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Plant conservation in Mediterranean-type ecosystems

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Abstract. The present paper is an overview of state of the art in plant conservation in Mediterranean-type Ecosystems (MTEs), highlighting current studies and neglected topics. A review of the literature dealing with this issue and a general analysis of the results was performed, delving into relevant plant conservation biology topics. The main topics considered were: 1) reproductive biology and genetic conservation, 2) threat factors and effects of global change, and 3) evaluation of conservation status and protected areas selection. This study illustrates differences in the number of documents published in northern countries of the Mediterranean Basin concerning southern and eastern countries and compared with other MTEs. It also highlights the paramount importance of public organizations as funding entities. Additionally, it points to a decrease in traditional subject categories related to plant conservation and increased multidisciplinary conservation research and novel methodologies (e.g., phylogenomics, SDM). To overcome existing biases among the different MTE regions, integrating actions at a transnational level would be necessary, with standard conservation policies and strategies. Moreover, research should be supported with more important participation and funding from private entities, with a clear focus on specific conservation proposals. In contrast, certain weaknesses were detected, some related to the limited information available about threatened plant species and the scarce use of the available data from genetic conservation research in management plans. Consequently, the authors consider that future conservation efforts should be addressed to improve the knowledge of threatened MTEs' flora and implement a manual of good practices, which would make use of the available research information to put forward more direct proposals for management and conservation.

Keywords: Conservation status; Endangered flora; Genetic conservation; Global change; IUCN categories; Plant reproductive biology; Protected areas; Threats.

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Introduction

Five Mediterranean-type Ecosystems (MTEs) cover different areas worldwide: the Mediterranean Basin, California, central Chile, Cape Region of South Africa, and southwestern Australia. They are located to the southwest margins of huge landmasses at about 30-40º N or S latitudes and share a climatic regime of mild (or cold) wet winters and hot, dry summers (Archibold, 1995; Schutlz, 1995). These areas contain plant species' diversity levels similar to some tropical regions, being higher than expected due to their latitude and low primary productivity (Cowling *et al.*, 1996; Linder, 2003). The endemic flora in MTEs reaches 35-75% out of native taxa, depending on the region (Cowling *et al.*, 2015), hosting narrowly distributed plant species usually restricted to a single and well-defined area within a given region as in the Mediterranean Basin (Thompson, 2005; 2020). Consequently, these regions are recognized as biodiversity hotspots (Médail & Quézel, 1997, 1999; Myers *et al.*, 2000), which include interesting patterns and processes in plant diversity. Although all these regions as a whole cover about 2% of the world's land areas, they are home to approximately 20% of all the plant species in the world (Cowling *et al.*, 1996; Rundel *et al.*, 2016).

Spatial and temporal niche separation across topographic, climatic, and edaphic gradients has occurred in all five regions, which have been and remain plant evolutionary keystones (Rundel *et al.*, 2018). Historically, environmentally stable MTEs have supported higher diversity owing to the more remarkable persistence of lineages over time. Variation in plant diversity is likely to be a consequence of the continuation of numerous pre-Pliocene clades in the more stable MTEs, rather than to differences in diversification rates. A common pattern occurring in southwestern Australia and the Cape Region, in contrast to central Chile, California, and the Mediterranean Basin (Cowling *et al.*, 2015).

Current conservation strategies on plant diversity are not sufficient enough to prevent a continuous decline in biodiversity. MTEs are suffering from high habitat loss because of human disturbance (Le Roux *et al.*, 2019; Myers *et al.*, 2000; Thompson, 2020), thus leading the growth of threatened species list at the same pace. Meanwhile, world governments fail to meet their

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commitment to achieving biodiversity conservation goals, such as the Aichi Targets or those in the Global Strategy for Plant Conservation (Heywood, 2017). Moreover, nowadays, Mediterranean ecosystems are among the most vulnerable due to global warming worldwide (Luterbacher *et al*., 2006; Gualdi *et al*., 2013; Hewitson *et al*., 2014; Spampinato *et al*., 2019). Consequently, Mediterranean areas are globally facing a challenge for management and decision-making policies addressing species and habitat conservation in the Anthropocene.

Habitat degradation and the vulnerability of ecosystems make the existence of a multidisciplinary science of "Conservation Biology" more necessary than ever, after more than 40 years of theoretical and empirical development (Dobson *et al*., 1992; Frankham *et al*., 2002; Groom *et al*., 2006; Avise, 2008). This science encompasses different concepts and tools related to ecology, demography, genetics, wildlife management, social sciences, and perceptions of conservation, among others (Frankel & Soulé, 1981). Nowadays, conservation biologists are concerned about managing threats to avoid the extinction of populations, species, and entire clades (Carroll & Fox, 2008). However, there is much variation in different stakeholders' perceptions of these problems among MTE's (Moreira *et al*., 2019).

Due to the multidisciplinary nature of Conservation Biology, the use of different approaches in this scientific discipline are necessarily diverse and transversal. Hence, in this paper, we attempted to cover various issues and concerns on this broad subject and three main inquiries: conservation genetics and reproductive biology, threat factors including global change, and evaluating both species conservation status and protected areas (reserves selection).

Reproductive Biology and Conservation Genetics

After habitat preservation, and understanding of the reproductive biology of an endangered, threatened, or invasive plant species is one of the key steps that should be taken to identify conservation priorities (Carroll & Fox, 2008). None of the mechanisms and strategies present in plant reproductive systems are exclusive to MTEs. However, different approaches may be particularly functional in Mediterranean environments, and thus, they explain at least partially, biodiversity assemblages and their evolution (Arroyo & Thompson, 2018). Reproductive characteristics (such as pollination, pollinator assemblages, seed dispersal, survival rate, reproductive lifespan, mating, or breeding system) integrate all those responses that allow plants to adapt to a particular environment (Moza & Bhatnagar, 2007). The study of these reproductive traits can help to understand limitations in plants that need to be subjected to a conservation strategy.

Given the transversality of plant conservation biology studies, it is impossible to treat reproductive biology independently of conservation genetics. Many genetic conservation tools are fundamental to understanding variation in breeding and mating systems among different plant species or populations within species. Major issues in the field, according to Frankham *et al.* (2002), include deleterious effects of inbreeding on reproduction and survival (inbreeding depression), loss of genetic diversity, and consequent reduced ability to evolve in response to environmental changes (loss of evolutionary potential), fragmentation of populations and reduction in gene flow random processes (genetic drift), or the deleterious effects on fitness that sometimes occur as a result of outcrossing (outbreeding depression).

Conservation genetics uses genetic theory and techniques to reduce the risk of extinction in threatened species (Frankham *et al*., 2002) and provides important insights for plant conservation protocols, especially in rare or endemic plants (Moreno-Saiz *et al*., 2018). According to Frankham *et al*. (2002), this approach can play a key role in conservation biology as in genetic management of small populations (maximizing genetic diversity retention and minimizing inbreeding); resolution of taxonomic uncertainties and delineation of management units; the use of molecular genetic analyses to understand species' biology.

Threats and effects of global change

Threats to biodiversity in Mediterranean areas have risen during the last decades, although patterns vary across and within the five regions (Underwood *et al*., 2009). The International Union for Conservation of Nature published the Threats Classification Scheme Ver. 3.2 (IUCN, 2018): a full hierarchical structure of threat types to assess and classify species into categories within the Red Lists. It is the most comprehensive and widely used method for determining the extinction risk for a given taxon (Rodrigues *et al.*, 2006). IUCN defines "direct threats" (i.e., sources of stress; proximate pressures) as the anthropic activities that have impacted in the past ("historical, unlikely to return" or "historical, likely to return"); are presently impacting; or may occur "in the future" (time frame of three generations or ten years – whichever is the longest – up to a maximum of 100 years).

In the Anthropocene, plant biodiversity is characterized by increased homogenization and accelerated extinction rates (Le Roux *et al.*, 2019). Conservation measures should incorporate the dynamic processes and patterns of biodiversity that ensure long-term conservation, a topic that is particularly challenging in the currently changing world context. Global change affects all aspects of protection because it drives large-scale shifts in the distribution of species and biological communities' composition. Novel or non-analog assemblages may occur, and high mountain species will face incremented extinction risks (Heywood, 2011). It will also affect the fixed boundaries of protected areas (Heywood, 2019a).

Global change drivers, especially rapid climate change, are already risk factors affecting a wide variety of organisms. Currently, an increasing number of authors have highlighted climate change as one the leading causes for biodiversity loss (Edwards & Richardson, 2004; Thomas *et al*., 2004; Thuiller *et al*., 2005; Brook *et al*., 2008; Maclean & Wilson, 2011; Mendoza-Fernández *et al*., 2019), and this topic has become bleeding-edge in science.

