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Spider conservation in Europe: a review

Filippo Milano^{a,1}, Theo Blick^b, Pedro Cardoso^c, Maria Chatzaki^d, Caroline Sayuri Fukushima^c, Peter Gajdoš^e, Alastair T. Gibbons^f, Sergio Henriques^{g,h,i}, Nuria Macías-Hernández^{c,j}, Stefano Mammola^{c,k}, Wolfgang Nentwig^l, Myles Nolan^m, Julien Pétilionⁿ, Nina Polchaninova^o, Milan Řezáč^p, Jonas Sandström^q, Helen Smith^r, Konrad Wiśniewski^s, Marco Isaia^{a,1,*}

^aDepartment of Life Sciences and Systems Biology, University of Turin, Italy

^bHummeltal, Germany

^cLaboratory for Integrative Biodiversity Research (LIBRe), Finnish Museum of Natural History (LUOMUS), University of Helsinki, Finland

^dDepartment of Molecular Biology and Genetics, Democritus University of Thrace, Greece

^eInstitute of Landscape Ecology, Slovak Academy of Sciences, Bratislava, Branch Nitra, Slovakia

^fSchool of Life Sciences, University of Nottingham, University Park, Nottingham NG7 2RD, UK

^gInstitute of Zoology, Zoological Society of London, Regent's Park, London NW1 4RY, UK

^hDepartment of Genetics, Evolution and Environment, Centre for Biodiversity & Environment Research, University College London, Gower Street, London WC1E 6BT, UK

ⁱGlobal Center for Species Survival, Indianapolis Zoological Society, 1200 West Washington Street, P.O. Box 22309, Indianapolis, Indiana 46222, USA

^jDepartment of Animal Biology, Edaphology and Geology, University of Laguna, La Laguna, Tenerife, Canary Islands, Spain

^kMolecular Ecology Group (MEG), IRSA – Water Research Institute, National Research Council, Verbania Pallanza, Italy

^lInstitute of Ecology and Evolution, University of Bern, CH-3012 Bern, Switzerland

^mc/o National Museum of Ireland - Natural History, Merrion St, Dublin 2 D02 F627, Ireland

ⁿUMR CNRS 6553 Ecobio, Université de Rennes, France

^oV.N. Karazin Kharkiv National University, Maidan Svobody 4, 61027 Kharkiv, Ukraine

^pFunction of Invertebrate and Plant Biodiversity in Agrosystems - Crop research Institute, Drnovska 507, CZ-16106 Praha 6 - Ruzyne, Czechia

^qSwedish University of Agricultural Sciences, Swedish Species Information Centre, Box 7007, S-75007 Uppsala, Sweden

^rBritish Arachnological Society, Waveney Cottage, Redgrave Road, South Lopham, Diss IP22 2JN, UK

^sInstitute of Biology and Earth Sciences, Pomeranian University in Słupsk, Arciszewskiego 22b, 76-200 Słupsk, Poland

*Corresponding author.

E-mail address: marco.isaia@unito.it (M. Isaia).

¹Equal contributions.

Abstract

Despite their ecological importance and diversity, spiders (Arachnida: Araneae) are underrepresented in conservation policies in comparison to other groups. We review all extant conservation tools focusing on spiders in Europe, highlighting general patterns, limitations, gaps, and future directions. We assembled a comprehensive online database reporting all available information concerning the legal protection and conservation status of 4,154 spider species. Existing international legislation has limited coverage, with only one species listed in the Bern Convention and EU Habitats Directive. At the national and subnational levels, 178 species are formally mentioned in the legislation of 19 European countries. Moreover, the International Union for Conservation of Nature (IUCN) includes assessments for 301 species worldwide, 164 of these threatened and eight native to Europe. In addition, spiders are mentioned in Regional Red Lists and Red Books in 28 out of 42 European countries considered in this review. Northern and Central European countries have the highest percentage of species assessed at the regional level in Red Lists and Red Books. The Mediterranean basin has the highest spider diversities in Europe but conservation efforts are lacking, both in terms of assessments and national or subnational legislation. Among European species, *Dolomedes plantarius*, *Argyroneta aquatica* and *Eresus kollari* are the most frequently mentioned in European conservation measures, possibly due to their ecological traits and their strict association with declining habitats. Considering the current threats to spiders in Europe, the protection of large areas of suitable habitat should be considered as the most effective approach to spider conservation.

Keywords: IUCN, invertebrate conservation, Araneae, Red List, environmental legislation, threatened species

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1. INTRODUCTION

Compared to other animal groups, especially vertebrates, invertebrates have similar or even higher extinction rates and proportions of threatened species (Cardoso et al., 2011), and are in urgent need of protection and monitoring (Cardoso et al., 2020; Samways et al., 2020). Yet, in conservation programmes invertebrates are largely neglected, both at regional and international scales. In addition, despite the global dominance of invertebrates in terms of richness, abundance, biomass and importance in ecosystem functioning (Stork, 2018; Wilson, 1987), the majority of biodiversity conservation research and effort is currently focussed on a few, well-known vertebrate taxa (Clark and May, 2002; Cardoso et al., 2011; Davies et al., 2018; Fukushima et al., 2020; Leather, 2013; Mammola et al., 2020b; Titley et al., 2017).

Among terrestrial invertebrates, spiders (Arachnida: Araneae) are one of the most important groups in terms of abundance, diversity, biomass, evolutionary history, and functional roles (Cardoso et al., 2008; Coddington and Levi, 1991; Coddington et al., 1991, 2009; Dunlop et al., 2018; Foelix, 2011; Jocqué et al., 2013; Mammola et al., 2017b; Nentwig, 2013; Turnbull, 1973). With more than 48,000 species currently described (World Spider Catalog, 2020), spiders are among the most common and ubiquitous animals in the majority of terrestrial habitats, where they play an important role as generalistic predators (Turnbull, 1973). A few species have even conquered the aquatic environment (McQueen and McLay, 1983; Seymour and Hetz, 2011). Spider assemblages are particularly diverse in richly vegetated areas, but they can also be found in habitats with stringent environmental constraints such as deserts, caves, and alpine habitats.

Preserving spider diversity, apart from being ethical in the framework of establishing a sustainable relationship with wildlife in general, is essential in recognition of the fact that they play a fundamental ecological role. They are an important food source for higher trophic levels (e.g. reptiles, birds, mammals) and are predators in most terrestrial ecosystems (Nyffeler and Birkhofer, 2017), thus providing vital ecosystem services to humans with respect to the control of arthropod pests in agroecosystems (King and Hardy, 2013; Michalko et al., 2019). Moreover, their silk, venom and hemolymph are a source of inspiration for biological engineering (Heim et al., 2009; Ko and Wan, 2018), pharmacology, and medicine (Corzo and Escoubas, 2003; Pineda et al., 2018; Riciluca et al., 2012). Yet, compared to more popular groups of invertebrates, spiders are lagging in conservation

studies and policies worldwide. For example, only one species among the nearly 4,500 spider species known from Europe, is listed in the EU Habitats Directive, whereas 50 butterflies out of 496 and 16 dragonflies out of 143 feature, demonstrating a remarkable taxonomic bias even within invertebrates (Cardoso, 2011). Furthermore, extinction risk has been assessed for fewer than 100 European species in the Global Red List of the International Union for Conservation of Nature (IUCN), mostly from the Macaronesian archipelagos of Madeira and Selvagens (Cardoso et al., 2017). By comparison, the extinction risk of 97% of European butterflies (van Swaay et al., 2010) and dragonflies (Kalkman et al., 2010) has been assessed.

We reviewed all international and regional conservation tools focusing on spider conservation in Europe, with the goal of highlighting general patterns, limitations, gaps, and future directions in the field of spider conservation. As a result, we compiled a thorough database reporting all available information about the conservation of spiders in European countries, noting Red Lists, Red Books, and any supranational, national and subnational legal acts referring to spiders (see Table A1 in Appendix A and Milano et al., 2021a, b). We also intend to add this information to the joint European network “Araneae – Spiders of Europe” (Nentwig et al., 2020).

2. DATA SOURCES

Conservation tools concerning spiders in Europe were investigated at international and regional levels. These included international conventions, regulations and EU Directives, national and subnational acts in force in the European countries considered, the IUCN Red List of Threatened Species, Regional Red Lists and Red Data Books. An overview of the conservation tools currently dealing with spiders in Europe is presented in Table 1.

We examined 42 European countries that are included in the European spider network “Araneae – Spiders of Europe” (Nentwig et al., 2020). Enclave and semi-enclave countries (Monaco, San Marino, and Vatican City), non-independent countries (Andorra), North African and South Caucasian countries, as well as the Outermost Regions and Overseas Countries and Territories of European countries were excluded. Russia is not considered in

this review, due to the lack of a national Red List for spiders and the difficulty of comparing the numerous (at least 140) regional non-IUCN Red Data Books (Popov et al., 2017).

In order to have a standard reference for all countries considered, we derived national species checklists from the most recent version of “Araneae – Spiders of Europe” (Nentwig et al., 2020). Updates or changes to national checklists not implemented in this source were not considered.

For each country examined, we obtained all the published local Red Lists, Red Books and legal acts concerning spiders, by means of literature surveys and with the assistance of a wide network of local experts and contributors (see acknowledgements). Whenever a country was not covered, information was derived from bibliographic surveys. We considered only the most recent versions of the regional Red Lists and Red Data Books and the currently valid legislation, and we carried out separate analyses on the different geographic levels adopted in each.

To ensure comparability, we assumed the categories of threat from different category systems as equivalent. Species listed as “Critically Endangered (Possibly Extinct)” were considered as Critically Endangered (CR). Species not evaluated or listed in the category “Not Applicable” (NA), were not considered in this review, as they are ineligible for assessment (IUCN, 2012b).

Disclaimer on taxonomy and terminology used in this work

The nomenclature used in this work refers to the latest version of the World Spider Catalog (2020). Species assessed by Red Lists or Red Books currently regarded as *nomina dubia* were not considered. For species split subsequently into multiple species, we applied the original assessments to the new species and note the taxonomic changes. In the case of a species lumped with another assessed within a different IUCN category, we adopted a precautionary approach and retained the higher risk category. Synonymies, misidentifications, and nomenclatural changes all followed current taxonomy as represented in the World Spider Catalog (2020). As a consequence, the final number of species reported in this review may differ from the number assessed in the original Red Lists and Red Data Books.

According to the definition of the IUCN (IUCN, 2012a), we used the term “Regional” in reference to any sub-global geographical level of assessment. However, here we used the terms “national”, “subnational” and “supranational” Red Lists in order to discriminate the

level at which the regional assessment was performed. The term “Global” is used when referring to the IUCN Red List of Threatened Species. We use the term “international” to define tools involving more than one country, irrespective of whether they have a European (Bern Convention and Habitats Directive) or global origin (IUCN).

3. INTERNATIONAL CONSERVATION TOOLS

Among the extant international tools focusing on the preservation of nature in Europe, very few mention European spiders. They are limited to the Bern Convention, the Habitats Directive and the Red List of Threatened Species of the IUCN. The Convention on International Trade in Endangered Species of wild fauna and flora (CITES) also considers spiders, but none of the spider species mentioned therein occur naturally in Europe, and therefore it is not considered in this work (for details, see Table 1 and Appendix B).

Bern Convention

The Bern Convention (Council of Europe, 1979), is the first formal international convention providing specific attention to the conservation of species in Europe, including spiders. A provisional list of candidate invertebrate species was initially proposed for inclusion in the Convention by the IUCN Conservation Monitoring Centre (Collins and Wells, 1987). The list was subsequently adopted by the Standing Committee as the basis for additions to the appendices of the Convention.

