened (CR, EN and VU), we analysed the data using multivariate analysis, considering countries, number of taxa per assessment category relative to total size of the national or regional floras, and percentage of the flora assessed. We applied Ward's algorithm to assess similarities and hierarchical clustering pattern between national red lists. Considering the number of groups revealed by cluster analysis, the total number or percentage of taxa per category, we analysed the multivariate distribution within countries and the contribution of each category by applying principal component analysis (PCA). PCA for the two principal components explaining most of the total variation (PC1 and PC2) were visualized on the PCA biplot. The contribution of each variable was calculated as the product of their loadings and the explained variance of the principal components. Multivariate analyses were performed using the R packages "stats", "FactoMineR", and "factoextra" (Alboukadel and Fabian, 2022; Francois et al., 2023; R Core Team, 2023).

We used different regression models to understand the relationship between singular threat categories (critically endangered, endangered and vulnerable) or their sum (threatened) to the total number of taxa considered in the national red lists. When using the number of red-listed taxa we employed robust linear models (RLM), while for data expressed as percentage on total flora, we calculated simple linear models (LM). Coefficients and their statistical significance, along with standard error and t-value, were calculated. The regression models were computed using the R core package "stats" and R package "sfsmisc" to compute the F test for RLM (Martin et al., 2023; R Core Team, 2023). We examined whether the model assumptions of a linear response were met by analysing the residuals.

To test whether countries where the entire flora was assessed differed from countries where flora was only partially assessed in terms of expenditure and investments on environmental protection, we performed a one-way PERMANOVA using the Euclidean similarity index with 9999 randomizations and Tukey test comparing the mean value in € million and the mean value of the percentage (on GDP) of national expenditure on environmental protection and of environmental protection investments in the total economy. PERMANOVA was performed using the adonis function in the R package "vegan" (Oksanen et al., 2019).

3. Results

3.1. Status of red lists at national level

Overall, we compiled 42 data sets for red lists from 41 countries (Fig. 1A). The full list of assessed national red lists with values per category is summarized in Appendix E. These were gathered from digital (web pages, databases, spreadsheets, pdf documents, published literature and reports) and non-digital (hard copies of books and reports) resources either in native languages and/or English. The process was not straight forward and we encountered several challenges. Since there is no national red list for Belgium, we have considered the red list of the vascular flora for Flanders and Wallonia separately. For Bosnia and Herzegovina, we only considered the assessment of the red list of the Federation of Bosnia and Herzegovina, as the red list for the Republika Srpska does not exist. For Serbia, only the Red Book of taxa classified as threatened with extinction or critically endangered is available. Red lists are missing for some of the Balkan countries: there is no national red list for Montenegro, and the national red list of Northern Macedonia is under development. Since only a few taxa were assessed at the time of our data compilation, we decided not to include it in the analysis.

There were substantial differences between countries but minor differences between groups of countries regarding the publication year of the red lists (Fig. 1B and Table 1). There are differences among countries in the format of available data (Fig. 1C). Most new red lists are available as websites, often accompanied by a publication. However, there are still many red lists that are only available in the form of publications (e.g., journal articles, monographs), either digital or printed. Most countries use standard or modified IUCN categories, with only two countries using their own categories (Germany and Latvia; Fig. 1D).

Finally, we received responses from 43 experts in 41 countries working in the field of plant conservation. Appendix B provides an overview of the of responses, indicated by country. For 9 of the 41 countries or regions with red lists, the frequency of publication was reported as regular, in <5 years, 25 countries update their red lists irregularly in >5 years, while 7 countries have only one edition. We obtained diverse and heterogeneous responses regarding the legal and financial impact of the red lists. In 19 cases, red list results led to conservation-related legal recommendations, while in 16 cases, there were no legal implications. The results helped improve national and regional conservation actions in 10 cases and were legally binding for conservation measures in 7 cases. From a financial perspective, red list results facilitated funding applications for some or all listed taxa in 18 and 6 cases, respectively. However, funding actions remained unaffected in 17 cases, and mandatory funding was required in only 2 cases for all or some listed taxa. These findings highlight the varying legal and financial consequences associated with red list assessments.

3.2. Red lists of complete vs. partial flora assessed

A total of 12 red lists, accounting for 27.3 %, encompasses the assessment of the complete national or regional flora (Fig. 1E and Table 1). Within EU countries, this percentage rises to 32.1 % of the assessments, whereas for non-EU countries, it stands at 21.4 %. In addition, countries of Eastern Europe (Latvia, Lithuania, Belarus, Ukraine, Moldova, Romania, Bulgaria, Serbia, the Federation of Bosnia and Herzegovina, Kosovo, Croatia and Slovenia), Southern Europe (Portugal, Spain, Greece), and Eastern Mediterranean (Turkey, Lebanon, Israel), but also one country of Northern Europe (Iceland), have a low proportion (<25 %) of their flora in the red lists compared to the countries of Central, Western and Northern Europe (Fig. 1E). Consequently, a larger percentage of threatened taxa results in countries where a larger proportion of the total flora has been assessed (Table 1, Fig. 1F).