The IUCN explicitly includes this factor among the main threats to biodiversity (11-Climate change & severe weather), together with 1) Residential & commercial development; 2) Agriculture & aquaculture; 3) Energy production & mining; 4) Transportation & service corridors; 5) Biological resource use; 6) Human intrusions & disturbance; 7) Natural system modifications; 8) Invasive & other problematic species, genes & diseases; 9) Pollution; and 10) Geological events. The number of secondary sub-categories in the whole drivers of species' decline reaches 45 classes; another tertiary subdivision adds 73 sub-classes; thus, these 118 different risk factors represent and standardize the most likely scenario for each taxon.

In this context, Mediterranean-climate ecosystems constitute reference laboratories for global change research because of their transitional climate, the high spatiotemporal variability of their environmental conditions, rich and unique biodiversity, and a wide range of socio-economic conditions (Doblas-Miranda *et al*., 2015).

Evaluation of conservation status and protected areas selection

The evaluation of possible threats becomes crucial when making decisions related to conservation. Hence, detecting factors that impact the populations of given taxa negatively is of paramount importance. From the authors' perspective, Red Lists (as synthetic tools to summarize plant species conservation in a given area), conservation genetics (given that they offer information on the degree of inbreeding present in populations), and selection of protected areas (which will help identify priorities for the selection of populations to preserve, according to different criteria, such as comprehensiveness, representativeness, adequacy, cost-efficiency, and vulnerability; Cabeza & Van Teeffelen, 2009) are among the most relevant issues associated with threat assessment and conservation.

Nowadays, the use of big data on biodiversity is increasing exponentially. A considerable part of herbarium and fieldwork information is already digitalized and available (e.g., GBIF; at https://www.gbif.org). Since the end of the last century, specialized software has emerged to enhance the automatic planning of interest areas (e.g., Andelman *et al*., 1999; Aggarwal *et al*., 2000; Ball & Possingham, 2000; Szumik & Goloboff, 2004). The use of big data together with GIS (Geographical Information System) has been proposed as a powerful tool when implemented as part of a multi-criteria decision-making framework (Pérez-García *et al*., 2007; Nemec & Raudsepp-Hearne, 2013; Mendoza-Fernández *et al*., 2014, 2015b; Martínez-Hernández *et al*., 2015).

Since the early days of plant conservation biology, much work has been done from many views or approaches and studies on plant conservation. MTEs are no exception here. The historical directions, strengths, and weaknesses of such work is thus described and analyzed in this paper.

A review of the international research on plant conservation in MTEs is now required to advance on which objectives and multiple targets should be pursued in the future. The present study aims to analyze plant conservation research in MTEs in the last fifty years, focusing on recent, relevant topics and highlighting the strength of plant conservation research at the MTE level and in Spain.

Material and Methods

In this work, a review of the literature related to plant conservation in Mediterranean areas was performed by a Scopus search to determine how to plant conservation in MTEs has been achieved. This bibliographic analysis was made using the key search terms: "plant" AND "conservation" AND "The Mediterranean" in title, abstract, and keywords. After the search, 1959 documents were screened. Metadata on authors' country of affiliation, year of publication, source, documents type, subject area, and founding sponsor, as well as title, abstract, and keywords (Appendix 1), were exported from the Scopus database.

Besides, data retrieved relative to the country of affiliation, source, and subject area were divided into four periods: 1970–1990, 1991–2000, 2001–2010, and 2011–2019. As subject area classifications hardly allowed for the differentiation among more specific topics (e.g., both Agricultural and Biological Sciences and Environmental encompass Ecology), subject categories were also analyzed. Scopus Subject categories were obtained from Scimago Journal & Country Rank (SJR) for each journal that included published papers in this main search. The comparison results for each period were plotted in different frequency histograms (for more information, see Appendix 2).

The search for commonly used terms in literature was performed using the text mining R package "tm" (Feinerer & Hornik, 2019). This package allows for constructing a term-document matrix after the so-called "text corpus" (i.e., group of texts to analyze, comprising titles and abstracts in this case). Afterward, a word stemming algorithm for collapsing words to a common root to assist comparison of vocabulary was performed with the "SnowballC" package (Bouchet-Valat, 2014). After removing plurals and other meaningless words, "wordcloud" package (Fellows, 2013) was used to represent the 150 most common terms contained in the text corpus. For graphs, "ggplot2" library (Wickham, 2016) was used.

From documents obtained after this general search, a more specific one was carried out by using characteristic keywords for each of the major topics relevant to plant conservation biology in MTEs. As a previous step, an analysis of keywords frequency in those documents (both author and index keywords) was performed. This decision was taken because Scopus Refined Search System only accepts refined search with a limited number of terms. Moreover, the use of this search system ensures that the present results are derived from counting the number of documents instead of the number of times a specific keyword appears in the text analyzed.

This analysis was performed with the aid of a free online text analysis tool Textalyser (http://textalyser.net/index.php?lang=en#analysis), which allows for the analysis of phrases. Both keywords' frequencies and the terms finally used in the different searches for each group of topics are available in Appendix 3.

Results

Literature review on plant conservation in MTEs

As a result of the metadata analysis on plant conservation literature in Mediterranean areas, the following results were obtained. First, there was a growing interest in the subject shown by the increasing number of publications in recent years (Figure 1a). Over the present century, it rose from around 17 documents in 2000 to 188 in 2019. Moreover, most of the papers were published by researchers from the Mediterranean Basin countries (Figure 1b) (Spain with 622, Italy 516, France 227, Turkey 69, and Greece 98), but also from other countries where MTEs are present (the United States 171, Australia 87, Chile, with 38 or South Africa, with only 29 publications).

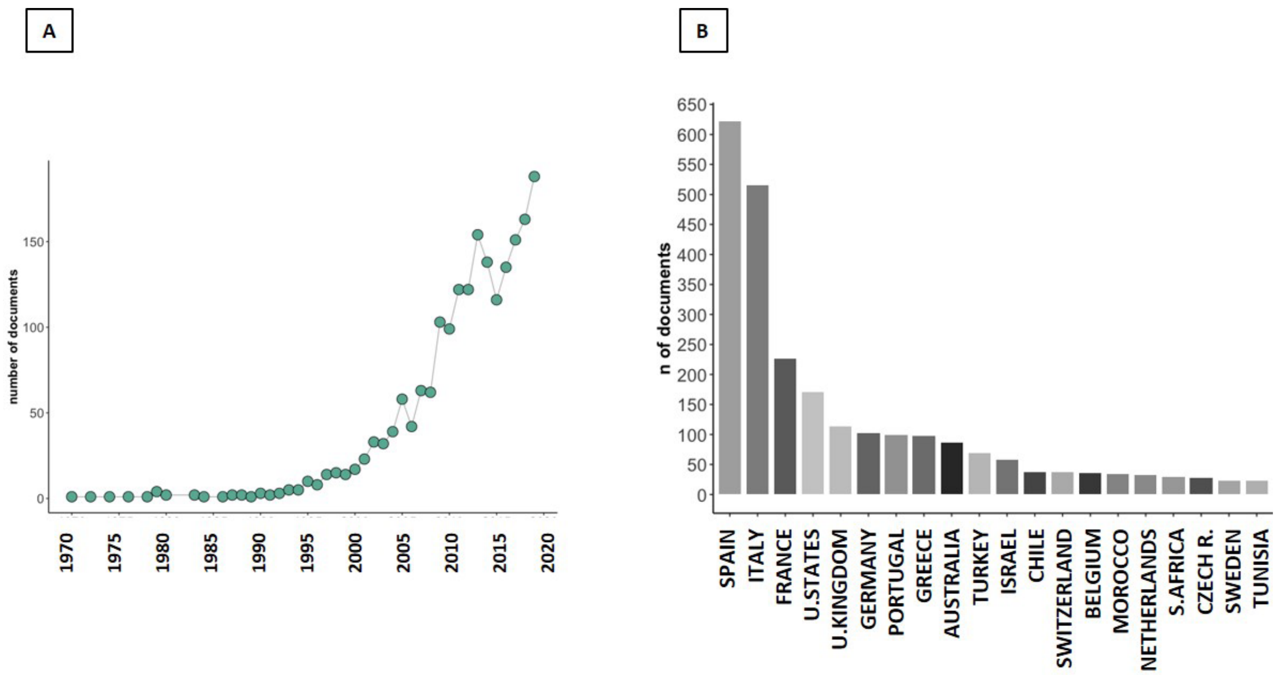

Figure 1. Results of the search performed on Scopus. Plots show the number of documents by year (A), country, or territory (B).