Two spider species were included in the provisional list: *Dolomedes plantarius* (Clerck 1757) (Pisauridae) and *Macrothele calpeiana* (Walckenaer 1805) (Macrothelidae), but only the latter was retained in the Bern Convention. *Macrothele calpeiana* is currently listed in the “strictly protected fauna” of Appendix II, granting it special protection against all forms of disturbance, capture, keeping, deliberate killing, and damage or destruction of breeding or resting sites. The restricted distribution of *M. calpeiana* (back then regarded as endemic to the Southern Iberian Peninsula), and the fragmentation and destruction of its putative preferred habitat in cork oak forests (*Quercus suber* L.), represented the main reasons for its inclusion in the Convention (Snazell, 1986; Snazell and Allison, 1989).

Habitats Directive

Following on from the Bern Convention, the Habitats Directive (92/43/EEC) was the first international law to regulate European conservation policy concerning spiders.

Once again, the only spider species mentioned in the Habitats Directive is *M. calpeiana*, listed in Annex IV among the species of European interest in need of strict protection. Unlike the Bern Convention, the Directive is mandatory, and the Member States are obliged to protect and monitor the conservation status of *M. calpeiana* and its habitat (Article 12), particularly through the establishment of a network of protected sites. Its main range of distribution is included in, or close to, Natura 2000 network sites and protected areas in the South-Western Iberian Peninsula. The inclusion of this species in the Habitats Directive was a consequence of its appearance in the Bern Convention, which deeply influenced the Directive in both conception and drafting, and constituted the basis for the composition of the lists in the Directive's Annexes (Epstein, 2013; van Helsdingen and Decae, 1992).

IUCN Red Lists and Red Data Books

The IUCN was established in 1948, and was the first international network to consider spiders in conservation issues. One of the most important tools promoted by the IUCN is the Red List of Threatened Species (or, the "Global" Red List), established in 1964 and widely accepted as the most comprehensive and objective source of information on the conservation status of species and their extinction threats (Lamoreux et al., 2003; Rodrigues et al., 2006; but see Cardoso et al., 2011, 2012). The Global Red List is based on a number of objective criteria, which are relatively easy to apply, repeatable and scientifically recognized as adequate indicators of the health of global biodiversity (IUCN, 2001).

The first IUCN Red List of Threatened Animals was published in 1986 by the IUCN Conservation Monitoring Service and it included 18 spider species, amongst which were the spiders mentioned in the first IUCN Invertebrate Red Data Book published three years before (Wells et al., 1983). This provided information on the threats to survival and conservation needs of six spider species: the theraphosid *Brachypelma smithi*, three

subterranean linyphiids (*Troglohyphantes gracilis* Fage 1919, *T. similis* Fage 1919, and *T. spinipes* Fage 1919), and two lycosids (*Adelocosa anops* Gertsch 1973 and *Pardosa diuturna* Fox 1937).

Currently, 301 spider species are listed in the Global IUCN Red List (IUCN, 2021). Three are Extinct, 164 are assigned to one of the three categories of risk (Critically Endangered, Endangered, Vulnerable), and 97 are in Near Threatened or Least Concern categories; further 37 species are in the Data Deficient category). Almost half of the species listed in the IUCN Red List are endemic to the Seychelles Islands (IUCN, 2021). This disproportion is due to the work of Gerlach (2014), who provided the first comprehensive assessment based on formal IUCN criteria of spiders within a geographically restricted region.

More recently, Red Lists and Red Books have been drawn up for geographic areas at different spatial scales (i.e. at the regional level) and for different purposes. Regarding the spatial scales, species evaluated as threatened in the Global Red List are considered endangered worldwide, but this assessment may not coincide with their conservation status at a national or subnational level. While the Global Red List addresses the current and future conservation status of species, i.e. their relative risk of extinction, Regional Red Lists may contribute to the effective conservation of threatened species on a smaller scale, influencing their protection and recovery. Regarding the purposes, whilst Red Books generally contain in-depth analyses of species' status, distribution, factors of decline and conservation measures, Red Lists are usually shorter and more specific, presenting concise references to distribution and status. Table 2 details those European countries which have used IUCN and Red List approaches to spider conservation.

Spider species occurring in Europe mentioned in international conservation tools

International conservation tools offer significant opportunities for the conservation and protection of biodiversity due to their cross-border approaches, long-term commitments, and consideration of the biology of the species (Trouwborst et al., 2017). Species distributions are seldom confined within national boundaries and conservation is an international concern that requires active collaboration among countries through trans-national actions.

At present, only nine spider species out of >4,000 occur in Europe (Nentwig et al., 2020) are considered in international conservation tools. One is included in the Bern Convention and

in the Habitats Directive, whilst the remaining eight are listed in the Global IUCN Red List of threatened species (IUCN, 2021).

The only spider mentioned in the Bern Convention and the Habitats Directive is *Macrothele calpeiana*. However, doubts have been raised regarding the needs of protection of this species and the ecological consequences of its ongoing spread in Europe probably due to commercial export of olive trees (Jiménez-Valverde et al., 2011; further details in the section “Spider species of conservation concern in Europe”).

Importantly, the conservation status of *M. calpeiana* has been recently assessed according to the IUCN criteria (Branco et al., 2019), proving this species to be eligible for the Least Concern category.

Eight native European spiders are listed in the global IUCN Red List of threatened species (IUCN, 2021):

- *Anapistula ataecina* Cardoso & Scharff 2009 (Symphytognathidae): a cave-dwelling spider endemic to a geographically restricted karst system in southern Portugal (Cardoso and Scharff, 2009), regarded as Critically Endangered (Cardoso, 2010).
- *Dolomedes plantarius* (Pisauridae): a semi-aquatic spider species with a Euro-siberian distribution. As a result of habitat loss and degradation, in 1996 the species was classified as Vulnerable by IUCN (World Conservation Monitoring Centre, 1996a). Because it was assessed before the publication of the new IUCN standards (version 3.1, 2001), the evaluation of *D. plantarius* is outdated and hard to compare with more recent ones.
- *Macrothele cretica* Kulczyński 1903 (Macrothelidae): a species endemic to Crete. Until recently, information was inadequate for evaluation of the global risk of extinction, and it was therefore listed as Data Deficient (World Conservation Monitoring Centre, 1996b). This species is listed as Vulnerable in the Red Book for Greece (Chatzaki, 2009).
- *Nothopantes horridus* Merrett & Stevens 1995 (Linyphiidae): Critically Endangered in the global IUCN Red List (Cardoso and Hilton-Taylor, 2015). Thought to be a subterranean-specialist living in limestone fissures, this species is endemic to the UK, where it is known from only three locations in the Plymouth area. It is considered Endangered on the British Red List (Harvey et al., 2017), and is listed in Section 41

of the Natural Environment and Rural Communities Act (2006) as a Species of Principal Importance in England.

- *Vesubia jugorum* (Simon 1881) (Lycosidae): a spider endemic to high altitude rocky areas in the South-Western Alps, straddling the border between France and Italy (Mammola et al., 2016). This species was listed as Endangered in the Global IUCN Red List of Threatened species on the basis of its limited geographic range and the predicted reduction of its natural habitat in the near future due to climate change (Isaia and Mammola, 2018).
- *Troglohyphantes gracilis*, *T. similis* and *T. spinipes* (Linyphiidae): three subterranean species restricted to Slovenia (Mammola et al., 2018a), where they figure in the national Red List due to their rarity (category R) (Uradni list Republike Slovenije, 2002). These species were listed in the first IUCN Red List (IUCN Conservation Monitoring Service, 1986) due to their restricted geographical distribution, and were assessed as Vulnerable in the 1996 IUCN Red List (World Conservation Monitoring Centre, 1996c, d, e), but their status has not been updated since.

4. REGIONAL CONSERVATION TOOLS

Of the European countries which have enacted legislation to safeguard and manage species within their territory, 19 have legislated in some way for spiders. Spider conservation is also promoted by regional Red Lists in 28 countries: we refer to those based on IUCN Criteria as “IUCN Red Lists” and those which do not strictly follow IUCN standards as “non-IUCN Red Lists”.

Spider conservation in European countries

Essential up-to-date information on current spider conservation from each country are presented in Tables 2 and 3. Due to space limitations, a detailed overview referring to (1) Regional IUCN Red Lists implemented at the national or subnational level, (2) Regional non-IUCN Red Lists, and (3) any legislation mentioning spiders promoted by the countries involved, is reported in Appendix B.

Red Lists and Red Data Books of spiders in Europe

A first review on spiders in European Red Lists reporting data from seven countries was published in 2000 (Franc, 2000). Since then, 20 countries have adopted national or subnational red lists considering spiders as an appropriate basis for prioritising and developing national conservation policies. Among the 42 European countries considered in this review, 28 (67%) currently have a list of threatened spider species, 20 of which operate at national level. Eight countries have Red Lists only at the subnational level, whilst seven countries have both national and subnational lists. Figure 1 provides the geographic distribution of national Red Lists and Red Books in the European countries.

Different criteria were used for assessing the conservation status of species. Several threatened species datasets in Europe follow IUCN criteria, but some countries utilise alternative categories and criteria. The IUCN assessment process has received wide acceptance and is being used consistently at national and other regional scales (Gärdenfors, 2001). Ten countries based their national Red Lists or Red Data Books on the most recent version of IUCN criteria (IUCN, 2001, 2012b), namely Bulgaria, Croatia, Denmark, Finland, Greece, Kosovo, Norway, Spain, Sweden and Great Britain. Slovakia adopted the 1994 IUCN criteria for their national lists (IUCN, 1994), whilst Latvia and Lithuania adopted a pre-1994 version.

The remaining countries with national inventories used national guidelines (see Blick et al., 2016), or based them on expert opinion (see, e.g., Groppali and Priano, 1992), or utilised modified IUCN Categories and Criteria (see for example Głowaciński and Nowak, 2004, Řezáč et al., 2015 and Staręga et al., 2002). Many such Red Lists were developed before the regional IUCN guidelines were published, as is the case with Germany where a standardised assessment scheme was developed and has been maintained since the 1970s by the Federal Agency of Nature Conservation (DS/IRV, 1971; Sukopp, 1974). As previously noted, other national lists were drawn up using alternative and highly individual categorization systems, for example, Italy (Groppali and Priano, 1992) and Slovenia (Uradni list Republike Slovenije, 2002). In these inventories categories of risk differ widely and criteria and category definitions are often neither explicit nor transparent.

In addition to national Red Lists, the Czech Republic, Denmark, Germany, Italy, Poland, Slovakia, and Spain also have subnational ones, which assess the conservation status of

spiders in one or more specific regions or districts of the country. Germany has the highest number of inventories of threatened spiders (13), including the national list and the supranational list (Wadden Sea).

Eight countries have supra- or subnational Red Lists but no national one. In France, spiders occurring in Nord-Pas-de-Calais and Picardie were assessed following the regional IUCN guidelines (Groupe ornithologique et naturaliste du Nord-Pas-de-Calais, 2018; Picardie Nature, 2016). As a result of the IUCN assessment carried out for selected taxonomic groups occurring in the whole Carpathian Region (Kadlečík, 2014; Mateleshko and Potish, 2011) a certain proportion of spiders in the Carpathian areas of Hungary, Romania, Serbia and Ukraine have been assessed according to IUCN guidelines. Furthermore, in Ukraine, there are also two other regional Red Lists (Tokarsky, 2013; Zalevskiy and Bronskov, 2017), drafted according to the national criteria adopted by the Red Book of Ukraine (Akimov, 2009).

The remaining countries (Austria, Belgium, Netherlands) used national criteria (e.g., Komposch and Steinberger, 1999) or regional IUCN guidelines which were integrated with different systems of evaluation (e.g., Maelfait et al., 1998 and Vangsgård et al., 1996). In Belgium (Maelfait et al., 1998), where the conservation of nature is responsibility of the regional governments, the Flemish red list of spiders is based on the 1994 IUCN criteria (IUCN, 1994) and on the criteria used in Germany (Schnittler et al., 1994). In the Red Book of the Wadden Sea area (von Nordheim et al., 1996), the approach to assessment is based on a combination of the IUCN criteria and the German (Blab et al., 1984) and the Danish (Asbirk and Søgaaard, 1991) systems. The geographic distribution of the subnational Red Lists in the European countries is displayed in Figure C3 Appendix C.