The division of the red lists into two groups based on the completeness of the assessed flora (Appendix F) also yielded strong support in statistical tests. Hierarchical clustering analysis showed that the subdivision based on flora completeness is the most suitable approach (Fig. 2). Furthermore, this subdivision is consistently supported by the principal component analysis. When examining the distribution of red lists by category percentage, countries with complete assessments are positioned at the opposite end of the gradient compared to countries with partial assessments. This gradient can be well explained by the direction and increasing contribution of the number of taxa in each threat category (Fig. 3). The pattern becomes even more evident when considering the total number of taxa per category. In this case, the gradient towards a larger red list size becomes even more pronounced. Red list size aligns with the vectors defined by the contribution of the number of taxa in each threat category (Fig. 4).

The response of individual threat categories or their cumulative counts against the total counts on assessed flora was effectively captured by six of the eight robust regression models. There were significant positive relationships between the number of endangered, vulnerable, or total threatened taxa and the percentage or total number of red-listed taxa. However, for critically endangered taxa, no significant relationships were observed (Fig. 5, Table 2).

Countries where the entire flora was assessed and those where it was only partially assessed differed in terms of expenditure and investments on environmental protection. Significant differences between countries with total assessment and countries with partial assessment were found by PERMANOVA ($F = 7.536$; $p = 0.009$). Specifically, countries in which the entire flora was assessed had higher mean values (in millions of