There are five areas where Mediterranean Type Ecosystems (i.e., Australia, South Africa, Chile, California, and Mediterranean Basin) were well-represented by 20 leading countries with at least 20 papers from 1970–2019 considering the authors' affiliation country. During this period, Spain and Italy stood out, followed by France and the United States (Appendix 4). If we consider the four periods of time aforementioned, results showed a different evolution in the number of documents published according to the geographical location of the countries: North of the Mediterranean Basin (MBN), South and East of the Mediterranean Basin (MBSE), countries from other MTEs different from the Mediterranean Basin (OMTE), and countries not belonging to MTEs (NMTE) (Figure 2).

Regardless of the period considered, results showed a predominance of MBN countries in the percentage of publications (60% approx.), except for the first period (1970–1990). Among them, the major contribution was made by three countries from the Western Mediterranean area: Spain, Italy, and France, whose combined contribution reached around 47% in the last three periods. Within the Mediterranean Basin, MBSE contribution increased from 0 during the first period (1970–1990) to about 6% of the total publications. In absolute terms, 115 documents were published during the last period analyzed (2010–2019).

Concerning the rest of the MTE regions (Southwestern Australia, Cape Region, California, and Central Chile), their contribution was always lower than that in the Mediterranean Basin, slightly dropping each period (from 18.5 to 11.3% of the total number of publications). In the case of countries where MTEs were not present, European countries stood out by showing an important contribution in the two first periods, which was similar to that of European MTEs (33% and 37% respectively), but decreasing during the latter period, reaching percentages of around 20%. The rest of the countries' contribution also decreased over the different periods reaching in the last one a ratio of about 6% of the total scientific literature.

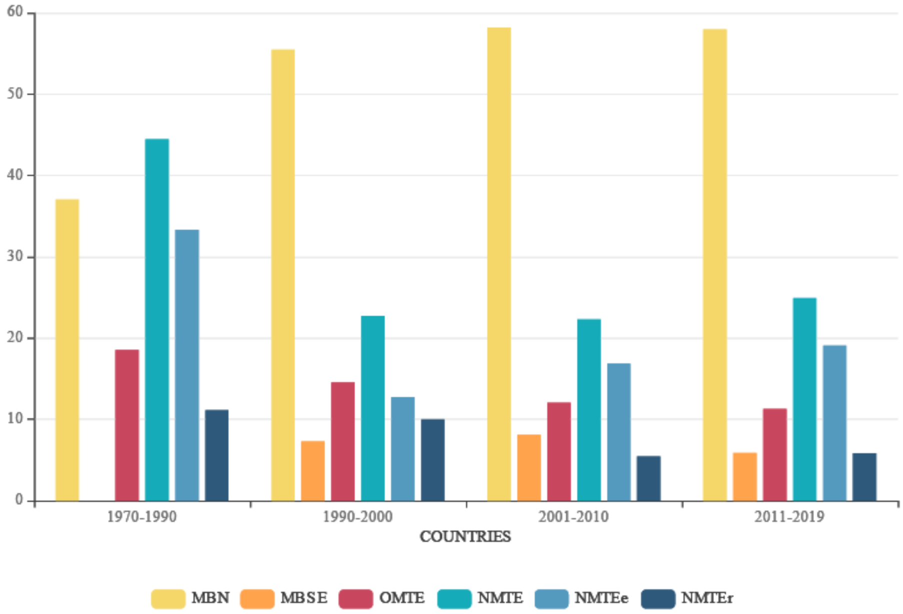

Figure 2. Percentage of documents published according to authors' country of affiliation for each of the four temporal periods considered. MBN: North Mediterranean Basin; MBSE: South and East Mediterranean Basin; OMTEs: Other MTEs countries; NMTE: Not in MTEs countries; NMTEe: European NMTE; NMTEr: Not European NMTE.

Concerning the subject area, the most important were Agriculture (43.2%) and Environmental Science (30.8%) (Figure 3a), being, as expected, conservation-related journals the most frequent. Hence, the most recurrent journals that publish papers on plant conservation in MTEs were *Biodiversity and Conservation* (72), *Biological Conservation* (57), *Plant Biosystems* (52), or *Journal for Nature Conservation* (24). However, there were also some from multidisciplinary areas (e.g., *PLoS ONE* with 46 items), or related to agriculture (*Acta Horticulturae* with 40) (Figure 3b). Regarding the type of document, the most common were articles (88.3%), followed by conference papers (4.6%) and reviews (3.7%) (Appendix 1).

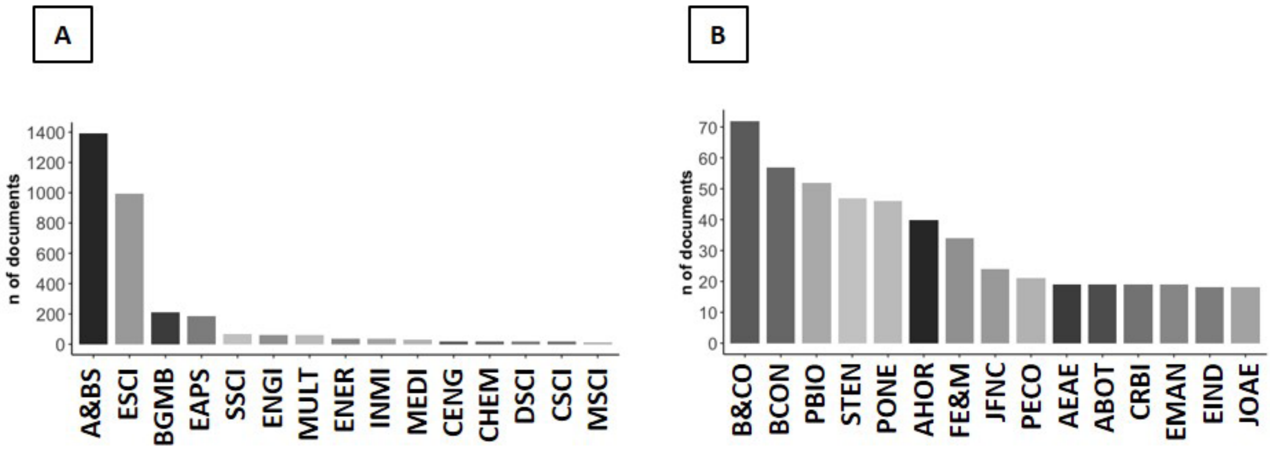

Figure 3. Results of the search performed on Scopus. Plots show the number of documents by subject area (A) and source title (B). Abbreviations are: A&BS: Agricultural and Biological Sciences; ESCI: Environmental Science; BGMB: Biochemistry Genetics and Molecular Biology; EAPS: Earth and Planetary Sciences; SSCI: Social Sciences; ENGI: Engineering; MULT: Multidisciplinary; ENER: Energy; INMI: Immunology and Microbiology; MEDI: Medicine; CENG: Chemical Engineering; CHEM: Chemistry; DSCI: Decision Sciences; CSCI: Computer Science; MSCI: Materials Science; B&CO: Biodiversity and Conservation; BCON: Biological Conservation; PBIO: Plant Biosystems; STEN: Science of the Total Environment; PONE: PLoS ONE; AHOR: Acta Horticulturae; FE&M: Forest Ecology and Management; JFNC: Journal for Nature Conservation; PECO: Plant Ecology; AEAE: Agriculture Ecosystems and Environment; ABOT: Annals of Botany; CRBI: Comptes Rendus Biologies; EMAN: Environmental Management; EIND: Ecological Indicators; JOAE: Journal of Applied Ecology.

Among the leading journals, only *Biological Conservation* was published from 1970 to 2019, while *Biodiversity and Conservation*, and *Science of the Total Environmental* were published from 1991, *Plant Biosystems* from 2001, and *PLoS ONE* from 2011. The number of documents published per journal in those leading five journals showed a decreasing percentage from 66.6 % in 1970–1990 to around 20% in the last 20 years. Besides, an increasing number of journals (Appendix 5) were found, varying from 11 during the first period to 161 in the last one.

During the four periods, subject areas showed the predominance of papers related to Agricultural and Biological Sciences (increasing from 30.8% to 42.9%) and Environmental Sciences (decreasing from 43.6% to 29.6%). These subject areas represented more than 70 % of the papers regardless of the period (Figure 4).