Although many European countries and regions now have Red Books and Lists of their threatened spiders, the lack of standardisation in the categories and criteria used is problematic. The alteration or misinterpretation of IUCN guidelines may lead to confusion if modifications of the criteria are not explicitly stated (Miller et al., 2007). If it were the case that every country applied its own approach, the criteria adopted would be subject to high levels of subjectivity which would reduce the comparability among regional Red Lists. For example, terms such as “vulnerable” or “endangered” have different meanings according to different evaluation systems. In addition, the category “rare” is used by several authors (Blick et al., 2016; Groppali and Priano, 1992; Komposch and Steinberger, 1999; Maelfait et al.,

1998) even though it pertains to the ecological characteristics of a species rather than its category of risk (de Grammont and Cuarón, 2006).

Such variation in national listings makes it difficult to synthesize information from different countries which is vital in order to create a general overview; this, in turn, can hamper efforts to consolidate information and provide recommendations.

To reduce bias and limit these inconsistencies, we recommend that standardised categories and criteria, as well as a unified categorisation system, are implemented and utilised. Currently, the only widely adopted system worldwide is the one by IUCN, which theoretically allows comparison of results from different countries and taxa under a common framework. This could be adopted across countries to guarantee such comparability and hence contributing to analyses beyond national borders. An effort must be made to guarantee similar interpretation of criteria, which is often hard and rarely accomplished, but essential for future protection of species whose ranges span different countries.

Threatened species in Red Lists and Red Data Books across Europe

One of the main problems facing spider conservation in Europe is the general lack of information on their true conservation status. Data are incomplete in the vast majority of the spider species, and are usually limited to the knowledge of their national occurrence. Detailed information on national distributions of species, ecological requirements, and threats affecting them at the regional level, are available only for certain countries. Efforts have been made primarily in Central and North-Western European countries, where national inventories of threatened species cover the highest percentage of resident spider species.

Overall, 1,552 (37%) of the 4,154 spider species currently known in the European countries considered (Nentwig et al., 2020) are assessed by regional inventories focusing on their conservation status. Czech Republic, Denmark, Finland, Germany, Norway, Sweden and the UK, list the majority of their native spider fauna, all with coverage >90% (Figure 3). This can be attributed to these countries having a greater number of arachnologists and local experts, resulting in a broader understanding of the spider fauna occurring within their national borders and, consequently, in higher numbers of spiders being assessed in national

inventories (see Table C3 in Appendix C). Conversely, in many other countries, only iconic species have been comprehensively assessed. The countries with the lowest species assessed-known ratio are Belarus and Lithuania (both 0.2%; 1 species out of 481 and 476, respectively), followed by Bulgaria (0.5%; 5 species out of 1,045) and Latvia (0.8%; 4 species out of 502). This low coverage in the assessment of native spider species is likely due to the scant number of local arachnologists and to the related deficit of adequate information with regard to the national distribution of species and their population size and dynamics.

The Mediterranean countries also have a low proportion of spiders assessed. Italy is one of the most species-rich countries in Europe (1,702 spider species), but has only assessed 148 species (8.7%). In Spain the ratio is even lower, with 10 out of 1386 species (0.7%) listed in the national Red Book, whilst Greece has 1285 species recorded but only 32 (2.5%) have been assessed (see Figure 3 for an overall comparison).

This significant lack of information on the status of spider species in the Mediterranean region is mainly the result of taxonomic (many less-known or recently described species) and geographical (only generic or partial data on species distribution range) uncertainty. Even if in some countries most of the species are recognized to be present, little is known regarding their distribution, and the overall knowledge of spiders is far from complete (Cardoso, 2008). Furthermore, the high frequency of endemic species in the Mediterranean countries, which are generally not well known or studied, contributes to the general difficulty in assessing species conservation status.

Regarding supranational Red Lists, the most species-rich list is the Carpathians Red List (Kadlečík, 2014), which considers 1,067 spider species (1,040 according to the current taxonomy) that occur across Czech Republic, Hungary, Poland, Ukraine, Romania, Serbia and Slovakia. This list complements the former version of the IUCN Carpathian List (Witkowski et al., 2003), which listed only 15 species of spiders for the Czech Republic and Slovakia. Other supranational lists available in Europe are the Red List of Upper Silesia, assessing 508 spiders (506 following the current taxonomy) from the Polish and Czech Silesia, and the Red List of the Wadden Sea, with 55 species assessed, occurring across the coastal region along Denmark, Germany and the Netherlands.

All the current Red Lists and Red Books on spiders in Europe were published after 1989, which is the year of publication of the oldest still valid national list on threatened spiders (the

Red Data Book for the Maltese Islands by Schembri and Sultana, 1989). Conversely, Denmark, Finland, Norway, Sweden and the UK have the most recent Red Lists, all published after 2015. Among Central European countries, Germany and Czech Republic have very recent assessments as well (2016 and 2015, respectively).

Due to both the difficulty in comparing the different evaluation systems used to produce national red lists, and to the lack of information on the conservation status of species, any depiction of Europe's threatened spider fauna cannot be complete or balanced. However, the inclusion of certain species in red lists across Europe does provide useful insights into species of conservation concern in Europe in general.

Overall, the highest number of regionally extinct and threatened spider species has been assessed from Central-eastern Europe (Figure 4). Czech Republic has the highest number of species assessed as regionally extinct, 26 out of 893 species occurring nationwide (3%), followed by Slovakia with 15 species (1.6%), and Germany with 7 species (0.7%) considered extinct or lost. Czech Republic also has the highest number of species considered as threatened (360 species, corresponding to more than 40% of the national spider fauna), followed by Slovakia with 260 species (27%), Germany with 254 (25%) and Poland with 206 spider species (24%).

These results would suggest a geographical pattern with a greater concentration of threatened species in Central and Eastern European countries. However, this picture remains crude. First, different assessment methods have been adopted in drafting national Red Lists so the definition of "threatened" may be inconsistently applied. Second, in some countries, assessments are limited to species supposed to be threatened *a priori*, i.e. those selected on the basis of expert judgment, without taking into consideration the entire national fauna. Third, some countries consider a limited number of species which are often regionally or ecologically clustered. Fourth, some countries do not even have a national Red List on spiders. Accordingly, these results are preliminary and are limited to those countries which both have a Red List and assess their spiders at national level.

Nevertheless, our results show similar geographic patterns to those seen in other terrestrial invertebrate groups, for which there is more comprehensive information available (Nieto and Alexander, 2010; Nieto et al., 2014; van Swaay et al., 2010). It has been shown that Central and Eastern European countries are hotspots for threatened species within Europe, and it is likely that our results on spiders follow a similar trend.

It is likely that this trend can be attributed to several factors: high anthropogenic pressure in these countries; agricultural improvements; changes to grassland and woodland management; infrastructure development; the degradation and drainage of wetlands, as well as isolation and loss of habitat connectivity. These threats are mostly in line with those identified as the more relevant to spider species worldwide (Branco and Cardoso, 2020). In addition, it could be argued that intensive environmental changes are more recent in Eastern countries, making the related effects on species more visible than elsewhere in Europe. These factors have led to a considerable decline in terrestrial invertebrates, particularly in Central and Eastern Europe (Birkhofer et al., 2017; Cáliz et al., 2018; Farkač et al., 2005; Hallman et al., 2017; Maes et al., 2019; Nieto and Alexander, 2010; Nieto et al., 2014; Seibold et al., 2019; van Swaay et al., 2010, 2012).

These geographical patterns have also been confirmed at a smaller scale. In the Carpathians Red List, the highest number of threatened species was recorded in the Slovak, Czech and Polish Carpathians (Kadlečík et al., 2014). In the Slovak part of the Carpathian Mountains, 1% of the spider species considered are regionally extinct (n=13) and more than 20% are threatened. Three spider species are known to occur in this region that are considered extinct in the Czech Carpathians, 25% of spiders have been assessed as threatened, whilst 15% are threatened in the Polish Carpathians (Kadlečík et al., 2014). For these regions the main threats are associated with industrialization and agricultural intensification around the mid-20th century, leading to a gradual anthropisation of the territory, and subsequent habitat loss and degradation (Kadlečík et al., 2014).

In Mediterranean Europe, the large-scale transformation in land use over the last few decades, the prevalence of wildfires, tourist developments, and unbridled urbanisation has resulted in large-scale alterations of the natural environment (Cuttelod et al., 2008). This has very likely impacted a high number of spider species and many with restricted ranges are possibly threatened or extinct. However, without accurate knowledge concerning their actual status, the real proportion of threatened species is hard to quantify.

In contrast, Northern European countries have the lowest percentage of threatened species. In Finland, only 21 spiders (3% of the national spider fauna), are considered threatened, and one species is described as regionally extinct (Hyvärinen et al., 2019). In Sweden, 20 species (3%) are assessed as threatened, and one as regionally extinct (SLU Artdatabanken, 2020). Norway considers 34 spiders endangered or 5% of the national

spider fauna (Henriksen and Hilmo, 2015), whilst Denmark has assessed 79 species as threatened (14%) and two species extinct (Bruun and Lissner, 2019). In these countries the majority of threatened species live primarily in forests, and thus changes to the forest environment, e.g. forestry, reduction of old forests, reforestation, and forest management, represent the major threats (SLU Artdatabanken, 2020; Bruun and Lissner, 2019; Henriksen and Hilmo, 2015; Hyvärinen et al., 2019). Furthermore, a large proportion of threatened species occur in semi-natural habitats, mainly traditional meadows and pastures, which have declined greatly over the past hundred years (SLU Artdatabanken, 2020; Bruun and Lissner, 2019; Henriksen and Hilmo, 2015; Hyvärinen et al., 2019). Climate change inevitably poses a large threat to species found in northern alpine areas, as well as to species occurring in wetlands and mires (SLU Artdatabanken, 2020; Hyvärinen et al., 2019).

Spiders in legislation in European countries

Generally, the institutions which most directly influence conservation actions and legislation are national or subnational governments. Conservation policies are mainly implemented at national and subnational levels. But, in Mediterranean countries the current national legislation on the protection of fauna and flora mainly derives from the transposition of EU legislation. National governments apply the provisions set forth under binding international conventions on nature conservation.

Among the 28 European countries that provided a threatened species list, 19 included spiders in national or subnational legislation (Figures 2 and 5, Table 3). These consider the threat status of a species when designating conservation priorities, planning conservation efforts or allocating conservation funds.

Most acts of law which incorporate spiders among nationally protected fauna are issued in Central-Eastern European countries. Austria has the highest number of spiders under legal protection, with 111 species, followed by Slovakia, Serbia and Ukraine, all of them listing 17 spider species, and then by Hungary with 16 species, Croatia with 12, and Poland with nine.

On one hand, Northern European countries have a very low percentage of species protected, but the lowest percentage of threatened species, possibly in relation to the low degree of environmental pressures therein. On the other hand, in Mediterranean countries,

few species are mentioned in national or subnational legislation, despite their higher values of spider diversity and the high level of pressure on local biodiversity.

The reasons behind this geographic pattern are not trivial. This could be related to the role of arachnologists in influencing local conservation policies. However, we failed to find a significant relation between the number of spider species listed in legal acts and the number of species assessed as threatened in regional Red Lists and Red Data Books. The same non-significant result was found when correlating the number of spider species listed in legal acts to the number of local arachnologists and experts on country basis (see Table C3 in Appendix C).