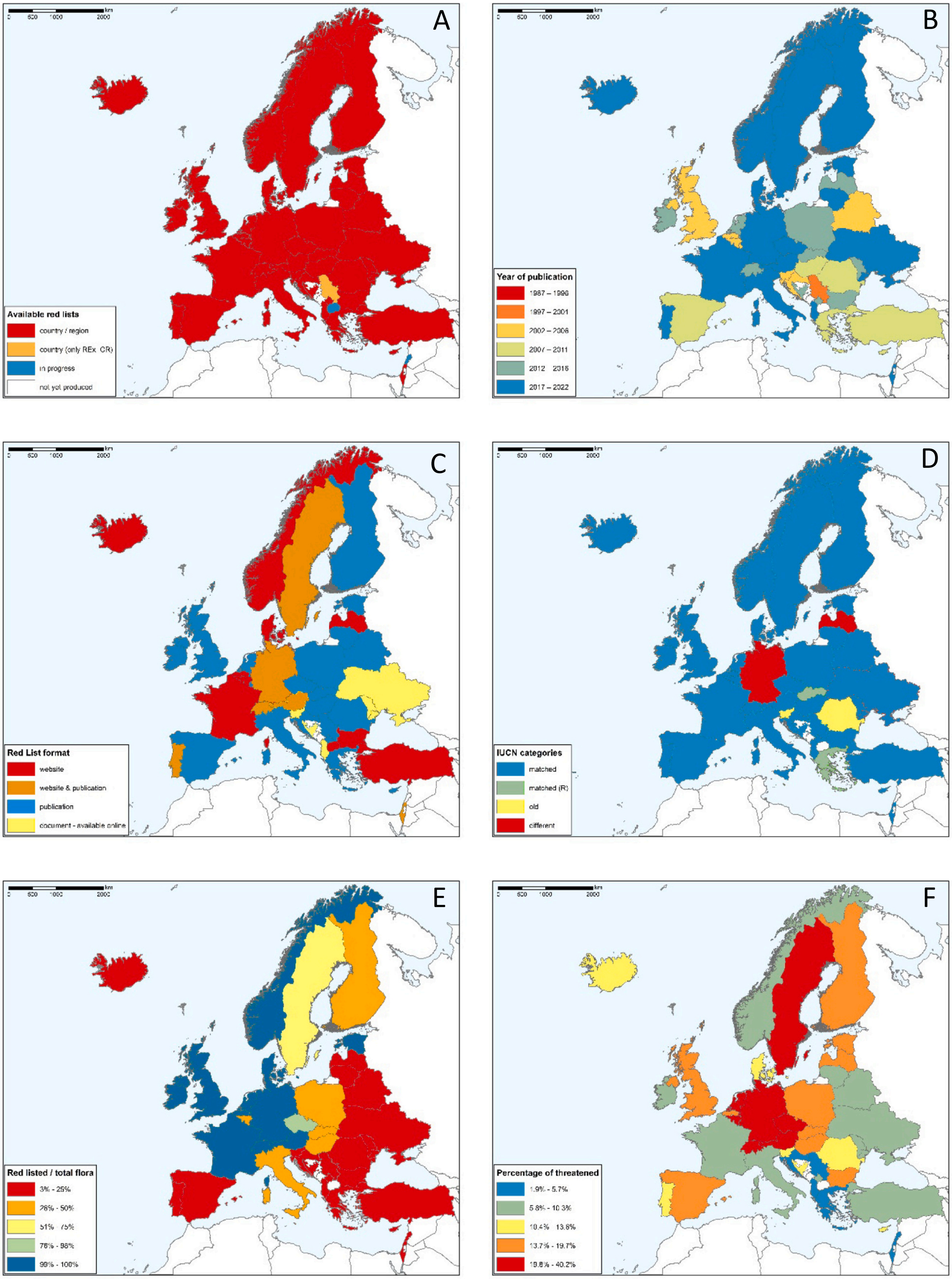

Fig. 1. National red lists of European vascular flora: (A) availability of national red lists, (B) year of publication of the latest version, (C) format available, (D) matching to IUCN categories for regional assessment, (E) percentage of the country's vascular flora assessed in the red list and (F) percentage of threatened flora assessed in the red list compared to the total flora.

Table 1

Summary statistics generated for the metadata considered in the study across all assessed countries/regions, as well as for different regions based on geopolitical and administrative similarities. It should be noted that the overall analysis considered the absence of National red lists for two countries, namely Montenegro and North Macedonia. For specific information regarding the categorization of individual countries within each group, please refer to Table S5.

	% countries/regions with red list assessments	% countries/regions with total flora assessed	Publication year (min, median, max)	% total flora assessed (min, average, max)	% flora assessed as threatened (min, average, max)
All countries/regions assessed	95.4	27.3	(1989) 2015 (2022)	(2.7) 45.9 (100)	(1.74) 14.8 (40.1)
EU-countries/regions assessed	100	32.1	(1989) 2015 (2021)	(4.4) 50.4 (100)	(3.10) 16.5 (40.1)
Non-EU countries/ regions assessed	87.5	21.4	(1999) 2015 (2022)	(2.7) 32.3 (100)	(1.74) 10.1 (25.5)

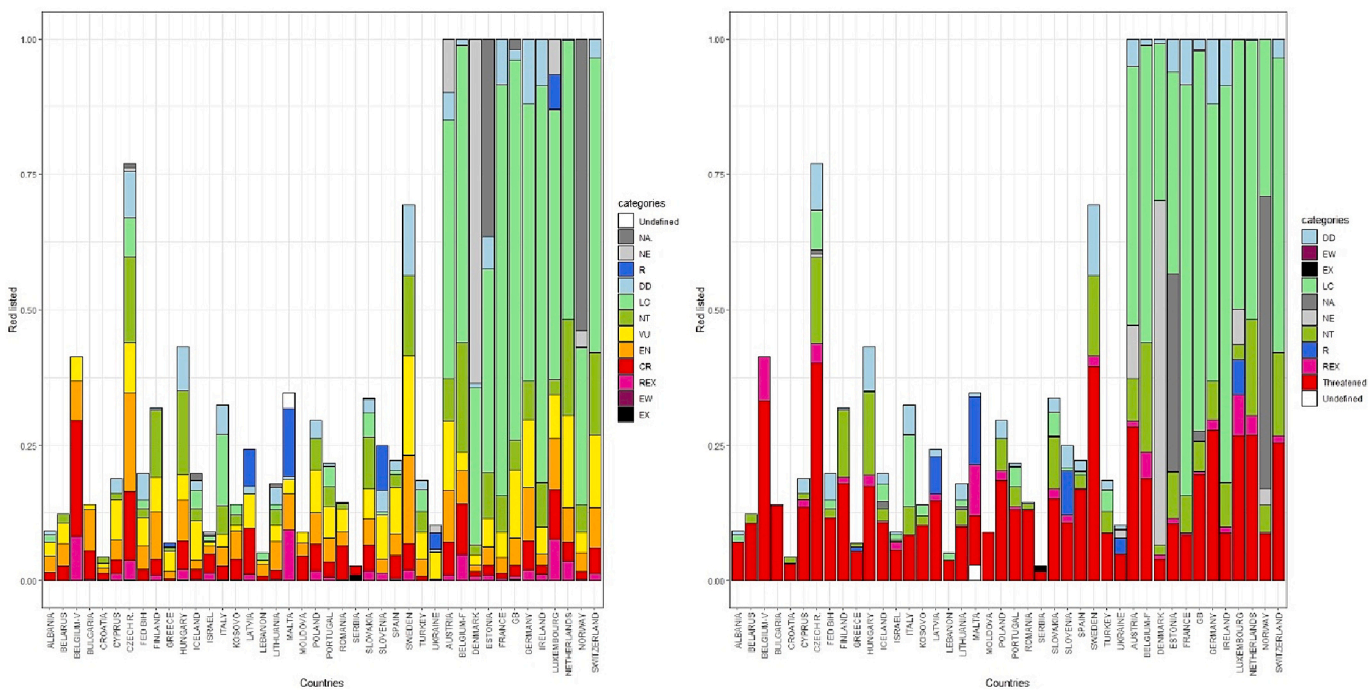

Fig. 2. (A) Distribution of all red list categories per country adjusted according to latest IUCN classification. (B) Distribution of red list categories per country with threat categories (CR, EN and VU) summarized into Threatened. Countries were classified according to Ward's classification into two main groups: complete flora included in the red list (Red listed = 1) or part of the total flora included in the red list (Red listed <1).