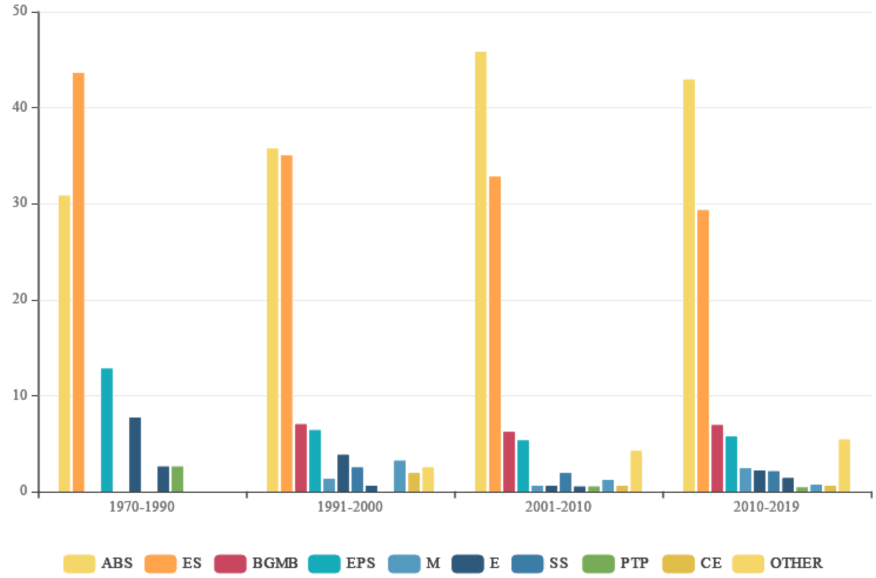

Figure 4. Percentage of documents published according to the main Scopus subject Area for each of the four temporal periods considered. ABS: Agricultural and Biological Sciences; ES: Environmental Science; BGMB: Biochemistry, Genetics and Molecular Biology; EPS: Earth and Planetary Sciences; M: Multidisciplinary; E: Engineering; SS: Social Sciences, E: Energy; PTP: Pharmacology Toxicology and Pharmaceutics; M: Medicine; CE: Chemical Engineering; OTHER: rest of subject areas.

A close look at the subject areas present in the journals and at their representativeness revealed more information. The main five subject categories were: Ecology, Evolution, Behaviour and Systematics, Plant Science, Ecology, Nature and Landscape Conservation, Management, Monitoring, and Policy and Law. These disciplines accounted for at least 50% of the total number of subject categories considered, ranging from 73.8% in the first period to 52.1% during 2010–2019 (Figure 5). Regarding the first three journals in the number of documents (*Biodiversity and Conservation*, *Biological Conservation* and *Plant Biosystems*), they represented the most frequent subject categories: Ecology, Evolution, Behaviour and Systematics, Nature and Landscape Conservation, Ecology, and Plant Science.

Besides, according to the different periods analyzed, a clear increase in the number of subject categories included in this analysis was found (Appendix 6), growing from 16 during the first period to 74 in the last one. Through grouping subject categories by affinities (e.g., Ecology with Ecology, Evolution Behaviour, and Systematics, etc., for further information see Appendix 6), it is possible to differentiate the following groups: Ecology, Plant Sciences, Conservation and Management, Agronomies, Animal Sciences, Environmental Sciences, Biochemistry, Genetics, and Molecular Biology. Considering these groups of subject categories, they would account for over 70% of the total subject categories analyzed.

Although ecology was prevailing in all periods, Conservation and Management followed it, but it decreased from 19% to 13.6%, and Plant Science from 16.7% to 11.5%. Minority groups of subject categories, such as Agronomies, Animal Sciences, Environmental or Biochemistry, Genetics, and Molecular Biology, progressively increased their representativeness in each period (from 4.8% to 23.7%).

Regarding the affiliation of researchers, they were predominantly European (Figure 6a). National public institutions devoted to research that also gathers multiple research centers, were found in leading positions. That was the case for CSIC (*Centro Superior de Investigaciones Científicas*; 91 publications, from Spain), CNRS (*Centre National de la Recherche Scientifique*, most of them from CEFE and IMBE; 89 publications, from France) or CNR (*Consiglio Nazionale delle Ricerche*; 64 publications, from Italy), but there were also particular Universities, such as *Università degli Studi di Cagliari* (74), or the *Universidad de Barcelona* (47). Here, differences were found in the affiliation among the three more prolific countries in publications. In France, research was mainly developed by public research institutions, whereas in Italy, universities were predominant. Regarding Spain, affiliation was more balanced between research institutions and universities.

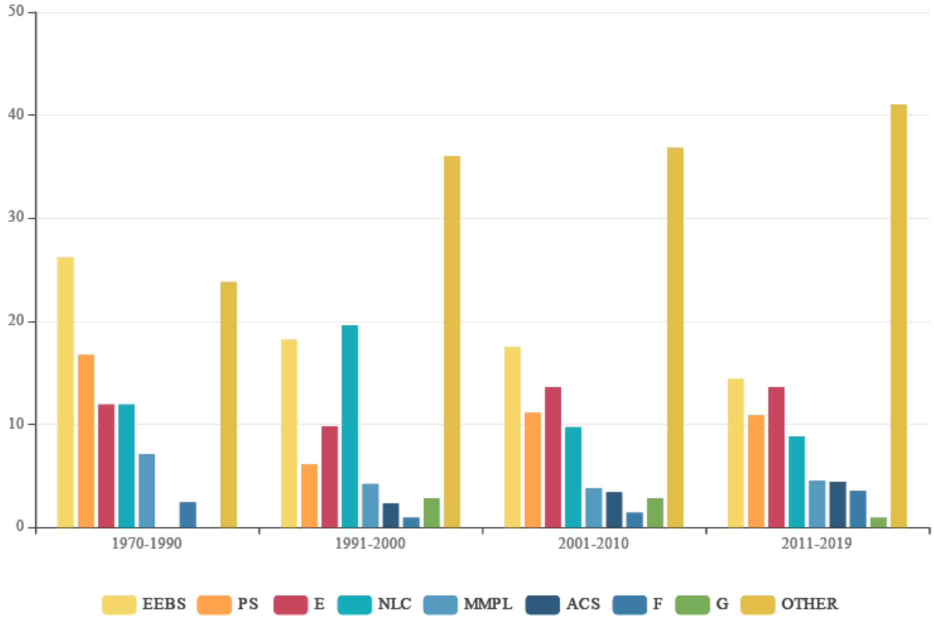

Figure 5. Percentage of documents published according to the main Scopus subject Category for each of the four temporal periods considered. EEBS: Ecology, Evolution, Behaviour and Systematics; PS: Plant Science; E: Ecology; NLC: Nature and Landscape Conservation; MMPL: Management, Monitoring, Policy and Law; ACS: Agronomy and Crop Science; F: Forestry; G: Genetics; OTHER: rest of subject categories.

As for the sponsors (Figure 6b) European organizations predominated, not only as regards EU funding (*European Commission, European Social Funds*), but also from different Mediterranean countries (*Fundación para Ciencia y Tecnología, Comisión interministerial de Ciencia y Tecnología*, *Centre National de la Recherche Scientifique*), or even regions (e.g. *Regione Autonoma della Sardegna*).

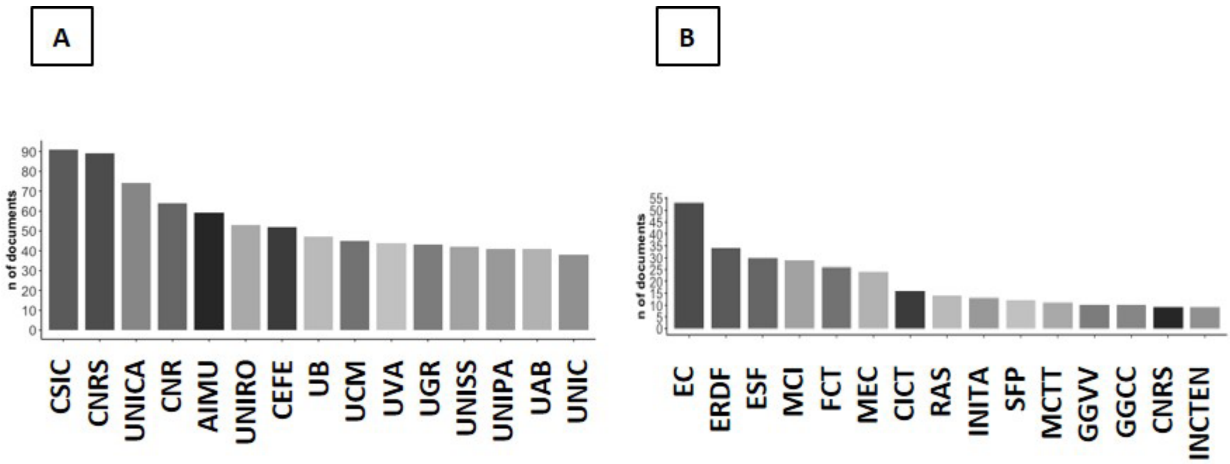

Figure 6. Results of the search performed on Scopus. Plots showthe number of documents by affiliation (A) and funding sponsor (B). Abbreviations are: CSIC: Consejo Superior de Investigaciones Científicas; CNRS: Centre National de la Recherche Scientifique; UNICA: Università degli Studi di Cagliari; CNR: Consiglio Nazionale delle Ricerche; AIMU: Aix Marseille Université; UNIRO: Università degli Studi di Roma La Sapienza; CEFE: Centre d'Ecologie Fonctionnelle et Evolutive; UB: Universitat de Barcelona; UCM: Universidad Complutense de Madrid; UVA: Universidad de Valencia; UGR: Universidad de Granada; UNISS: Università degli Studi di Sassari; UNIPA: Università degli Studi di Palermo; UAB: Universitat Autònoma de Barcelona; UNIC: Università degli Studi di Catania; EC: European Commission; ERDF: European Regional Development Fund; ESF: European Social Fund; MCI: Ministerio de Ciencia e Innovación; FCT: Fundação para a Ciência e a Tecnologia; MEC: Ministerio de Economía y Competitividad; CICT: Comisión Interministerial de Ciencia y Tecnología; RAS: Regione Autonoma della Sardegna; INITA: Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria; SFP: Seventh Framework Programme; MCTT: Ministerio de Ciencia Tecnología y Telecomunicaciones; GGVV: Generalitat Valenciana; GGCC: Generalitat de Catalunya; CNRS: Centre National de la Recherche Scientifique; INCTEN: Instituto Nacional de Instituto Nacional de Ciência e Tecnologia para Excitotoxicidade e Neuroproteção.