Socio-cultural aspects provide a more reliable explanation, in particular when considering local cultural values and the associated perception of wildlife. It is likely that different cultural backgrounds create variable levels of information on the subject of the environment and generate different perceptions about nature conservation. The availability of information on environmental issues may have strong implications for how individuals relate to the environment and perceive environmental policies, resulting in a greater influence in these areas and in related conservation actions. As illustrated in the European Commission report on the attitude of European citizens towards the environment (Eurobarometer, 2008), the best informed citizens are likely to live in the northern and western part of the EU, while those who tend to feel they lack information are likely to come from southern Europe and the new Member States. The media representation of spiders in Southern Europe does not help either (data from Italy; Mammola et al., 2020a). Accordingly, it seems likely that an enhanced awareness of wildlife promotes wildlife conservation even in a neglected group such as spiders.

In some countries a nature conservation economic value per specimen is also provided. In Hungary, this amounts to a monetary value from 5,000 forints to 10,000 forints (ca. 15–30 €) depending on the species. Protected species in Slovakia are valued at 230 €. These economic values refer to all listed species, whether alive or dead, or any part or derivative thereof. According to these economic values, whoever kills a specimen of the protected species may be subjected to the payment of the relative amount.

5. SPIDER SPECIES OF CONSERVATION CONCERN IN EUROPE

Macrothele calpeiana

Macrothele calpeiana (Figure 6) is the only spider protected at the European level, being listed both in the Bern Convention and in the EU Habitats Directive.

The appropriateness of legal protection for this species, as for many other invertebrates, has been called into question (Bellvert and Arnedo, 2016; Jiménez-Valverde et al., 2011; van Helsdingen, 1993; van Helsdingen and Decae, 1992), showing that the selection of species to be protected by environmental legislation at the European scale can be subject to bias (Cardoso, 2011; Leandro et al., 2017).

The rationale underlying the protection of *M. calpeiana* derived fundamentally from knowledge available at the time (Snazell, 1986; Snazell and Allison, 1989), which described both the species and its habitat as threatened. This knowledge has since developed considerably as a result of new and extensive research, which was very likely catalysed by its protected status, and thus consequently revealed a different conservation status.

In addition, *M. calpeiana* is, among spiders, one of those species which better complies with the aesthetic standards that seem to be preferred for a species to be eligible for protection (Collins and Wells, 1987), as the species is highly recognisable and easily identified and detected by the general public. In general, protected invertebrates are significantly bigger than the average invertebrate size (see Leandro et al., 2017), and the fact that *M. calpeiana* is the largest spider in Europe is a relevant factor.

As for many other invertebrates listed in Habitats Directive, the inclusion of *M. calpeiana* does not accurately reflect whether its protection is actually necessary.

IUCN red listed spiders

In the IUCN Global Red List of threatened species, only eight native European spiders currently appear (IUCN, 2021). This scant number explains to some extent the existing under-representation of spiders in the international conservation tools, and indicates a substantial disparity between groups. The number of species in the global IUCN Red List is highly biased in favor of the best-known and more charismatic animals, notably vertebrates, and, amongst invertebrates, Odonata, Lepidoptera and Orthoptera (See Figure C1).

Taxonomic bias in biodiversity conservation has been widely recognized (Cardoso et al., 2011; Donaldson et al., 2016; Leandro et al., 2017; Leather, 2013; Mammides, 2019; Titley et al., 2017), and is mainly due to data deficiencies and technical limitations. However, this unbalanced consideration has deep implications for scientific research and conservation priorities towards spiders, suggesting a compelling need for more evaluations of the conservation status of such species.

Overall, at the national level, 55 spiders in Europe were assessed as Regionally Extinct (or comparable categories) from eight different countries. Among them, only one species, the linyphiid *Agyneta decora* (O. Pickard-Cambridge 1871) is considered extinct in two countries, the Czech Republic and Slovakia.

In the European countries considered, 714 spider species (17%) have been identified as threatened with extinction in national Red Lists, and listed in the IUCN categories Vulnerable (VU), Endangered (EN) and Critically Endangered (CR) or other comparable categories used by other classification systems. In addition, 30 species appear in the threatened categories of national Red Lists or Red Data Books from five or more European countries (Table 4). Many of the 714 species are habitat specialists or have highly restricted ranges (324 species occur in only one country, and 202 species at most in two countries) (Nentwig et al., 2020).

Despite this, only 178 European spiders have full legal protection across the European countries (Figure 5) and only 17 species feature in conservation acts of two or more countries (Table 5). Here we present information on the most frequently mentioned spider species in the European conservation tools.

Dolomedes plantarius

Dolomedes plantarius (Figure 6) is the spider species featuring the most in Red Lists and protection programmes across Europe. It has been assessed by 13 out of 20 European countries in national Red Lists and Red Data Books and features as threatened in seven of them (Table 4). Nine European countries consider *D. plantarius* in acts of law, protecting the species and its habitat (Table 5). The extent of consideration given to this species is related in part to its wide distribution, and especially to the large-scale degradation and loss of its wetland habitat (Duffey, 1995; Leroy et al., 2013, 2014; van Helsdingen, 1993). This habitat has been increasingly subjected to alteration due to land-use intensification, changes in

hydrology, physical modification, eutrophication, and pollution (Junk et al., 2013; Smith, 2000). Wetlands are recognized as being of paramount importance for biodiversity and as a preferential target of conservation efforts, mainly due to the number of threatened and charismatic taxa (Finlayson et al., 2019; Geijzenborffer et al., 2018).

Argyroneta aquatica

Argyroneta aquatica (Figure 6) also inhabits wetlands and has benefited both from this conservation interest and from interest in its unique biology, since it is the only almost wholly aquatic spider species (Seymour and Hetz, 2011). It has been assessed by the national Red Lists of 11 countries, six of which consider it to be threatened (Table 4), and is included in the conservation legislation of seven countries (Table 5).

Marpissa radiata

Marpissa radiata (Grube, 1859) (Figure 6) is another species strictly associated with wetlands. It figures in national Red Lists and Red Data Books of nine countries, seven of which consider it vulnerable (Table 4). However, this species is protected only in Austria, in the 59th Regulation of 2015 of Carinthia (LGBl. Nr. 59/2015). Even if widespread in Europe, this species is rather rare, being confined to wet habitats, and is considered threatened in most of its distribution range as a consequence of wetland decline.

Eresus spiders

Spiders of the genus *Eresus* (Figure 6) often feature in European conservation tools. Currently, 12 species are known to occur in Europe (Nentwig et al., 2020) but only three of them, *E. kollari*, *E. sandaliatus*, and *E. moravicus* Řezáč 2008, feature in inventories on threatened species or in conservation acts. These species were formerly lumped into one morphospecies and have been treated as such in most conservation tools, but recent taxonomic revisions have shown three species are involved (Řezáč et al., 2008; Miller et al., 2012). *Eresus kollari* is one of the most considered spider species in conservation acts of law, figuring as legally protected in seven European countries (Table 5). In addition, it occurs in the national Red Lists of seven countries, and is considered threatened in five of them (Table 4). *Eresus sandaliatus* is considered in five countries, and is protected in four (Tables 4, 5). *Eresus* spiders are mainly threatened by habitat loss and degradation due to anthropogenic pressure, and by large-scale fragmentation of their habitats. Recently, they

have become flagship species for the conservation of relic rocky steppes in several central European countries (Řezáč et al., 2008), and their habitat requirements have been studied in detail (Řezáč et al., 2007, 2018; Řezáč and Heneberg, 2014, 2019). The fact that these species are amongst the most beautiful spiders in Europe (Miller et al., 2012)—which also makes them the most collectable European spiders, also present in the pet trade—may have strongly influenced their inclusion in conservation tools and their consideration as species of conservation concern.

Atypus spiders

The European species of the genus *Atypus* (Atypidae) (Figure 6) are well covered by conservation measures (Tables 4, 5). *Atypus affinis* Eichwald, 1830 has been assessed by six national Red Lists, is considered threatened by three of them and figures in the conservation legislation of four European countries. *Atypus muralis* Bertkau, 1890 is both listed as threatened, and protected, in five countries. *Atypus piceus* (Sulzer, 1776) is listed as threatened in three countries and is protected by law in four countries. These spiders mainly occur in open xerothermic grasslands and are threatened by changes in the management of their habitats, including intensive grazing or the overgrowth of grass and woody plants (Řezáč et al. 2007; Řezáč and Heneberg 2014).

6. PERSPECTIVES AND CONCLUSIONS

Ongoing conservation actions in Europe

At an international level, the increased adoption of tools compliant with the IUCN Red List has added to the number of assessments of spider species. These tools aim to increase the number of evaluations in order to obtain an indicator that reliably represents the overall conservation status of this group (Shirey et al., 2019). However, changes in the overall conservation status of European spiders are still hard to define, due to a lack of both comprehensive knowledge and monitoring data for individual species. To reliably determine trends, it would be necessary to obtain solid baseline knowledge of the current conservation status of species and to perform regular and timely assessments of these species over time, as recently recommended by Harvey et al. (2020) in the roadmap for insect conservation and recovery.

In this regard, the conservation profiles of a sample of 200 species — including several European species — randomly selected from the spider Tree of Life, has been evaluated (Seppälä et al., 2018a, 2018b, 2018c, 2018d). These contributions aim to create a baseline for comparison with a future spider Sampled Red List Index which will ideally operate as a randomized indicator of the changing state of a taxonomic group based on the IUCN Red List criteria (Baillie et al., 2008).

In addition, new standardized sampling protocols for megadiverse taxa have been developed (Borges et al., 2018; Cardoso, 2008; 2009). These aim to facilitate biodiversity assessment and monitoring, and have clear and direct applications in spider conservation. Other approaches suitable for terrestrial invertebrates may be difficult to apply for spiders. For instance, involving citizen scientists in spider surveys may be very useful by way of improving a general lack of knowledge of the group (see Hart et al., 2018 and Wang et al. 2018 for successful examples), and ultimately developing effective conservation strategies (Devictor et al., 2018). However, given that for many species, an expert-based examination of sexual characters is required, this approach may be of limited use.

Our understanding is that several species are currently under regional assessment in different parts of Europe. For example, a recent study confirmed the status of *Macrothele cretica* as Vulnerable since its distribution is restricted to western Crete and its habitat is threatened, putting it at risk of extinction (Chatzaki and Komnenov, 2019).

Similar studies focusing on *Dolomedes plantarius* in Italy (Milano et al., 2018), on the cave-dwelling steno-endemic *Histopona palaeolithica* Brignoli 1971 (Agelenidae) (Mammola et al., 2019a), on the endemic alpine *Pimoa delphinica* Mammola, Hormiga & Isaia 2016 (Pimoidae) (Mammola et al., 2017a), and on cave-dwelling species of *Troglohyphantes* in the Western Alps (Mammola et al., 2018b) underline the need for more detailed knowledge of their status in order to provide new assessments of extinction risk. Concerning *Vesubia jugorum*, a five-year monitoring program led by the University of Turin and the Natural Parks of Mercantour (France) and Alpi Marittime (Italy) began in 2019, aiming to monitor the health of local populations through a trait-based approach (see Mammola et al., 2019b).

In Great Britain, all spiders listed as Species of Principal Importance under the NERC Act (2006) in England, and equivalent acts in Wales, Scotland and Northern Ireland, have action plans prepared for their conservation at national and often also at regional levels. For

many of these rare species, the primary action is still to improve understanding of their status and ecology to inform future conservation action. For some species the plans and conservation actions are well-developed. *Eresus sandaliatus* and *Dolomedes plantarius* are both subjects of long-term monitoring and translocation programmes. Translocations of *E. sandaliatus* began in 2003 and have increased the number of locations from one to around 17. Translocations of *D. plantarius*, begun in 2010 (Smith et al., 2013), have increased the number of sustainable populations from three to seven. Both translocation programmes followed IUCN guidelines (IUCN/SSC, 2013). They have substantially reduced the threat of extinction of these species in Britain and have been used to test the development of the IUCN Green List (Akçakaya et al., 2018) for assessing conservation recovery.