euros) of national expenditures on environmental protection ($p = 0.016$; Fig. 6) and environmental protection investment of total economy ($p = 0.019$; Fig. 6) than countries in which the flora was only partially assessed. No significant differences between countries with total assessment and countries with partial assessment emerged when considering the percentage (on GDP) of national expenditure on environmental protection and of environmental protection investments in the total economy.

4. Discussion

Our results confirm the concern that the conservation status of the European vascular flora is not fully addressed. We also found that efforts on conservation assessments are not evenly distributed across European regions. There were marked differences in the availability of red lists, the regularity of the updates and the implementation of the assessment methodologies. The goals of the Global Strategy for Plant Conservation (CBD; Convention on Biological Diversity, 2010) address the challenges posed by threats to global plant diversity. A particular concern among the goals is to assess the conservation status of all known plant taxa, as far as possible, to guide conservation action. It had become clear that the increase in conservation activities was not in line with the targets to be achieved by 2020 (Bachman et al., 2019, 2018). Therefore, plant conservation goals under the post-2020 biodiversity framework focus on progressing and redoubling efforts to document the conservation status of unassessed plants. This will eventually enable better conservation decisions and conservation of the most threatened taxa (CBD (Convention on Biological Diversity), 2022, 2021).

The IUCN Red List is provided in a comprehensive and freely accessible database that is easy to update (https://www.iucnredlist.org). National red lists, on the other hand, come in a variety of formats either in native language or in English, from convenient online databases, scientific publications, commercially available printed books, to legislative documents available in government portals. The most recent red lists are usually available online, as websites or as publications, but they are not always freely available. In some cases, only printed versions are still available. It should be highlighted that the efficient communication of information is fundamental to the proper support of conservation decisions (Seavy and Howell, 2010). Importantly, the notable heterogeneity of red list formats hinders the accessibility of information to conservationists and to the scientific community outside the country boundaries. Moreover, our results showed a great diversity with respect to the age and regularity of publication, as also reported by Holtz et al. (2022). There are no clear geographical inequalities regarding the age of issuing individual red lists. In an internal survey we conducted among experts in the field of