The most frequent terms included in the title, keywords, and abstract of the selected documents, was plant, conservation, and Mediterranean. The words that appeared most frequently were species, soil, diversity, biodiversity, population, or management (Figure 7).

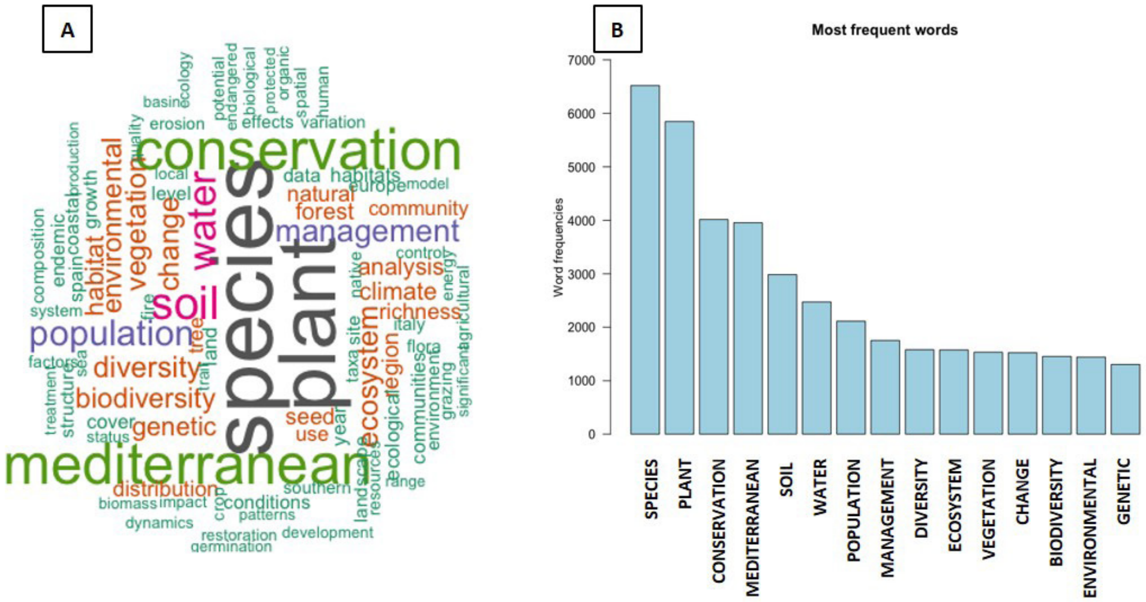

Figure 7. WordCloud (A) and Histogram of frequencies (B) for the most relevant terms present in Scopus search, related to plant conservation in MTEs (obtained after "wordcloud" R package).

Major topics regarding Plant conservation in MTEs

Reproductive biology and conservation genetics

Regarding reproductive biology, the current search selected 547 documents (Appendix 7). Most of them related to topics such as germination (108), seedling (116), pollination (33), or dispersal (105). In line with the general search, most of the documents were produced in European countries (642), mostly from Mediterranean Basin countries (476). Representation for the rest of MTEs was significantly lower (USA 57, Australia 32, Chile 11, South Africa 5).

Conservation genetics resulted in the selection of 484 documents (Appendix 7). Most of them directly related to conservation genetics, such as genetics (132), taxonomy (84), evolutionary (85), gene (126), or molecular (100). Most of the documents were produced in Europe, mostly from Mediterranean Basin countries (Italy 145, Spain 137, France 75). The rest of MTEs was significantly lower (USA 34, Australia 25, Chile 10, South Africa 8).

Threat factors and effects of global change

In the case of threat factors and global change effects, the analysis of literature selected 1127 documents (Appendix 7). The most common threat factor mentioned was Agriculture & aquaculture (cited 373 times, taking into account several sub-factors' aggregation: crops, farming, livestock, plantations). Secondly, Climate change & severe weather, mentioned in the text as climate change (cited 205 times) and droughts (cited 141 times). Thirdly, Pollution as a threat factor reached 92 references in the search. In the fourth place, "Natural system modifications" arose as a significant risk factor for the loss of biodiversity, basically due to the high frequency of the term fire (cited 139 times). Other threat factors found can be separated into those related to Invasive & other problematic species, genes & diseases, Human intrusions & disturbance, and "Residential & commercial development" (with more than 200 citations). Most of the documents were produced in European countries, mostly from Mediterranean Basin countries (Italy 272, Spain 370, France 115). The rest of MTEs was significantly lower (USA 115, Australia 63, Chile 21, South Africa 24).

Evaluation of conservation status and protected areas selection

Considering keywords related to the evaluation of conservation status and protected areas selection, 1034 documents were found (Appendix 7). Among the most frequent terms were: conservation management (197), environmental protection (165), endemic (367), or richness (332). Bibliographic search focusing on the term "Red List(s)" resulted in 57 documents, which also addressed plant conservation issues. After classifying the data according to the country of origin, it was found that Italy held the first place with 17 publications; followed by Spain (11), Hungary and Turkey (5), United Kingdom and Switzerland (4), and France, Greece, Portugal, and Croatia (3 each of them). Furthermore, in 12 other European Union countries, at least one study has been published about plant conservation and Red Lists (papers on this topic appeared in a total of 19 out of the 27 European Union countries).

Regarding the topic Protected areas, the search report showed 663 documents (Appendix 7). Also, adding other keywords such as richness, endemic, rarity, complementarity, or gap analysis are frequently linked. Some Spanish scientific teams were pioneers in plant reserve selection (Laguna *et al*., 2004; Sánchez-Gómez *et al*., 2005). Unsurprisingly, Spain held the first place in terms of scientific production in this regard (204 papers), followed by Italy (174), and France (87).

Discussion

General review of literature on plant conservation in MTEs

Since 1990, the number of publications related to the conservation of plants in MTEs has risen exponentially. A closer look at the number of publications in the different countries by periods (see Appendix 4) revealed the coincidence with the increasing numbers in Mediterranean Basin countries and Spain, Italy, and France. Such predominance was similar to that found by Nardi *et al.* (2016) on the Mediterranean Forest's evolution, which has experienced exponential growth from 1994. These statements should be taken cautiously, given the low number of publications found before 1990 and the potential bias in the search resulting from the keywords and the only database used. A similar tendency was present in the other four MTEs, with the period 2001–2010 being the interval where the number of publications grew most quickly. This growth was also detected in the study by Nardi *et al.* (2016).

Research has taken advantage of the specific funds provided by the European Union, which has been focused on the Development of the Natura 2000 network and the conservation of the species present in the annexes of the Habitats Directive. Other efforts have also been channeled through The European Strategy for Plant Conservation (ESPC), supported by the Plant Europe Network and the Council of Europe from 2001. ESPC, the regional contribution to the Global Strategy for Plant Conservation (GSPC), is a targeted response to prevent loss of plant diversity in Europe. This strategy has received support from different international entities (IABG, BGCU, IUCN, etc.) searching for sponsors, public entities, and private financers, or as a supporter in establishing networks.

During the 21st century second decade, a clear deceleration in the number of publications per year is observed. It has been found in general in research related to biodiversity. Stork & Astrin (2014) investigated the evolution in the number of publications related to biodiversity and detected this drop together with a noticeable decrease in the use of the term "conservation" during 2012. Here, the authors did not propose any specific explanation for that. The use of the term biodiversity in scientific publications was in progressive growth until 2009 (Liu *et al*., 2011). Although these authors do not mention it, the decrease found could be associated with extrinsic causes, such as the 2008 global financial crisis. According to the present results, the number of publications related to MTEs' plant conservation declined during 2014 and 2015 (compared to the previous year). The countries with the highest decrease (considering the number of publications during the last year) were Spain, Italy, France, and the United States (those that contributed with the highest number of publications). It makes sense in the context of the global financial crisis's effects, as the typical duration of research projects is about 4 or 5 years.