In Sweden, two spiders are included in national action plans, namely *Eresus sandaliatus* and *Cheiracanthium pennyi* O. Pickard-Cambridge, 1873; the latter is considered in actions aiming to restore sand dune habitats.

Several projects aiming to create inventories of threatened spiders or to update the existing ones, are currently in progress in European countries (See Table C2 in Appendix C).

Concluding remarks

Regional Red Lists and Red Data Books are the most reliable source of information on the current conservation status of spiders in Europe. Accurate evaluations of the conservation status of species represent a tool of paramount importance in conservation efforts focussing on threatened spiders. These tools provide quantitative data for informing national conservation priorities and for developing species-based management strategies. The IUCN developed a system of criteria aiming to enhance the objectivity and comparability of these Red Lists. Even though these lists do not confer any legal protection to the species assessed, they inform and influence conservation policies and legislation.

Unfortunately, the availability of Red Lists on spiders is far from homogeneous across European countries, many of which lack regional inventories or have outdated ones. This means that there are large knowledge gaps in the conservation status of the European spider fauna. For many species, data is incomplete or out-of-date, resulting in assessments based on poor quality information, and thus excluding potential candidate species from

threatened species lists. To gain a better indication of the current status of a national fauna, data needs to be analysed and digitised, so that research priorities for species conservation may be more efficient and timely.

A major shortfall is the lack of monitoring of spider populations, which is essential to assess the long-term dynamics of species and their possible decline. Documenting changes in populations provides key information for assessing the conservation status of a species. Monitoring helps to provide baselines against which changes can be evaluated, and to understand the population dynamics of species and how they can change in response to environmental disturbance. Comprehensive and reliable population trends are not available for most European spider species. As a consequence, spider species are very rarely assessed based on population size (Criteria A, C and D) and most of the available assessments are based on species' geographic range (Criterion B). In turn, species with restricted distributions (endemic) are most frequently assessed, whilst information on declines in more common species is lacking. An exception is the Amber List (Harvey et al., 2017), recently adopted in Great Britain to highlight common species appeared to have undergone substantial decline, and which therefore need more frequent and detailed assessment (for details, see Appendix B). It is one possible approach to identifying and initiating actions for rapidly declining species that do not yet qualify for threatened status. Better monitoring of spider populations in Europe is urgently needed in order to understand and assess their potential risk of extinction.

This patchy understanding of the conservation status of spiders in Europe, together with the generally scant consideration given to this group, represents a considerable obstacle to the inclusion of spiders in conservation legislation and conservation planning.

Some studies (e.g. Chichorro et al., 2020) suggest using, in the absence of reliable data on species distribution and population trends, species traits as predictors of extinction risk. Using traits could help to reduce the knowledge gap, allowing prioritization of future research, monitoring and conservation efforts even for largely unknown and neglected taxonomic groups (Lowe et al., 2020). The recent development of the World Arachnid Trait database is a major step towards achieving this goal (Pekár et al., 2021).

In spite of the recognised ecological role of this group, and the scientific efforts to assess the conservation status of spider species and highlight the extent to which they are

threatened, spiders are rarely included in legislation and funding programs devoted to conservation. For example, given that virtually no spider species are included in the Habitats Directive, the conservation of spiders as a group receives no EU financial investment through the LIFE program (Mammola et al., 2020b).

To date, almost one third of the European spiders have been assessed in at least one European country (1,552 out of 4,154 total species occurring). Among these, almost half are considered as threatened (714), and only very few species benefit from legal protection (178) in at least one country. The existing knowledge of the risk of extinction of many European spiders is not properly reflected in effective conservation measures. Although the main aim of the Red Lists should be assessing the risk of extinction of the species rather than determining conservation priorities (Mace et al., 2008), they are widely used to identify those species for which it is urgent to implement effective conservation actions. However, for spiders, assessments of conservation status have been seldom conflated in calls for species protection. This suggests that these lists are not effective in influencing national species conservation policies, and exposes the lack of a direct link between lists of threatened spider species and legislation.

Conversely, some of the spiders listed in legislation are far from being threatened. This is the case for *Macrothele calpeiana* (Figure 6), for which there is a substantial debate questioning the need for its protection.

This lack of connection between Red Lists and legal protection diminishes the usefulness and appropriateness of both tools in spider conservation.

The number of spider species, and especially the quality of data underlying the choice of species to protect, should be improved in legislation, both at the regional and international level. Accordingly, the appropriateness of the implementation of some European spiders in CITES should be evaluated. Because no native European spider is currently included in CITES, and as there is no quantitative data on the existing trade in spiders from Europe, more studies should verify which species might be harmed by trade, and its potential impact should be assessed.

To date, the protection of large areas of suitable habitat has been addressed as the most effective approach to spider conservation (Branco and Cardoso, 2020). Indeed, the protection of sites hosting key habitats plays a crucial role in effective conservation

strategies (Coetzee et al., 2014; Geldmann et al., 2013; Gray et al., 2016; Harvey et al., 2020). The Natura 2000 network of protected areas accounts for 18% of the EU's land territory (European Environmental Agency, 2012). Even considering ecological corridors connecting these areas, which may mitigate large-scale future threats (see for example Leroy et al., 2014), the percentage of protected areas is far from adequate to conserve spider diversity. Spider species within these habitats will presumably benefit but a large proportion of threatened species are poorly covered by the Natura 2000 network, and no priority areas specifically for conserving spiders exist. The new 2030 Biodiversity Strategy intends to transform at least 30% of the European territory into managed protected areas. This plan is ambitious, but absolutely necessary to halt the loss of spider diversity. The current threats to spiders in Europe indicate the need to expand existing protected areas and to designate new ones in order to include more spider species that need protection (Mammola et al., 2020b). With the limited resources available for the protection of biodiversity, areas hosting high concentrations of endemic and threatened spider species should be considered clear priorities for conservation.

Declaration of competing interest

We declare that there are no conflicts of interest regarding this research and manuscript.

On the behalf of the authors,

Marco ISAIA

and

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CRedit authorship contribution statement

FM and MI conceived the study. FM and MI contributed equally to the work. AG, MN and HS proofread English and provided substantial ameliorations to the original text. FM retrieved data on legal acts and Red Lists across Europe, built the species database, and wrote the first draft. MI suggested the general line of enquiry, coordinated the group of contributors, created maps, and provided amendments to the first draft and to the final revised version. TB provided information on Austria, Germany and Switzerland. PC provided information on Finland, Portugal and Macaronesia and contributed substantially to the organization of the text. MC provided information on Greece. CSF provided information on CITES and spider trading. PG provided information on Slovakia and other Eastern European countries. AG provided information on Great Britain. SH provided valuable contribution to different sections of the manuscript during the first round of revision. NMH provided information on Spain. SM revised different sections of the manuscript, improved the revised version and prepared barcharts. WN provided information on spider distribution in Europe and ensured the collaboration with Araneae – Spider of Europe network. MN provided information on Great Britain and Ireland. JP provided information on France. NP provided information on Ukraine. MR provided information on the Czech Republic. JS provided information on Sweden. HS provided information on Great Britain and contributed significantly to the final version of the text. KW provided information on Poland and other Eastern European countries. All authors contributed significantly to the writing of the manuscript by means of comments and additions to the text.

Data repository statement

Our data are stored within World Arachnid Trait database (Milano et al., 2021a, b) at <https://spidertraits.sci.muni.cz/datasets/160> and <https://spidertraits.sci.muni.cz/datasets/162>.

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FIGURES

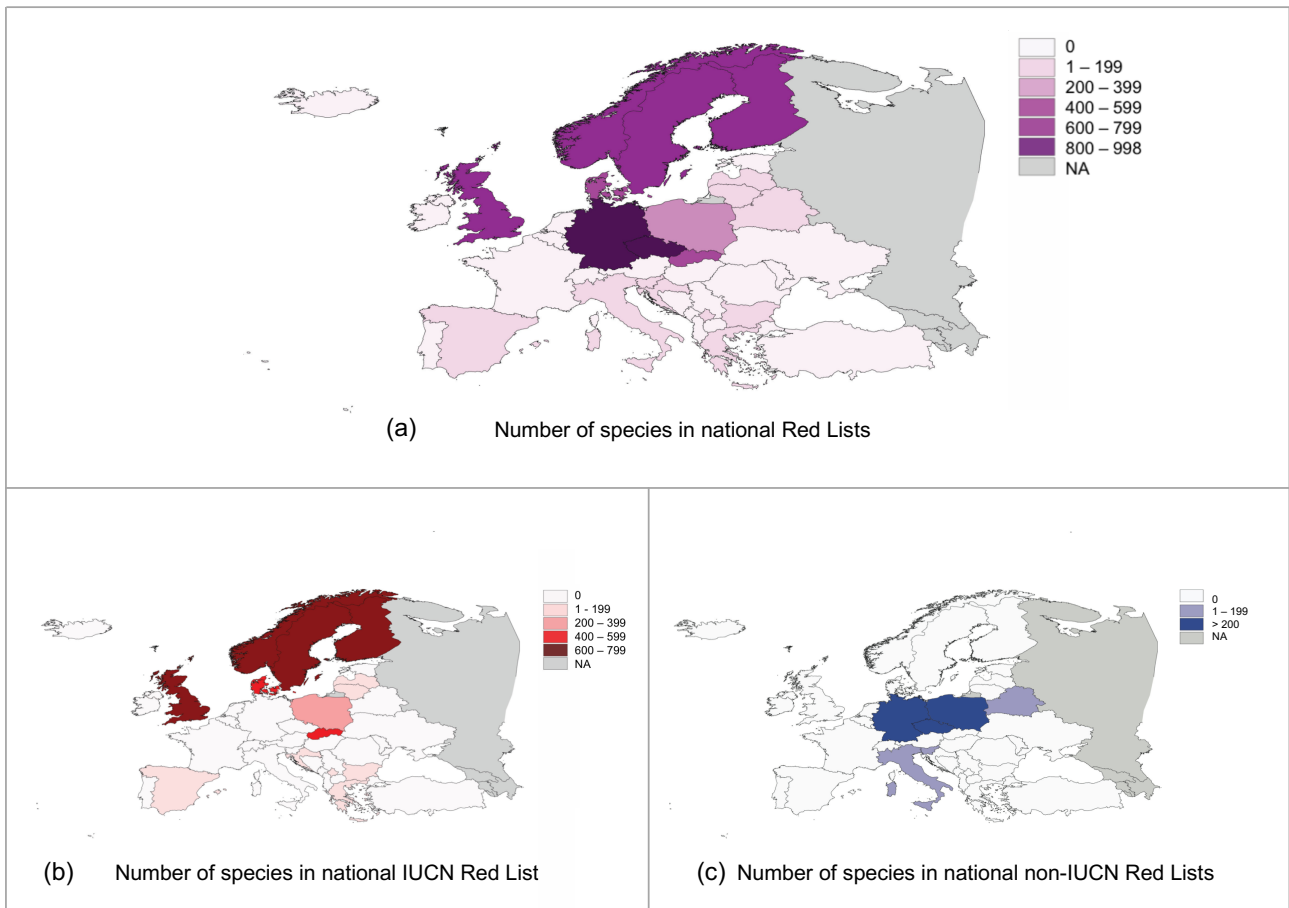


Figure 1. – Number of spider species considered by inventories of threatened species in Europe. (a) Number of species listed in national Red Lists in Europe (Malta, not displayed in map, is in the range 1-199); (b) Number of species listed in national IUCN Red Lists in Europe; (c) Number of species listed in national non-IUCN Red Lists in Europe (Malta, not displayed in map, is in the range 1-199). Northern and Central European countries stand for having the highest number of species mentioned in Red Lists. NA = Not Available.