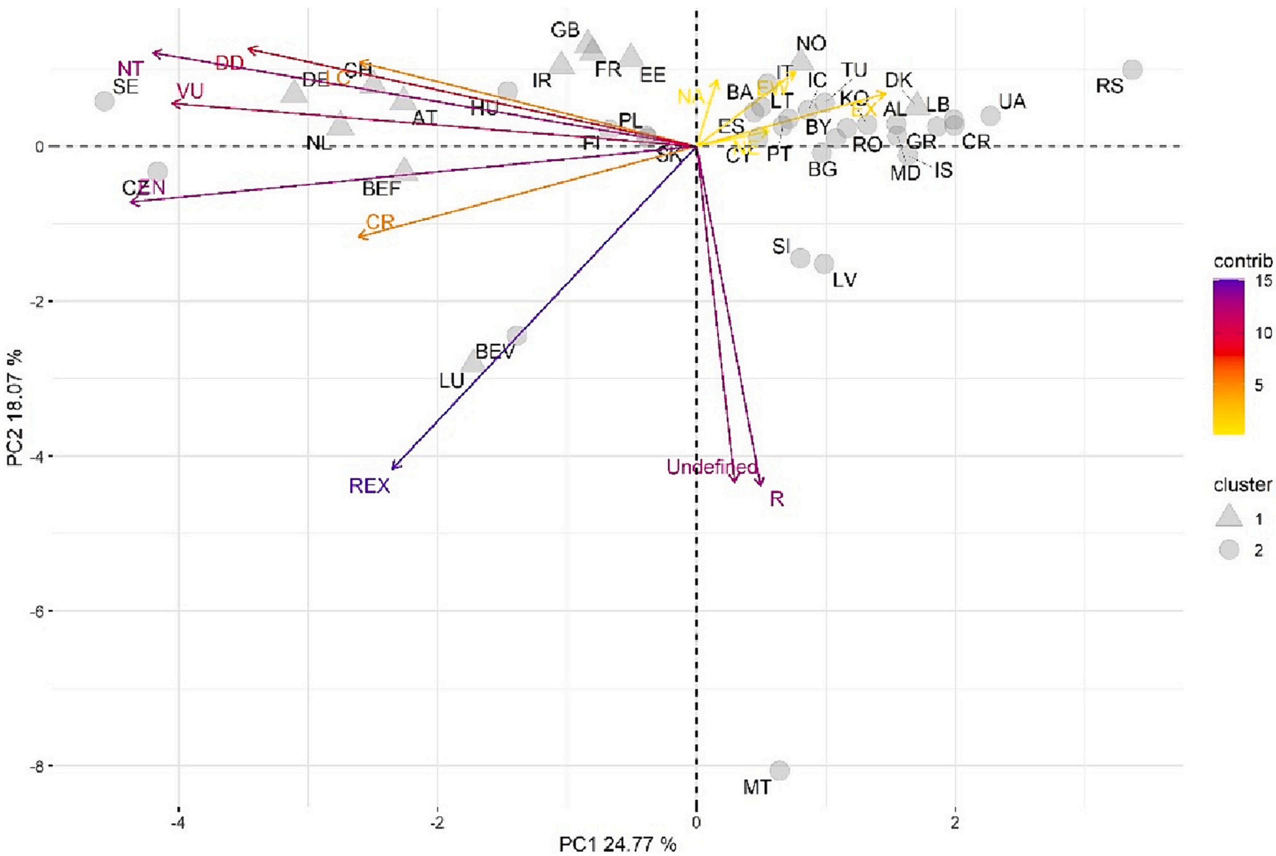

Fig. 3. Results of principal component analysis shown on the first two axes for the percentage distribution of Red List categories by country (indicated by acronyms). Each country is represented with the cluster symbol according to Ward's classification into two main groups: the whole flora included in the Red List (Red listed = 1; cluster 1) or part of the whole flora included in the Red List (Red listed <1; cluster 2). The arrows indicate the direction and contribution of the influence of the number of taxa within each Red List categories to the overall variability.

plant conservation within the COST Action ConservePlants (CA 18201) - we found that only 10 of 41 countries or regions with red lists that participated in the survey had regular updates (every 5 to 10 years) of national red list assessments. Only regularly updated red lists can provide valuable warning and monitoring tools for detecting emerging conservation issues (Rodrigues et al., 2006). Also, despite the increasing efforts by IUCN to stimulate countries to follow their recommendations (e.g., the publication of freely available Guidelines), some countries still apply their own categories and criteria to create red lists, which is not the case only in plants but in other taxonomic groups as well (Maes et al., 2019). At the geographical level, we found that many countries from Eastern and Southern Europe and the from the Eastern Mediterranean have a very low proportion of the total flora included in the assessments. In addition, the red list assessments are completely missing for some countries (e.g. Montenegro, North Macedonia). Worryingly, these countries are in areas considered as hotspots of European plant diversity, such as the Mediterranean basin and the Balkan Peninsula. In this way, some of the endemic taxa that are unique to the countries are completely excluded from any extinction risk assessments. This can be already noticed by the complete absence of taxa from some Balkan countries in the IUCN European Red List of vascular plants (Bilz et al., 2011). The socio-economic status of countries in relation to proper conservation policies plays a major role in red listing. As stated previously, a clear relationship exists between the amount of threatened or declining taxa and various indices of economic inequality (Mikkelson et al., 2007). In an analysis of EU LIFE funding patterns, it has been shown that south European countries, albeit usually richer in biodiversity, received less funds for conservation actions than northern countries with a generally lower diversity (Adamo et al., 2022).

Although red list data are often used to inform conservation management practices (Rodrigues et al., 2006) it is important to note that they do not necessarily carry direct legal consequences (Rossi et al., 2016) or to prioritize conservation actions (Mace et al., 2008; Mace and Baillie, 2007). It is ultimately up to individual countries to determine how they will use this information to shape their conservation policies and practices. Beside red lists, there are other documents (particularly at national levels) declaring protected and strictly protected taxa that are not identified with extinction risk assessment but with more regulated conservation measures (Brito et al., 2010; Fenu et al., 2017). As a result of an internal questionnaire distributed among COST Action ConservePlants participants (CA 18201), we found that out of 43 participating countries, only 11 can confirm that red list assessments lead to legal consequences at the national level on at least on some group of species. In most cases (19 out of 43) red list assessments maintain only their recommendation role to support legal actions for conservation or imply in national or regional conservation actions (14 out of 43). In the European context, in recent decades much attention has been paid to nature conservation policies adopted and implemented in member or candidate countries of the European Union. The main focus of European nature conservation has been on the implementation of the Habitats and Birds Directives. While red lists are drawn up at national (or regional) level and cover a broader spectrum of biodiversity, providing a more comprehensive overview of a country's conservation priorities, the Bird and Habitat Directives operate at supranational level within the European Union and focus on specific taxa and habitats. Considering the Habitat directive, at the level of plant conservation, this primarily means achieving objectives related to taxa listed in Annex II and in some cases in Annexes IV and V. However, the listing of taxa in the Annexes does not