The MTEs countries different from the Mediterranean Basin were found among the most relevant concerning the number of publications but not always in leading positions (Appendix 4). These results are consistent with those obtained by Nardi *et al.* (2016), relative to the scientific production on MTEs forests. On the other hand, considering bibliometric studies related to biodiversity (Melles *et al*., 2019), they were always present in high positions. Moreover, in terms of the protection and conservation of MTEs, they showed indices higher than those established by the Mediterranean Basin (Underwood *et al*., 2009). It seems that MTEs does not play an essential role in these countries' conservation research, yet a certain bias in the present results might also have arisen from the search method used.

When the north Mediterranean Basin countries began to emerge

By analyzing the number of publications per period considered, a change was found in the countries located in the first positions. Predominant countries range from mainly English-speaking countries (with a significant role for the United Kingdom) to Mediterranean countries such as Spain, France, and Italy (repeatedly among the top three positions). It has also been observed by Melles *et al*. (2019) in a general bibliometric study on terms related to conservation biology and applied ecology. In this research, the authors showed how these countries are present in most recurrent journals in disciplines such as 'Environmental Management,' 'Policy and Law Conservation Biology,' 'Aquatic Sciences' and 'Ecology / Environment.' This interest in conservation issues is not surprising for several reasons. The area occupied by the Mediterranean Basin encompasses close to 73% of the total surface area of MTEs in the world (Cowling *et al*., 1996; Underwood *et al*., 2009; Thompson, 2020).

Furthermore, the number of endemic species in this biodiversity hotspot is significantly high, almost similar to the Cape Region, and higher than in the rest of MTEs (Cowling *et al*., 1996; Thompson, 2020). This area has been populated by humans for thousands of years, producing a severe impact on the landscape. Moreover, the European continent has been the cradle of important scientists dedicated to studying plants in the past. Studies by Cesalpino (1583), and more recently or Cavanilles (1795−1797), Willkomm (1852), or Boissier (1867−1884) regarding Mediterranean flora are seminal. Also, Mediterranean Basin countries have enjoyed many botanical gardens, a fundamental tool in the conservation of plants, for around 700 years (Heywood, 2015).

In addition, the existence of a supranational structure has favored the development of transnational projects on plant protection. European institutions have developed powerful frameworks for the protection of habitats specific to Mediterranean ecosystems. At this point, the development of the Natura 2000 network within the framework of the Habitats Directive is worthy of notice, as well as the funding of research projects in Mediterranean areas by the European Union. One of the EU's priority means to achieve its objectives is to increase internal cohesion through multinational programs, as has happened with the funds from the Interreg program (www.interregeurope.eu), financed by the European Regional Development Fund (ERDF), or COST initiative (European Cooperation in Science and Technology). This initiative provides networking opportunities for researchers and innovators in order to strengthen Europe's capacity to address scientific, technological, and societal challenges. All institutions enlisted in the first 23 positions are from Spain, France, or Italy.

Regarding funding institutions, results are similar to those obtained in research institutions; until position 14, all the organisms belonged to these countries or supranational structures in the European Union. Regarding the prevalence of public or private funding, merely considering governmental organizations and universities as public funders (not accounting for foundations), 418 documents were found. Although it should be noted that there are 1,477 that do not have a defined financing entity, it is still an overwhelming majority of public funding compared to private financing.

In the rest of the MTE countries not belonging to the Mediterranean Basin (mainly the USA), governmental organizations' participation in the very same government is much lower than participation by foundations and private organizations. In the specific case of Australia, the weight of universities is higher than in the USA (59/87), also being the participation of European organizations and projects also important, which demonstrates the involvement of the EU in the protection of MTEs around the world.

North West vs. South and East of the Mediterranean Basin

Different publications illustrate the differences between the north (particularly three north-western countries Spain, France and Italy) and the south and east of the Mediterranean Basin (Rundel *et al*., 1998; Valderrábano *et al*., 2018; Heywood, 2019b) in relation to studies of Plant conservation biology. The causes of these differences are complex. According to Heywood (2019a), there is a sharp contrast in plant conservation achievements and prospects. While there are legislative structures and conservation agreements in the European Union, such as the Habitats Directive or the Berne Convention, and a network of protected areas such as the Natura Network 2000, there is nothing similar to the south and east of the Mediterranean Basin. Furthermore, there is little tradition of conservation actions for individual species in these regions, with few recovery programs or successful reintroductions.

From the point of view of Valderrábano *et al*. (2018), the number of botanists and taxonomists is insufficient, and there is not enough generational turnover for those who are finishing their careers. There is an urgent need to train more specialists in conservation biology and conservation practices. Moreover, threatened plants receive legal protection in only a few countries. National policies for the conservation of flora should be strengthened. Thus, it is difficult to develop studies with the aim of conserving species.

Much more cooperation between institutions in the European Mediterranean and those in the south and east countries of the Mediterranean Basin would help address these problems. EU disposes of specific cooperation funds that have been used to carry out very effective collaborative projects, thanks to specific sections of the Interreg programme (which have temporarily included direct investment in countries of the N of Africa and E of the Mediterranean to improve their infrastructure and training of conservation staff). The main fund for such collaborations, ENPI funds, are included in the financial scheme of the European Neighbourhood Instrument (ENI) (https://ec.europa.eu/neighbourhood-enlargement/neighbourhood/southern-neighbourhood_en). A clear example of these financial tools has been the Interreg SEMCLIMED and GENMEDOC projects, under which GENMEDA (Network of Mediterranean Plant Conservation Centres) was developed (http://www.genmeda.net/). This network currently brings together 22 entities; of them, 6 are from Southern and Eastern Mediterranean countries. ENPI ECOPLANTMED project has also made progress in the construction of this network.

Moreover, the efforts of different international entities with Mediterranean headquarters should be noted, which have mainly promoted cooperation between entities on both sides of the Mediterranean, including collaboration among research teams. On the one hand, the United Nations, through UNEP/UNEP, promoted the establishment of the RAC/SPA (Regional Activity Centre for Specially Protected Areas) in Tunisia, which has been specializing in the protection of marine areas. On the other hand, much more active for cooperation in the conservation of terrestrial flora, it is worth highlighting the impulse of the Mediterranean Office of the IUCN, based in Malaga, which has promoted projects such as the red list of Mediterranean flora or international meetings of experts to develop IUCN evaluations of specific groups of Mediterranean flora. All these can be powerful tools that enhance collaboration between the two shores.

Subject areas and subject categories of journals where MTEs papers are published

In the last decades, it has been observed how the number of journals where MTEs plant conservation papers are published has increased (from 11 to 161). This is also in line with the growth in the number of subject categories (new publications are described in many cases with new subject categories). Meanwhile, with the single consideration of those subject areas automatically generated by the Scopus analyser, hardly any differences in the frequencies of the different periods studied for each category would have been found: there was a clear predominance of Agricultural and Biological Sciences and Environmental Science over the rest of the subject areas. Similar results have been obtained in the bibliometric analysis of Global biodiversity research by Liu *et al*. (2011).

The increase in the number of journals and subject categories and the progress in the different periods analyzed indicates a more significant number of knowledge areas in the study of flora conservation in MTEs. It would also be in accordance with the results obtained after analyzing the leading five journals for each period, which represent in each successive period a smaller percentage of the total number of documents published (around 20% during the last period). It was also found that subject category related to plant conservation were in the majority (Ecology, Conservation and Management, and Plant Sciences), although with a decreasing representation of the total subject categories considered in each period (from 74% during the first to 53% in the last one). Those journals where the documents of interest are published frequently belong to ecology, flora, conservation, and management categories but show a progressive decrease in time.

Other subject categories that could be considered interdisciplinary (more closely related to the use of natural resources and the effects of man's actions on the environment, such as Agronomy and crop science, Pollution, Water Science and Technology, Waste management and disposal), Environmental Sciences or Animal Science, increased. This increase would explain the decrease in the contribution of the subject categories more related to plant conservation.

Finally, according to the evolution found in the different subject categories, a marked predominance was found of those that are more closely related to the generation of knowledge than to those that involve direct management actions. This is a general trend seen in the different periods analyzed and will become more marked in the successive periods.