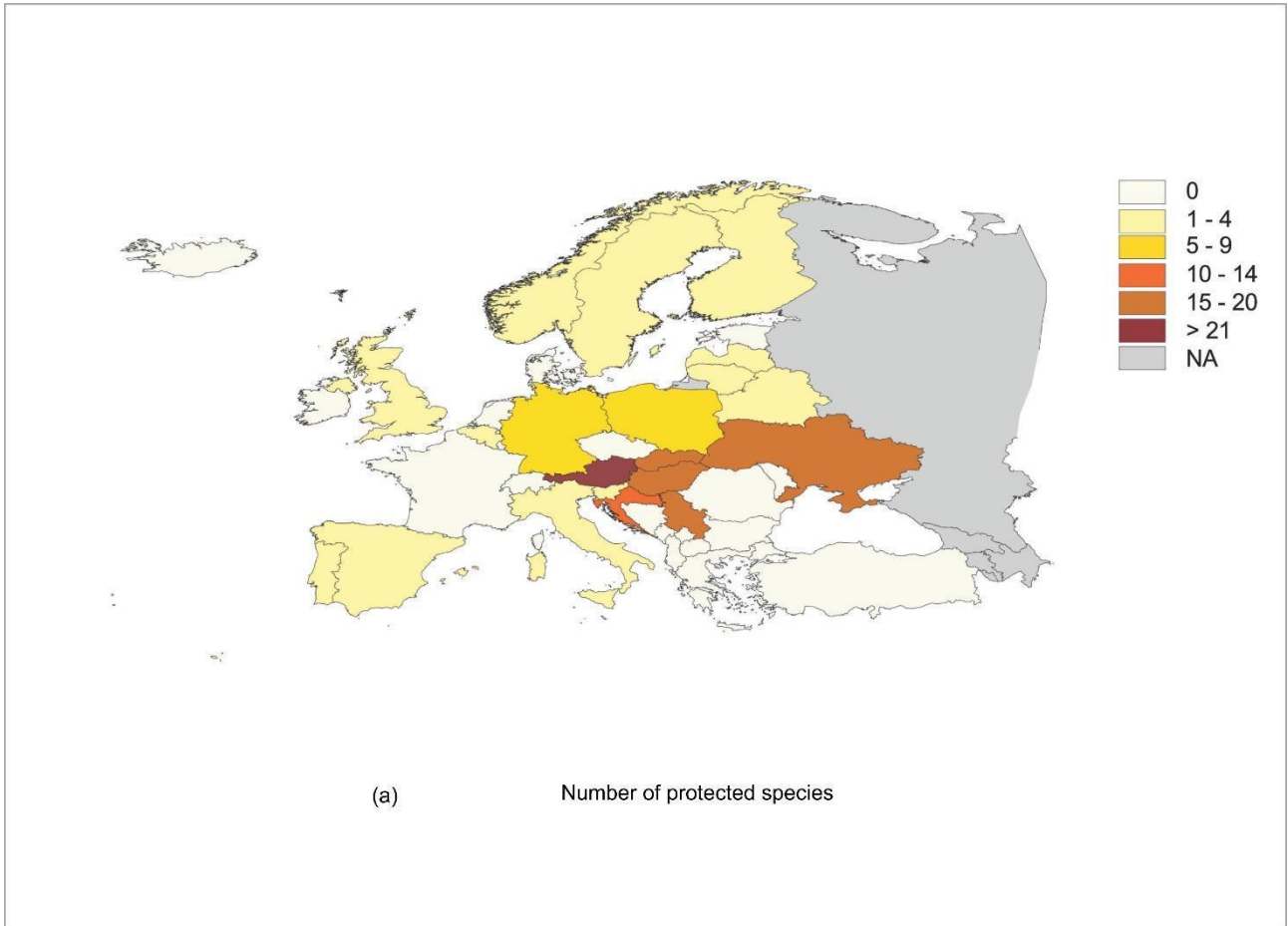


Figure 2. - Number of spider species protected by legislation in European countries (a). Central-Eastern European countries have the highest number of protected species. Note that an additional 38 species are listed as species of “principal importance” for conservation, receiving a lower level of protection under UK laws (see text). NA = Not Available.

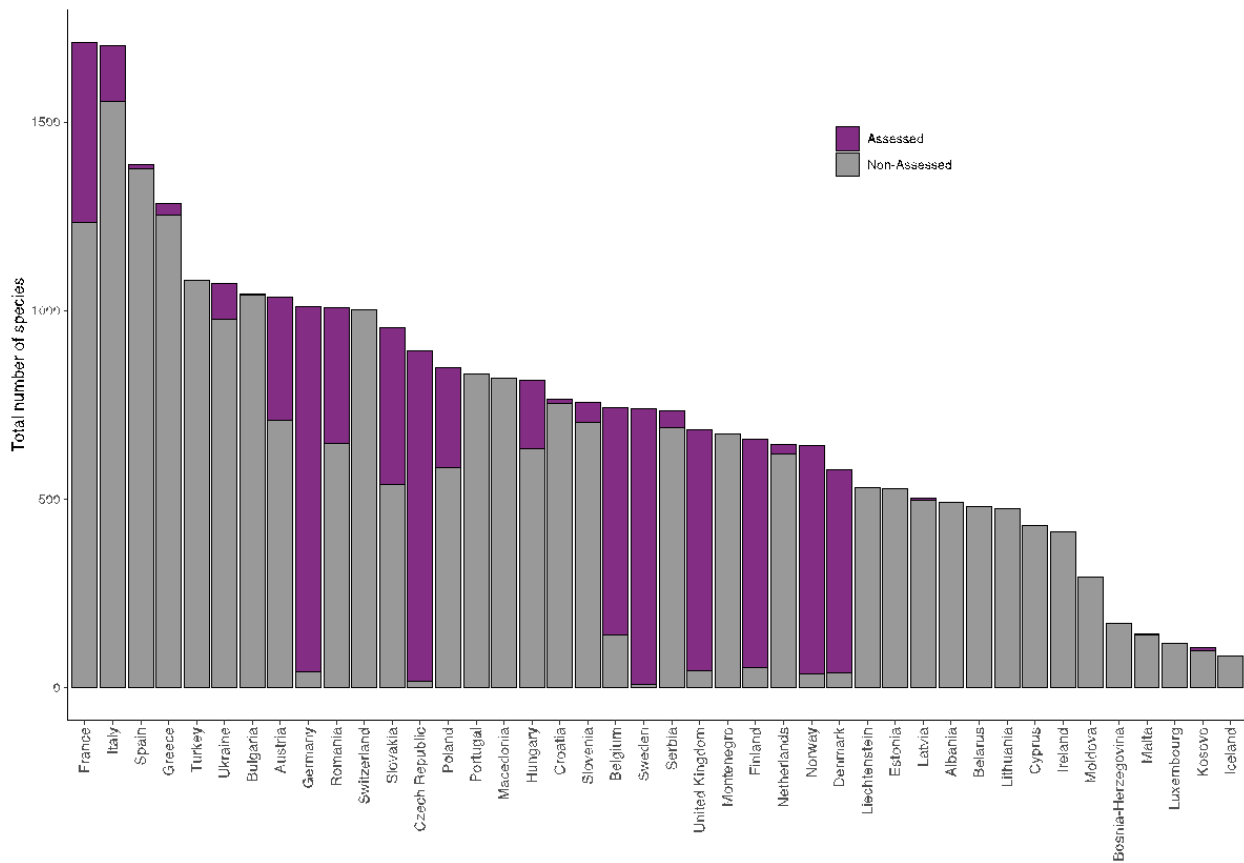


Figure 3. - Number of spider species assessed in Red Lists and Red Data Books in Europe in relation to the total number of spider species per country as reported in Nentwig et al. (2020). There is no correlation between the number of species occurring in a country and the number of species assessed in Red Lists and Red Data Books.

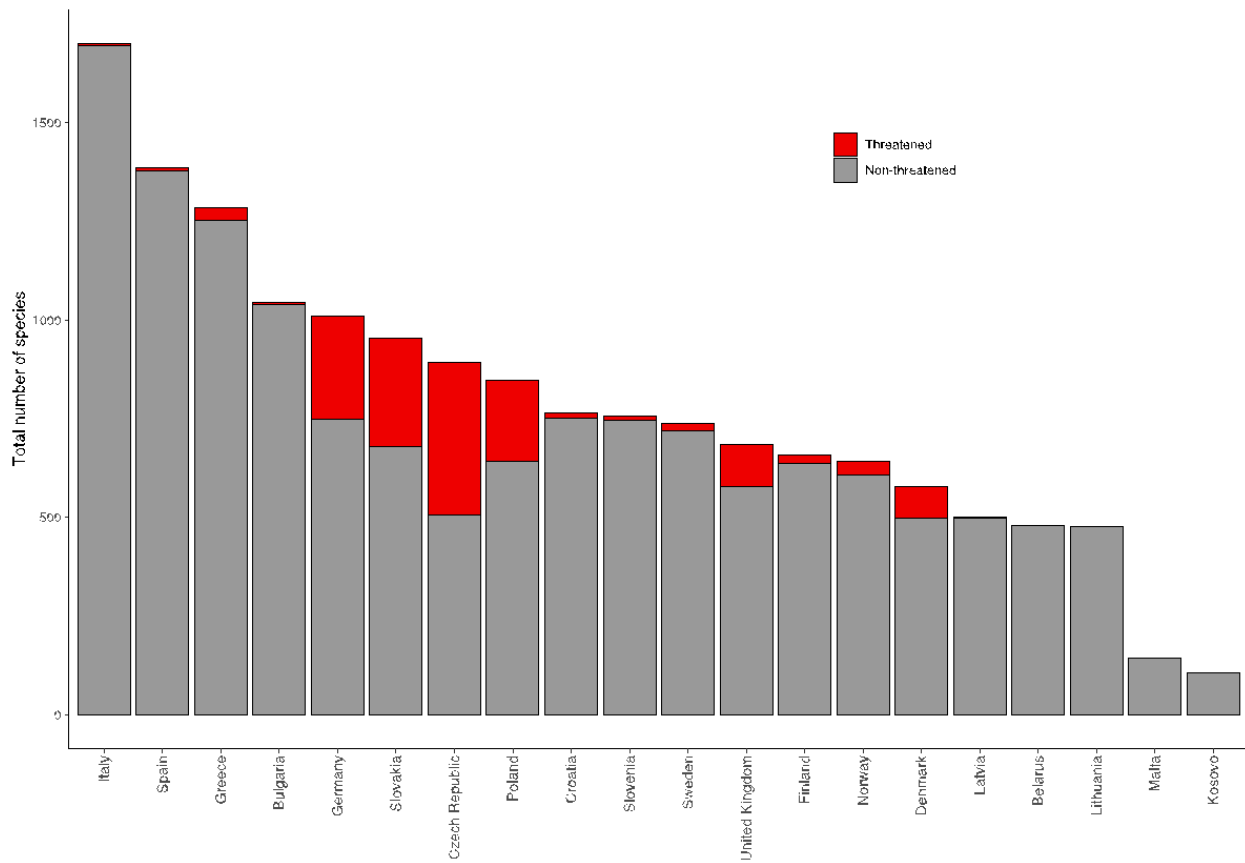


Figure 4. - Number of spider species considered as threatened in national Red Lists and Red Data Books in relation to the total number of spider species per country as reported in Nentwig et al. (2020). There is no correlation between the number of species occurring in a country and the number of threatened species in Red Lists and Red Data Books