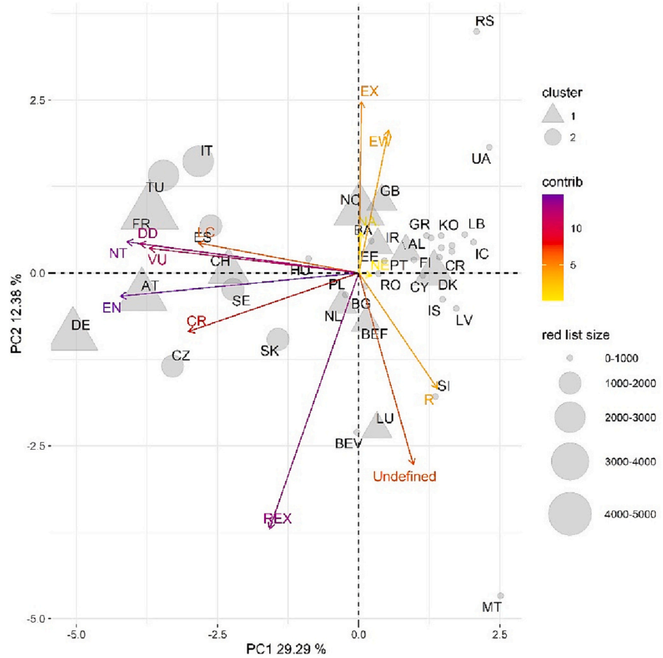

Fig. 4. Results of principal component analysis presented on the first two axes for the overall distribution of Red List categories by country (indicated by acronyms). Each country is represented with the cluster symbol according to Ward's classification into two main groups: the whole flora included in the Red List (Red listed = 1; cluster 1) or a part of the whole flora included in the Red List (Red listed <1; cluster 2). The size of the symbol corresponds to the number of taxa included in the national Red List. The arrows indicate the direction and contribution of the influence of the Red List categories to the total variability.

fully reflect their extinction risk: some currently listed taxa have a relatively low extinction risk, while some other, currently not included in the Annexes, should arguably be considered of higher conservation concern (Amos, 2021; Moser et al., 2016). In addition, a total of 592 vascular plant taxa are listed in Annex II of the Habitats Directive. Given the 6987 taxa listed in Europe's national red lists across 37 countries as threatened (Holz et al., 2022), we can conclude that <10 % of Europe's threatened flora is classified as a priority for conservation in Habitat Directive. One possible reason for the incomplete red list assessments in certain countries from the biodiversity-rich European southeast, particularly those aspiring for EU membership, is the prioritization of actions aimed at fulfilling EU commitments.

One of the important issues arising from our results is the relevance of the inclusion of countries' whole floras in the assessments. Almost three quarters of the European red list assessments have been conducted for only a selected number of taxa. When comparing total assessments to partial ones, we found a greater proportion of threatened taxa in the first group. However, there are also countries or regions that include a very large number of taxa in the assessment (e.g. Sweden, Czech Republic, Wallonia). Although they do not consider the entire flora, a similar pattern can be recognised with a large proportion of taxa considered threatened. By assessing a limited number of taxa only, we thus risk overlooking the conservation status of less attractive or taxonomically problematic taxa. It is generally observed that more conservation concern is paid to the more charismatic taxa, especially animals (Colléony et al., 2017). However, similar biases are found also in plant conservation. This is clearly evident in the tendency for morphological and colour characteristics to have a significantly greater influence on the selection of wild flowering plants to be studied than characteristics related to ecology and rarity (Adamo et al., 2021). The same was observed in the overview of the EU LIFE funding patterns, where more funding was allocated to more attractive plants, regardless of their extinction risk (Adamo et al., 2022). The lack of taxonomic and