Reproductive biology and conservation genetics

Although most of the publications related to reproductive biology and conservation genetics belong to the Mediterranean Basin, outstanding studies from other MTEs areas were found. For instance, Medel *et al*. (2018) reviews the ecology of pollination in the Chilean MTEs, Bradshaw *et al.* (2011) discuss the origin of fire-adapted plant traits, or Millar *et al*. (2020) studies the reproductive biology of *Banksia* species present in SW Australia plains to improve restoration activities. Other good examples are the review on seed regeneration in Mediterranean temporary ponds (Carta, 2016), typically threatened habitats of MTEs, or the study of the effect of wood fragmentation in Central Chile on plant-insect interaction (Figueroa *et al*., 2018).

Many studies are focused on hybridization, detecting ongoing hybridization processes, as is the case of the circunmediterranean genus *Cyclamen* L. (Thompson *et al*., 2018). Also, it is primordial to identify hybrid taxa, as in the case of the rare species from Western Australia *Adenanthos x cunninghamii* (Walker *et al*., 2018). The importance of climate change in hybridization processes is also evident in Gómez *et al*. (2015) study. Other authors highlight the utility of intraspecific hybridization to recover populations genetically depauperated, as in the Californian pine species *Pinus torreyana* Parry (Hamilton *et al*., 2017).

Further literature study fragmented or vulnerable habitats, as the research on coastal dune flora (De Vitis *et al*., 2018 in Mediterranean region; Cowling *et al*., 2019, in Cape Floristic Region), or edaphic islands (on Iberian dolomites, Salmerón-Sánchez *et al*., 2014; on granitic habitats in Western Australia, Bezemer *et al*., 2019). Many of them are focused on how habitat fragmentation affects genetic diversity, as in the case of *Stachys maritima* Gouan (Massó *et al*., 2016; in Mediterranean Basin), or *Pouteria splendens* Macl. (Carvallo *et al*., 2019; in Central Chile).

Among the different studies that focus on conservation genetics, some stand out for novel methodologies based on high-throughput sequencing. It is worth pointing out the characterization of leaf transcriptome in *Banksia hookeriana* Meisn. (Lim *et al*., 2017) or ddRAD (double-digest restriction-site associated DNA sequencing) in studying the genetic structure of endangered salt marsh plants in California (Milano *et al*., 2020). These methodologies can be useful in taxonomy, which has increased during the last years (e.g., Gardner *et al*., 2016; Uribe-Convers *et al*., 2017). A good example is the study of the worldwide distributed genus *Plantago* L. (Hassemer *et al*., 2019), with representatives present in MTEs. These novel methodologies are also useful to evaluate the validity of morphology as a taxonomic character (e.g., lignotuber state in *Eucalyptus* L'Hér; Gosper *et al*., 2018). Taxonomical studies can establish (by describing novel species; e.g., genus *Ceanothus* L. in California; Burge *et al*., 2017) or modify the conservation status (Massó *et al*., 2018) in the case of *Cynara baetica* (Spreng.) Pau subspecies.

Multidisciplinary approaches are becoming more relevant. For example, in CFP, Baldwin's review (2019) highlights studies on a regional scale, spatial patterns of Californian species' richness, phylogenetic diversity, and phylogenetic endemism. Also, in CFP or Kling *et al.* (2018), novel analyses of the different facets of phylodiversity, allows the establishment of conservation priorities.

One more prominent paper (Medail & Baumel, 2018) reviews the use of phylogeography to propose conservation plans for threatened endemic plants within biodiversity hotspots. Here, the authors remark on the scarce use of these studies in plant conservation genetics. Some illustrative examples are the genetic studies by Salmerón-Sánchez *et al*. (2014a, 2104b, 2017) dealing with different plant species that grow on particular substrates (*Jurinea pinnata* (Pers.) DC., *Convolvulus* *boissieri* Steud and *Jacobaea auricula* (Bourg. ex Coss.) Pelser respectively). Other studies use phylogeography and population genetics to propose different conservation units: Management Units (Willyard *et al*., 2020); Relevant Genetic Units for Conservation (RGUCs) (Pérez-Collazos *et al*., 2008; Peñas *et al*., 2016); Units for Conservation (Coates *et al*., 2014; Dick *et al*., 2014); or significant evolutionary units (ESUs) (Llorens *et al*., 2015; Millar & Byrne, 2020).

Threat factors and effects of global change

The most important threats and their category have varied depending on the Mediterranean region considered (Domínguez-Lozano *et al*., 2013). Thus, regarding the increase of human population, and in comparison with other MTEs, the Mediterranean Basin has experienced the most significant growth in urban areas (Underwood *et al*., 2009), with coastal lowlands undergoing urbanization and development associated with tourism for decades (Grenon & Batisse, 1989; Vogiatzakis *et al*., 2006). In this area an increase of urbanization in foothills has been detected (Underwood *et al*., 2009). However, both in South Africa and Australia, urban development was concentrated around Cape Town and Perth, respectively. No changes have been detected in foothills and mountain areas. This could be a consequence of the high degree of protection in the upper elevations and their location far from main urban centres, at least in South Africa and Spain (Rouget *et al*., 2003; Mendoza-Fernández *et al*., 2010).

However, the impact of agriculture was higher in Australia, where the clearing of native vegetation for wheat cultivation in the southwest has led to the fact that only 2 to 3% of native vegetation remains, even though it contains a large number of rare and endangered plant species (Hobbs, 1998; Hopper & Gioia, 2004). In return, in the Mediterranean Basin, almost one-third of the area was classified as agriculture. Nevertheless, the increase in mechanization in the countries from the southern Mediterranean Basin has led to cereal crops on large steppe vegetation areas (le Houérou, 1981), while crop intensification is endangering very significantly plant species in northern countries (Mendoza-Fernández *et al*., 2015a).

For Spain, Bañares *et al*. (2004) identified the main risks based on the Red Book of Spanish Vascular Flora. Furthermore, Moreno-Saiz *et al*. (2013) highlighted that these main risks in mainland Spain were related to "human intrusions & disturbance" (13.6%) and to "agriculture" (11.8%). For the Balearic Islands, the main risks related to "human intrusions & disturbance" (14.4%) and "natural system modifications" (11.9%), while on the Canary Islands, the main threats detected were those associated with "climate change and severe weather" (15.1%) and "Invasive species and genes" (14.9%).

In general, these previous results coincide with the literature trends discussed: overgrazing appeared as the most frequently cited factor (in almost 40%), closely followed by competition with other plant species, land change, and traditional or collector harvesting. However, some traditional activities such as grazing are key to maintaining plant diversity in some MTEs (e.g. *Linaria nigricans* Lange, Peñas *et al*., 2011; *Lepidium navasii* (Pau) Al-Shehbaz, Mota *et al*., 2013). Other authors highlight climate change as a leading threat factor (which has been noted in the Sierra Nevada, the Canary Islands or other Mediterranean countries, e.g., Italy; Blanca *et al*., 2002; Marrero *et al*., 2003; Fenu *et al*., 2017). According to the present results, this threat factor is being widely cited. Nonetheless, Bañares *et al*. (2004) also indicated that despite the increase in the "climatic change" factor, its predominance might be caused by additional influences. Risk factors of anthropogenic origin associated with land-use changes: i.e., agriculture, pollution, or habitat loss can act synergistically with climate change, although the latter factor remains underestimated.

The relevance of the global change subject has been recently noted in papers on plant conservation in MTEs. In the last eight years, the topic has been incorporated in the majority of studies. Most of the research was related to climatic change and land-use changes, including habitat fragmentation, agriculture, or fires. The ability of species to adapt to climate change is becoming an important research field, specially the capacity of species to cope with change and to survive through *in situ* management (Greenwood *et al*., 2016). For example, more attention should be paid to drought-related forest decline and the current relevance of historical land use (Doblas-Miranda *et al*., 2015). More studies related to fragmented or vulnerable habitats are those that imply special edaphic substrates, as is the case with gypsum outcrops. Several dimensions of this habitat of community interest (Iberian gypsum vegetation, *Gypsophiletalia*; see Mota *et al*., 2011, 2016, 2017; Pérez-García et al., 2018) have been studied.

Climate change is increasing the risk of invasive plants' expansion worldwide, but few studies have specified the relationship between the expansion of invasive plants and eco-regions at a global scale under climate change (Wang *et al*., 2019). MTEs are not strongly affected by invasive species except the Mediterranean islands and mountains, which are important plant endemism hotspots (Peñas *et al*., 2005; Cañadas *et al*., 2014), and are prone to alien invasion (Chytrý *et al*., 2005, 2008; Celesti-Grapow *et al*., 2016). Herbivores (natural or livestock) and fire are the most important items of study among the disturbance drivers affecting both composition and structure of vegetation in MTEs, because of their potential key role as ecosystem engineers for the conservation and restoration of Mediterranean habitats (i.e., Fernández-García *et al*., 2019; De Almeida *et al*., 2020; etc.).