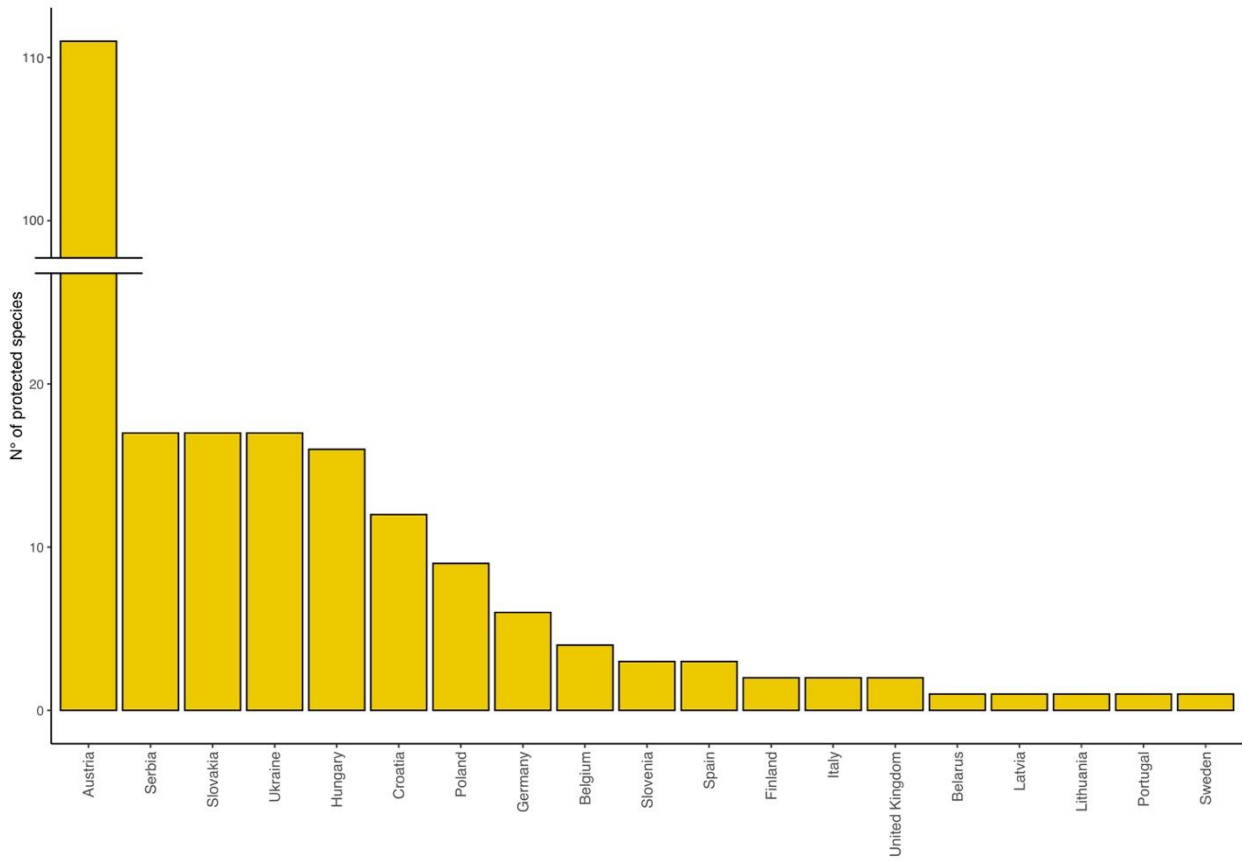


Figure 5. - Number of legally protected spider species in European countries. Note that an additional 38 species are listed as species of “principal importance” for conservation, receiving a lower level of protection under UK laws (see text).



Figure 6. - Highlights in spider conservation in Europe. *Dolomedes plantarius* (above left, Photo credit Emanuele Biggi), *Marpissa radiata* (above right, Photo credit Janusz Kupryjanowicz), *Argyroneta aquatica* (below left, Photo credit Emanuele Biggi) and *Eresus* spp. (below right, Photo credit Emanuele Biggi) benefit from full legal protection in several countries across Europe and have been assessed as threatened in most European countries. *Macrothele calpeiana* (below center, Photo credit Tiziano D'Elia) is the only native European spider species that features in the Habitats Directive and the Bern Convention.

TABLES

Table 1. Conservation tools currently in force in Europe mentioning spiders, with focus on their objectives, signatory parties, legal value and species mentioned, with relative conferred status. The year (in brackets) refers to the date the conservation tool came into force.

Level	Conservation tool	Objectives	Signatory parties	Legal value	Spider species mentioned	European species included	Conferred status	Notes
International	Bern Convention (1982)	<ul style="list-style-type: none"> to conserve wild flora and fauna and their natural habitats to promote cooperation between States to give particular attention to endangered and vulnerable species including endangered and vulnerable migratory species 	51 EU countries, other European countries, some African and Middle Eastern countries	No	1	1	Strictly protected	<ul style="list-style-type: none"> opened for signature in 1979 by European environment ministers, and came into force in 1982 with the approval of the Council of the European Union the first international act addressing the conservation of wild species in Europe a voluntary agreement, constituting no law or obligation, aiming to protect wild flora, fauna, and their natural habitats (listed in the appendices).
	CITES (1975 worldwide, 1996 in EU)	<ul style="list-style-type: none"> to ensure that international trade in specimens of wild animals and plants does not threaten their survival 	183 countries from all continents	Yes	36	0	Species not necessarily threatened with extinction but that may become so unless trade is closely controlled	<ul style="list-style-type: none"> the conservation agreement with the largest membership an international agreement between governments aiming to regulate and monitor the international trade in wild species drafted as a result of a resolution adopted in 1963 at a IUCN meeting although legally binding on the Parties, CITES does not take the place of national laws

							(Appendix II)	<ul style="list-style-type: none"> • none of the spiders listed occur naturally in Europe
	Habitats Directive (92/43/EEC) (1992)	<ul style="list-style-type: none"> • to protect habitats and species listed in the directive's Annexes 	27 EU countries	Yes	1	1	Strictly protected	<ul style="list-style-type: none"> • the EU response to the Bern Convention • the main legal document regulating Europe's nature conservation policy, together with the Birds Directive (2009/147/EC), • a European law, mandatorily transposed to national laws of EU countries.
	IUCN Red List of Threatened Species (1964)	<ul style="list-style-type: none"> • to evaluate and classify the global conservation status of the species, classifying them in categories of risk 	No signatory parties, only partner Member Organisations (States, government agencies, NGOs, Scientific Societies)	No	293	8	Critically Endangered (2 species), Endangered (1 species), Vulnerable (4 species), Data Deficient (1 species)	<ul style="list-style-type: none"> • the first international organization to focus on the protection and sustainable use of natural resources • one of the main authorities on environmental management and nature conservation • commonly used in decision-making process and as a guide to revise international or local agreements such as CITES
Regional	National IUCN Red Lists and Red Data Books	<ul style="list-style-type: none"> • to evaluate and classify the conservation status of species at national level, classifying them in categories of risk following the IUCN standards 	No signatory parties. 13 Countries providing Red Lists	No	1098	1098	Species listed in the IUCN categories	<ul style="list-style-type: none"> • commonly used in decision-making process

	National non-IUCN Red Lists and Red Data Books	<ul style="list-style-type: none"> to evaluate and classify the conservation status of species at national level, classifying them in categories of risk according to modified IUCN criteria, national guidelines or expert opinions 	No signatory parties. 7 Countries providing Red Lists	No	1178	1178	Varying categories of extinction risk	<ul style="list-style-type: none"> commonly used in decision-making process
	Sub- or supranational IUCN Red Lists and Red Data Books	<ul style="list-style-type: none"> to evaluate and classify the conservation status of species at the subnational level, classifying them in categories of extinction risk following the IUCN standards 	No signatory parties. 12 regions providing Red Lists	No	1041	1041	Species listed in the IUCN categories	<ul style="list-style-type: none"> commonly used in decision-making process
	Sub- or supranational non-IUCN Red Lists and Red Data Books	<ul style="list-style-type: none"> to evaluate and classify the conservation status of species at the subnational level, classifying them in categories of extinction risk according to modified IUCN criteria, national guidelines or expert opinions 	No signatory parties. 19 regions providing Red Lists	No	1099	1099	Varying categories of extinction risk	<ul style="list-style-type: none"> commonly used in decision-making process
	National laws	<ul style="list-style-type: none"> to protect the species within the national territory 	19 Countries	Yes	178	178	Legally protected at the national level	<ul style="list-style-type: none"> The preeminent instruments to protect species

Table 2. Regional Red Lists (RLs) and Red Data Books (RDBs) at national and subnational level in the European countries, showing the number of spider species known for each country, relative number of species assessed and number of species considered as extinct and/or threatened, compliance with IUCN standards, references to the species list, and number of native European spider species on the Global Red List. For detailed information on spider conservation in each European country, see Appendix B.

	Spider species	RLs and RDBs	N species assessed	N species extinct and/or threatened	System adopted	References	N species in global IUCN RL
Albania	491	No	0	0	NA	NA	0
Austria	1035	Subnational (Carinthia)	325	57	non-IUCN	Komposch and Steinberger, 1999	1
Belarus	481	National	1	1	IUCN modif	Red Book of the Republic of Belarus, 2015	1
Belgium	743	Subnational (Flanders)	604	213	IUCN modif	Maelfait et al., 1998	1
Bosnia-Herzegovina	171	No	0	0	NA	NA	0

Bulgaria	1045	National	5	5	IUCN	Golemansky et al., 2015	1
Croatia	765	National	12	12	IUCN	Ozimec et al., 2009	1
Cyprus	431	No	0	0	NA	NA	0
Czech Republic	893	National	875	386	IUCN modif	Řezáč et al., 2015	1
		Subnational (Upper Silesia)	506	5	IUCN 1994	Staręga et al., 2001	
		Subnational (Carpathians)	285	170	IUCN	Gajdoš et al., 2014	
		Subnational (Carpathians)	14	13	IUCN	Witkowski et al., 2003	
Denmark	579	National	538	81	IUCN	Bruun and Lissner, 2019	1

		Subnational (Wadden Sea)	14	5	IUCN modif	Vangsgård et al., 1996	
Estonia	528	No	0	0	NA	NA	1
Finland	658	IUCN	604	22	IUCN	Hyvärinen et al., 2019	1
France (Metropolitan)	1712	Subnational (Picardie)	51	5	IUCN	Picardie Nature, 2016	2
		Subnational (Nord-Pas-de- Calais)	469	70	IUCN	Groupe ornithologique et naturaliste du Nord-Pas-de- Calais, 2018	
Germany	1011	National	968	261	non-IUCN	Blick et al., 2016	1
		Subnational (Baden- Württemberg)	357	150	non-IUCN	Nährig et al., 2003	
		Subnational (Bavaria)	838	321	non-IUCN	Blick and Scheidler, 2004	

	Subnational (Berlin)	544	162	non-IUCN	Kielhorn, 2017
	Subnational (Brandenburg)	548	123	non-IUCN	Platen et al., 1999
	Subnational (Lower Saxony and Bremen)	673	234	non-IUCN	Finch, 2004
	Subnational (Mecklenburg- West Pomerania)	569	94	non-IUCN	Martin, 2012
	Subnational (North-Rhine Westfalia)	662	92	non-IUCN	Buchholz et al., 2011
	Subnational (Saxony)	612	176	non-IUCN	Hiebsch and Tolke, 1996
	Subnational (Saxony-Anhalt)	643	195	non-IUCN	Sacher and Platen, 2001, 2004
	Subnational (Schleswig- Holstein)	565	43	non-IUCN	Lemke et al., 2013

		Subnational (Thuringia)	622	209	non-IUCN	Sander et al., 2001	
		Subnational (Wadden Sea)	55	38	IUCN modif	Vangsgård et al., 1996	
Greece	1285	National	32	32	IUCN	Chatzaki, 2009	2
Hungary	815	Subnational (Carpathians)	181	0	IUCN	Gajdoš et al., 2014	1
Iceland	85	No	0	0	NA	NA	0
Ireland	415	No	0	0	NA	NA	0
Italy	1702	National	25	2	non-IUCN	Groppali and Priano, 1992	2
		National	123	3	IUCN modif	Ruffo and Stoch, 2006	