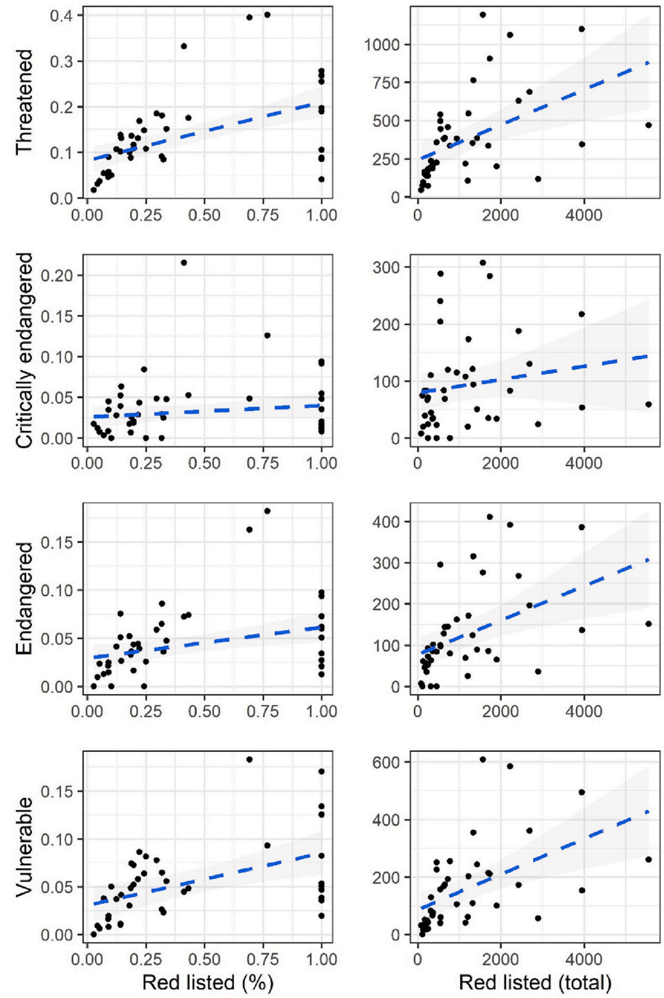

Fig. 5. Results of the robust linear models (RLM) applied to fit the relationship between percentage value of Critically endangered, Endangered, Vulnerable taxa and their sum (Threatened) and the percentage of total flora (left). Results of linear models (LM) applied to fit the relationship between total number of Critically endangered, Endangered, Vulnerable taxa and their sum (Threatened) and the total flora (right). The summarized results of each model are shown in Table 1.

distribution data, together with data on the biology of species, is identified as one of the main factors preventing adequate conservation (Aronne et al., 2023; Whittaker et al., 2005). However, financial capabilities play an important role in determining the extent of these shortcomings. In this study, we have shown that countries in which the entire flora was assessed have higher mean values of national expenditure on environmental protection within the overall economy. Interestingly, these are also the countries with the highest GDP (gross domestic product), so one could argue that the differences may be the result of cost differences. However, according to Jacobsen and Hanley (2009) the demand for biodiversity conservation increases with the wealth of a nation, leading countries with a high GDP to engage more intensively in conservation measures, as shown by the fact that the entire flora in these countries was assessed.

Red lists are valuable tools for biodiversity conservation, providing us with information on severity of threats to all or selected taxa that have been considered in the assessment. They are an important warning and monitoring system for biodiversity. The extent to which conservation measures are derived from the assessments and implemented is another matter. But even without legal status, the red lists are already a success story in Europe, as they (usually) cover a larger number of species within

Table 2
Summarized results of the robust linear models (RLM) applied to fit the relationship between percentage value of Critically endangered, Endangered, Vulnerable taxa and their sum (Threatened) and the percentage of total flora (Red listed (%)). Summarized results of linear models (LM) applied to fit the relationship between total number of Critically endangered, Endangered, Vulnerable taxa and their sum (Threatened) and the total flora (Red listed (total)).

	Red listed (%)				Red listed (total)			
	Estimate	Std. error	t value	p	Estimate	Std. error	t value	p
Threatened	2.22	0.492	4.513	<0.05	5.057	0.070	1.366	<0.05
Critically endangered	1.752	1.733	1.011	>0.05	2.536	2.332	1.087	>0.05
Endangered	4.005	0.914	4.383	<0.05	5.208	1.586	3.284	<0.05
Vulnerable	5.057	0.989	5.113	<0.05	4.165	1.134	3.673	<0.05

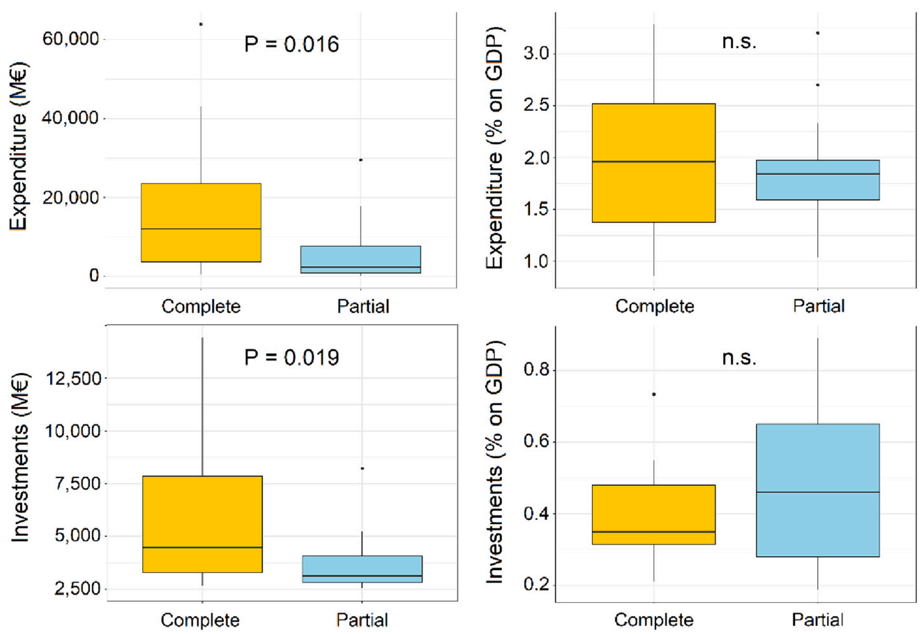

Fig. 6. Differences between countries where the flora was completely assessed (yellow boxplots) and countries where the flora was only partially assessed (light blue boxplots) in terms of expenditure on environmental protection (in millions of euros and percentage on GDP) and environmental protection investments of the total economy (in millions of euros and percentage on GDP). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