Nowadays, man-mediated activities are among the most prominent drivers disturbing composition, structure, or function components of biodiversity (Cazorla *et al*., 2020). Therefore, more investigation in MTEs will be necessary to achieve more adaptive conservation strategies and solutions. It would imply the adoption of both *in situ* and *ex situ* measures on populations, species or habitats and ecosystems, and various geographical scales, in response to climatic and other changes in the Anthropocene.

In some cases, agriculture has obliterated entire plant habitats from the map and many of the threatened species integrated into them. And that has happened in the blink of an eye (Mota *et al*., 1996; Mendoza-Fernández *et al*., 2019).

Although the IUCN considers Global Change as the main risk cause for biodiversity, the lack of necessary information about the majority of the species, or the certainty of prospects, could be some of the reasons why it is rarely mentioned as a primary factor in the Red List of flora. This data has been contrasted in the Andalusia region (South Spain); in studies on Mediterranean countries e.g. in Italy; or in other countries like Australia, where flora has not presented significant differences in the proportion of high, medium and low risk species under climate change listed as CR, EN or VU (Moreno-Saiz *et al*., 2008; Fenu *et al*., 2017; Dudley *et al*., 2019; Mendoza-Fernández *et al*., 2019). This could represent a serious drawback in evaluating the conservation status of species, in particular those especially sensitive to drastic changes in environmental conditions.

Evaluation of conservation status and protected areas selection

The present study's results confirmed the fact that European countries have a long tradition in publishing Red Lists of biodiversity and in their analysis (Pleguezuelos *et al*., 2002; Madroño *et al*., 2004; Butchart *et al*., 2007; Palomo *et al*., 2007; Quayle *et al*., 2007; Juslén *et al*., 2016; Orsenigo *et al*., 2018), as in Spain, where the case of threatened flora has occupied a top priority place for a considerable period of time (e.g., Barreno *et al*., 1984; Bañares *et al*., 2004; Moreno-Saiz *et al*., 2008; Bañares *et al*., 2010). In the past 35 years, Spanish researchers and stakeholders have worried about vascular flora's conservation status and about promoting research, recovery, and conservation of threatened flora populations (Moreno-Saiz *et al*., 2004). However, the national project "Atlas and Red Data Book of Threatened Vascular Flora of Spain" has been the main strategy on this topic, which began in the 2000s. It brought together information on Spanish-threatening flora assessments and included the Red List threat category based on the IUCN criteria. Moreover, subsequent addenda have expanded and updated the data. In this regard, Spain would have met the 12th Aichi target of the 10th Conference of the Parties to the Convention on Biological Diversity (Tittensor *et al*., 2014). Nevertheless, in terms of plant conservation, the expected relationship between red lists and conservation laws was not consistent since the threat categories published in those documents frequently showed contradictory ratings (Mendoza-Fernández & Mota, 2016).

Currently, researchers resort to recent methodologies for the preparation of conservation management plans, like Species Distribution Modelling (SDMs), which are implemented along with other methods for different purposes related to plant species conservation. According to Elith & Leathwick (2009), SDM relates species distribution data (occurrence or abundance at known locations) to information on those locations' environmental and/or spatial characteristics. This model can provide understanding and predict species' distribution across a landscape in two ways (Elith & Leathwick, 2009): SDMs are made to predict new sites within the range of environments sampled in the same general time frame as that in which the sampling occurred (model-based interpolation to unsampled sites), or to predict new and unsampled geographic domains for future or past climate scenarios.

Finally, in various MTE regions, some challenges remain. For example, Monks *et al*. (2019), in their study about the recovery of threatened plant species in the Southwest Australian Floristic Region, mentioned that which would be the research leading to improved knowledge and management about them. These authors highlighted the need for delimiting taxon boundaries and units for conservation, as well as the knowledge on the intrinsic limits on population viability, managing and prioritizing threats, restoration and translocations. According to Valderrábano *et al*. (2018), in other MTE areas, such as the South and East of the Mediterranean Basin, there are some gaps in the coverage and ecological representativeness of protected areas and the level of protection and management is not always adequate; only a small percentage of threatened species have been the subject of recovery actions, etc., although recent works present information related to Important Plant Areas (IPAs; Plantlife International, 2004) and Key Biodiversity Areas (KBAs; IUCN, 2016) which are important bases for setting conservation priorities, related to implementing effective conservation, both area-based and species-based, on the ground (Darbyshire *et al*., 2017).

Final remarks

After analyzing the state of the art for plant conservation in Mediterranean-type Ecosystems, with the documents published in the 50 years from 1970 to 2019, by reviewing the relevant topics and highlighting the strength of plant conservation research, we could extract the following reflections and findings.

There is an unbalance in the research carried out in the Mediterranean Basin concerning other MTEs, and between countries to the south and southeast of the basin compared with countries on the northern shores of the Mediterranean Sea. Although there are international forums for the exchange of knowledge among the different MTEs (i.e., MEDECOS; Conference on Mediterranean-type Ecosystems), or the development of the Network of Mediterranean Plant Conservation Centres, with the presence of entities from the entire Mediterranean Basin (i.e., GENMEDA), the new perspective of common programs for all of them should be considered in the foreseeable future. There are established and tabulated criteria given by the IUCN, but they are not applied in the same way, even in the same region. There is a substantial need for integration of actions at transnational level. Mediterranean Basin countries illustrate comprehensively this problem. There are not common conservation policy instruments, strategies or planning at regional scale.

As founding entities, public research centers and governmental organizations are fundamental, while private foundations and institutions' role is marginal. Although, as mentioned above, efforts have been made in the search for sponsors or private entities, especially through important international entities (i.e., IABG, BGCI, IUCN...), greater involvement of the private sector would be necessary to help support conservation efforts in MTEs.

There is a decrease in the expected subject categories in MTEs' plant conservation. Main subjects such as those directly related or Ecology, Plant Sciences, Management or Conservation decreased, whereas multidisciplinary sciences increased. The most frequent subject categories were more related to the generation of knowledge than to the implementation or application of that knowledge, in the present case, diversity conservation, and management measures. Consequently, the scientific community's responsibility is to focus their research on clear and specific conservation proposals to give priorities and emphasis on important subjects that are still poorly developed.

Among the major topics, an outstanding progression was found in the research related to each of them. Advances have been achieved, both in the use of multidisciplinary approaches and in the implementation of novel methodologies (phylogenomics, SDM, etc.) and the use in different management strategies. Regarding the top countries that predominate in each of them, the same bias was found in the general analysis, being the most important western Mediterranean countries. Apart from that, different weaknesses emerged as a common pattern:

- Concerning threat factors and effects of global change, the limited information available about most species (especially in the east and southeast of the Mediterranean basin), together with the certainty of prospects, could represent a severe drawback in evaluating the conservation status of plant species. For example, projects such as Life Adaptamed (LIFE14CCA/ES/000612) to assess the protection of key ecosystem services by adaptative management of Climate Change in endangered Mediterranean socio-ecosystems can generate valuable information for nature protection, and also constitutes a demonstrative initiative to incorporate the ecosystem functioning and services dimension into the adaptive management.
- In coincidence with the poor application of scientific knowledge in conservation measures, there was a scarce use of conservation genetics studies in the development of both *in situ* and *ex situ* conservation programmes As Medail & Baumel (2018) remark, phylogeographic studies are underutilized in plant conservation genetics, despite offering fundamental information for decision-making in conservation plans as they describe the distribution of genetic variability among plant species populations. It should prioritize populations to preserve the evolutionary potential of the threatened species (Peñas *et al*., 2016). Perhaps the inclusion of a manual of good practices or guidelines that establish these studies' use as compulsory in conservation strategies would help make more direct proposals aimed at conservation. Proposals of this type have been made in Spain (e.g., First National Meeting of Genetic Conservation of Plants, 2011), but unfortunately, they have not yet borne fruit.
- Finally, regarding the evaluation of the protected area and species conservation status, it would be necessary to delimit taxa boundaries and units for conservation and increase the knowledge of the intrinsic limits on population viability and prioritize threats, risk management strategies, restoration, and translocations. In addition, in some MTE regions, it would be necessary to implement effective management and conservation measures, both area-based and species-based. It would be appropriate to contemplate situations that could range from the network of natural protected areas in Andalusia (RENPA: the most extensive network of NPA within peninsular Spain, www.juntadeandalucia.es/medioambiente/site/portalweb), to such interesting designs of flora micro-reserves that make nature conservation compatible (towards singular species) with the private ownership of the land (Laguna *et al*., 2004).

To conclude, it is important to emphasize the need to favour trans-Mediterranean studies that encompass the different research approaches related to flora and vegetation conservation. We must insist that the different methodologies used in the different MTEs regions should be uniform (e.g.: plots to make species-area relationships, molecular markers, criteria for selecting priority areas for conservation, demographic studies, etc). New objective and integrative scientific arguments and conceptual bases should be developed in plant conservation biology.

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