		Subnational (Bolzano-Alto Adige)	273	82	non-IUCN	Noflatscher, 1994	
Kosovo	107	National	8	0	IUCN	Ibrahimi et al., 2019	0
Latvia	502	National	4	3	IUCN pre-1994	Spuris, 1998	1
Liechtenstein	532	No	0	0	NA	NA	0
Lithuania	476	National	1	0	IUCN pre-1994	Ministry of Environment, Order D1-814 of 10th September 2018	1
Luxembourg	117	No	0	0	NA	NA	0
Malta	144	National	5	0	IUCN modif	Schembri and Sultana, 1989	0
Moldova	293	No	0	0	NA	NA	0

Montenegro	673	No	0	0	NA	NA	1
Netherlands	646	Subnational (Wadden Sea)	26	11	IUCN modif	Vangsgård et al., 1996	1
North Macedonia	820	No	0	0	NA	NA	0
Norway	642	National	605	34	IUCN	Henriksen and Hilmo, 2015	1
Poland	848	National	263	206	IUCN modif	Staręga et al., 2002	1
		National	3	3	IUCN modif	Głowaciński and Nowak, 2004	
		Subnational (Carpathians)	120	87	IUCN	Gajdoš et al., 2014	
		Subnational (Upper Silesia)	477	41	IUCN 1994	Staręga et al., 2001	

		Subnational (Bielsko-Biała)	288	18	IUCN 1994	Staręga et al., 2001	
		Subnational (Częstochowa)	247	1	IUCN 1994	Staręga et al., 2001	
		Subnational (Katowice)	270	2	IUCN 1994	Staręga et al., 2001	
		Subnational (Opole)	325	22	IUCN 1994	Staręga et al., 2001	
Portugal (excluding Macaronesia)	831	No	0	0	NA	NA	1
Romania	1009	Subnational (Carpathians)	360	25	IUCN	Gajdoš et al., 2014	1
Serbia	734	Subnational (Carpathians)	44	15	IUCN	Gajdoš et al., 2014	1
Slovakia	955	National	415	275	IUCN 1994	Gajdoš and Svatoň, 2001	1

		Subnational (Carpathians)	355	203	IUCN	Gajdoš et al., 2014	
		Subnational (Carpathians)	15	15	IUCN	Witkowski et al., 2003	
Slovenia	759	National	53	10	non-IUCN	Uradni list Republike Slovenije, 2002	4
Spain (excluding Macaronesia)	1386	National	10	7	IUCN	Verdú et al., 2011	1
		Subnational (Andalusia)	22	6	IUCN	Barea-Azcón et al., 2008	
Sweden	739	National	726	21	IUCN	SLU Artdatabanken, 2020	1
Switzerland	1003	No	0	0	NA	NA	1
Turkey	1081	No	0	0	NA	NA	0

Ukraine	1073	Subnational (Carpathians)	80	14	IUCN	Gajdoš et al., 2014	1
		Subnational (Ukraine Carpathians)	1	0	IUCN	Mateleshko and Potish, 2011	
		Subnational (Kharkiv)	6	0	non-IUCN	Tokarsky, 2013	
		Subnational (Donetsk)	12	0	non-IUCN	Zalevskiy and Bronskov, 2017	
United Kingdom	684	National	639	105	IUCN	Harvey et al., 2017	2

Table 3. - Acts of law concerning spiders in European countries, with number of species and number of protected species.

	Spider species	Legal Acts	N species
Albania	491	None	0
Austria	1035	LGBI. Nr. 70/2007 32. Stück (Carinthia)	22
		LGBI. Nr. 59/2015 (Carinthia)	109
		Vienna Nature Conservation Regulation (Wr. NschVO)	2
Belarus	481	Law on Protection of The Environment 1992 no. 1982-XII, Ministry of Natural Resources and Environmental Protection Decree 2014 no. 26	1
Belgium	743	Species Decree (Flemish Government Decree 2009)	4
Bosnia-Herzegovina	171	None	0
Bulgaria	1045	None	0
Croatia	765	Nature Protection Act (Official Gazette 70/05, NN 139/2008)	12
Cyprus	431	None	0
Czech Republic	893	None	0
Denmark	579	None	0
Estonia	528	None	0
Finland	658	Nature Conservation Act 1096/1996, Nature Conservation Decree 160/1997 Appendix 4 471/2013	2
France (Metropolitan)	1712	None	0
Germany	1011	Bundartenschutzverordnung (BartSchV) 2005	6
Greece	1285	None	0
Hungary	815	Government Decree no. 348/2006 (XII.23.), Appendix 2 of the Ministerial Decree no. 13/2001 (V.9) Köm	16
Iceland	85	None	0
Ireland	415	None	0
Italy	1702	L.R. 10/2008, D.g.r. n. 8/7736	2
Kosovo	107	None	0
Latvia	502	Regulation nr. 396 of Minister of Cabinet	1
Liechtenstein	532	None	0
Lithuania	476	Law on the Protected Fauna, Flora and Fungi Species and Communities (No. VIII-499), Order D1-814 of Ministry of Environment	1
Luxembourg	117	None	0
Malta	144	None	0
Moldova	293	None	0
Montenegro	673	None	0
Netherlands	646	None	0
North Macedonia	820	None	0
Norway	642	None	0
Poland	848	Decree of the Ministry of Environment 2016, concerning the Bill of Nature Protection No. 92/2004	9
Portugal (excluding Macaronesia)	831	Decree Law no. 140/99 Annex B-IV	1
Romania	1009	None	0
Serbia	734	Official Gazette of the RS no. 5/2010, 47/2011, 32/2016 and 98/2016	17

Slovakia	955	Ministry of Environment Decree SR nr. 158/2014	17
Slovenia	759	Regulation on the Protection of Endangered Species Ur. l. RS 57/93	3
Spain (excluding Macaronesia)	1386	Royal Decree 139/2011	1
		DOE nr. 30 decreto 37/2001:2349-2364	1
		Orden 6/2013 (Valencian Community)	1
		Decreto Foral 254/2019 (Community of Navarre)	1
Sweden	739	Species Protection Ordinance SFS 2007:845 Section 6	1
Switzerland	1003	None	0
Ukraine	1073	Order z0847-18 no. 237	6
		Order z1202-17 no. 333	12
United Kingdom	684	Wildlife and Countryside Act 1981 Schedule 5	2*
Turkey	1081	None	0

*Note that an additional 38 species are listed as species of “principal importance” for conservation, receiving a lower level of protection under UK laws (see text).

Table 4. – Spider species in Europe ranked according to their number of occurrences in extinct and/or threatened categories across European National Red Lists and Red Data Books (NRL & NRDB) (only >5 occurrences are shown).

Genus	Species	Author	Family	Occurrences in NRL & NRDB
<i>Dolomedes</i>	<i>plantarius</i>	(Clerck, 1757)	Pisauridae	7
<i>Marpissa</i>	<i>radiata</i>	(Grube, 1859)	Salticidae	7
<i>Argyroneta</i>	<i>aquatica</i>	(Clerck, 1757)	Dictynidae	6
<i>Brommella</i>	<i>falcigera</i>	(Balogh, 1935)	Dictynidae	6
<i>Gnaphosa</i>	<i>nigerrima</i>	L. Koch, 1877	Gnaphosidae	6
<i>Lasiargus</i>	<i>hirsutus</i>	(Menge, 1869)	Linyphiidae	6
<i>Midia</i>	<i>midas</i>	(Simon, 1884)	Linyphiidae	6
<i>Hygrolycosa</i>	<i>rubrofasciata</i>	(Ohlert, 1865)	Lycosidae	6
<i>Attulus</i>	<i>distinguendus</i>	(Simon, 1868)	Salticidae	6
<i>Marpissa</i>	<i>pomatia</i>	(Walckenaer, 1802)	Salticidae	6
<i>Enoplognatha</i>	<i>oelandica</i>	(Thorell, 1875)	Theridiidae	6
<i>Lasaeola</i>	<i>prona</i>	(Menge, 1868)	Theridiidae	6
<i>Psammitis</i>	<i>sabulosus</i>	(Hahn, 1832)	Thomisidae	6
<i>Xysticus</i>	<i>luctator</i>	L. Koch, 1870	Thomisidae	6
<i>Atypus</i>	<i>muralis</i>	Bertkau, 1890	Atypidae	5
<i>Cheiracanthium</i>	<i>pennyi</i>	O.P.-Cambridge, 1873	Cheiracanthiidae	5
<i>Clubiona</i>	<i>juvenis</i>	Simon, 1878	Clubionidae	5
<i>Eresus</i>	<i>kollari</i>	Rossi, 1846	Eresidae	5
<i>Berlandina</i>	<i>cinerea</i>	(Menge, 1872)	Gnaphosidae	5
<i>Echemus</i>	<i>angustifrons</i>	(Westring, 1861)	Gnaphosidae	5
<i>Haplodrassus</i>	<i>minor</i>	(O.P.-Cambridge, 1879)	Gnaphosidae	5
<i>Carorita</i>	<i>limnaea</i>	(Crosby & Bishop, 1927)	Linyphiidae	5
<i>Centromerus</i>	<i>levitarsis</i>	(Simon, 1884)	Linyphiidae	5
<i>Centromerus</i>	<i>semiater</i>	(L. Koch, 1879)	Linyphiidae	5
<i>Trichoncus</i>	<i>hackmani</i>	Millidge, 1955	Linyphiidae	5
<i>Agroeca</i>	<i>lusatica</i>	(L. Koch, 1875)	Liocranidae	5
<i>Zora</i>	<i>armillata</i>	Simon, 1878	Miturgidae	5
<i>Heliophanus</i>	<i>dampfi</i>	Schenkel, 1923	Salticidae	5
<i>Neon</i>	<i>valentulus</i>	Falconer, 1912	Salticidae	5
<i>Robertus</i>	<i>ungulatus</i>	Vogelsanger, 1944	Theridiidae	5

Table 5. - Spider species in conservation acts in Europe ranked according to the number of countries protecting them (only >2 countries are shown).

Genus	Species	Author	Family	Number of Countries
<i>Dolomedes</i>	<i>plantarius</i>	(Clerck, 1757)	Pisauridae	9
<i>Argyroneta</i>	<i>aquatica</i>	(Clerck, 1757)	Dictynidae	7
<i>Eresus</i>	<i>kollari</i>	Rossi, 1846	Eresidae	7
<i>Atypus</i>	<i>muralis</i>	Bertkau, 1890	Atypidae	5
<i>Atypus</i>	<i>affinis</i>	Eichwald, 1830	Atypidae	4
<i>Atypus</i>	<i>piceus</i>	(Sulzer, 1776)	Atypidae	4
<i>Eresus</i>	<i>sandaliatus</i>	(Martini & Goeze, 1778)	Eresidae	4
<i>Dolomedes</i>	<i>fimbriatus</i>	(Clerck, 1757)	Pisauridae	4
<i>Argiope</i>	<i>lobata</i>	(Pallas, 1772)	Araneidae	3
<i>Arctosa</i>	<i>cinerea</i>	(Fabricius, 1777)	Lycosidae	3
<i>Macrothele</i>	<i>calpeiana</i>	(Walckenaer, 1805)	Macrothelidae	3
<i>Araneus</i>	<i>grossus</i>	(C. L. Koch, 1844)	Araneidae	2
<i>Argiope</i>	<i>bruennichi</i>	(Scopoli, 1772)	Araneidae	2
<i>Gnaphosa</i>	<i>nigerrima</i>	L. Koch, 1877	Gnaphosidae	2
<i>Arctosa</i>	<i>stigma</i>	(Thorell, 1875)	Lycosidae	2
<i>Geolycosa</i>	<i>vultuosa</i>	(C. L. Koch, 1838)	Lycosidae	2
<i>Philaeus</i>	<i>chrysops</i>	(Poda, 1761)	Salticidae	2