a group, unlike the Habitats Directive or other international conservation protocols, which only consider selected taxa. As Parties to the CBD, countries should work to achieve the shared objectives and targets of the Global Strategy for Plant Conservation. National conservation priorities should be established to ensure an assessment of the conservation status of as many known plant taxa as possible. To provide meaningful warning tools, assessments should be repeated regularly using standardized and comparable methods. Through the storage and presentation of these results in ready and usable systems, with quick and easy access, would ideally support the future implementation of strategies and effective conservation measures for the European vascular flora.

4.1. Implications for practice

Red lists fulfil important political, social, and scientific needs in biodiversity conservation and avoid subjective judgement of a particular taxon. National red lists often serve as a readily available resource for in-country decision makers to achieve systematic and defensible biodiversity investment decisions. However, the major shortcomings of using incomplete, inconsistent, and/or outdated red lists are the bias in decisions making especially during species-based conservation programs and the inability to visualize and quantify the impact of threat to biodiversity across a biogeographic range (e.g., Europe) due to the narrow taxonomic, spatial, and temporal coverage. This demonstrates the need for thoughtful decision making when using red lists during inherent trade-offs between taxa (e.g., red listed vs. non-red listed). As this study shows, red lists that cover a preselection of taxa can under-represent the full range of taxa threatened with extinction in a country. There is an urgent need for national, regional, and local policy makers and professionals to focus and allocate resources on red listing of the complete national flora by using IUCN recommended standards and update them at regular intervals. Findings of our study can be used as a knowledge base to formulate a roadmap to close the gap and variability in red listing along with capacity building and resource allocation within and across countries, through a coordinated framework and network of partnerships.

CRediT authorship contribution statement

Peter Glasnović: Writing – review & editing, Writing – original draft, Supervision, Formal analysis, Data curation, Conceptualization. **Edy Fantinato:** Conceptualization, Data curation, Formal analysis, Writing – original draft, Writing – review & editing. **Gabriella Buffa:** Data curation, Writing – original draft, Writing – review & editing. **André Carapeto:** Writing – review & editing, Writing – original draft, Data curation. **Snežana Dragićević:** Writing – review & editing, Writing – original draft, Data curation. **Živa Fišer:** Writing – review & editing, Writing – original draft, Data curation. **Michael Kiehn:** Data curation, Writing – original draft, Writing – review & editing. **Tiiu Kull:** Data curation, Writing – original draft, Writing – review & editing. **Marcin**

Klisz: Data curation, Writing – original draft, Writing – review & editing. **Udayangani Liu:** Data curation, Writing – original draft, Writing – review & editing. **Martina Lužnik:** Writing – review & editing, Data curation, Writing – original draft. **Detlev Metzing:** Writing – review & editing, Writing – original draft, Data curation. **Anastasia Stefanaki:** Writing – review & editing, Writing – original draft, Data curation. **Nina Lončarević:** Writing – review & editing, Writing – original draft, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

Nothing to declare.

Data availability

Data available within the article or its supplementary materials

Acknowledgements

This article is based upon work from COST Action CA18201 — An Integrated Approach to Conservation of Threatened Plants for the 21st Century (ConservePlants), supported by COST (European Cooperation in Science and Technology). This paper is based on results of activities developed by the WG3 – Filling the gaps in plant conservation. We greatly acknowledge all who helped us to gather the information: Karin Ahrne, Necmi Aksoy, Dalibor Ballian, Oz Barazani, Igor Boršić, Magda Boudagher, Guy Colling, Joana Cursach Seguí, Cvetanka Cvetkovska, Laura Daco, Andreas Ensslin, Marianne Evju, Jozef Pal Frink, Sandrine Godefroid, Johan Gourvil, Marko-Tapio Hyvärinen, Rhea Kahale, Renata Kjushterevska, Elez Krasniqi, Sandro Lanfranco, Maja Lazarević, Predrag Lazarević, Conor Meade, Koenraad Van Meerbeek, Tine Mlač, Jesper Moeslund, Taras Parpan, Dhimiter Peci, Theodora Petanidou, Radoslaw Puchalka, Valerijus Rašomavičius, Gabriela Romanciuc, Ieva Rurane, Murat Sarginci, Ole Seberg, Suzanne Sharrock, Jozef Sibik, Pete Stroh, Boštjan Surina, Katalin Szitár, Rannveig Thoroddsen, Ivaylo N. Tsvetkov, Philippine Vergeer, Petr Vit, Margareta Walczak.

Appendices. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2024.110568.

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