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EUCAMED: the first inventory of eucalypts introduced to the Mediterranean Basin

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ABSTRACT
The eucalypts (genera *Eucalyptus*, *Corymbia*, and *Angophora*) comprise 934 species, most of them endemic to Australia. In Mediterranean countries their long introduction history is evident in plantations and is well documented in an extensive literature that details their propagation and uses. This study provides the first comprehensive inventory of the eucalypts introduced to the Mediterranean Basin. Specifically, it seeks to quantify the number of species and hybrids currently introduced, and to harmonize available records into an informative, and spatially explicit inventory. EUCAMED (Eucalypt records in the Mediterranean Basin) currently comprises 4,103 records (taxon × country × site) on 387 taxa spread across 21 Mediterranean countries extracted from 445 references. These are categorized into: 3,811 records (387 taxa) as cultivated, 205 records as casual (19 taxa), 50 naturalized records (17 taxa), 34 records (14 taxa) that failed to establish populations, and 3 invasive records represented by two taxa. Overall, 296 species, 17 subspecies, 17 autonyms, 3 varieties, 2 cultivars, and 52 hybrids were found. Each record incorporated into the inventory was verified by qualified plant experts. EUCAMED provides a new resource to support macroecological and biogeographical research on this environmentally and socioeconomically important taxonomic group in the Mediterranean Basin.

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Introduction

The "eucalypts" comprise three related genera within the family Myrtaceae: *Eucalyptus*, *Corymbia*, and *Angophora*. Collectively, these genera include 934 species (Slee et al. 2020) that contribute significantly to landscapes of the entire continent of Oceania.

Almost all eucalypt species are endemic to Australia, where they show a near-continuous distribution across a wide range of habitats, from mesic forests to semi-deserts and mountain environments (Fensham et al. 2020). However, eucalypts have been widely introduced beyond their native range and are now present in many regions worldwide. In Mediterranean countries the history of eucalypt introductions is reflected both in the landscape (i.e. through plantations, provenance trials, land reclamation projects, botanic gardens, arboreta, ancient villas) and in a substantial body of scientific and grey literature. The introduction history of eucalypts has also been reviewed in several studies, notably those of Silva-Pando and Pino-Pérez (2016) and Silva-Pando (2021). These sources provide insight into the first introductions of *Eucalyptus* to Spain and other parts of Europe based on the examination of historical documents and research carried out in various countries. According to Silva-Pando and Pino-Pérez (2016), the first eucalypt species to arrive in Europe (*Eucalyptus obliqua*) was planted in the greenhouses of the Royal Botanic Gardens, Kew (Kew Gardens) in 1774 from seed donated by Captain Tobias Furneaux. The first eucalypt to be planted outdoors was *E. robusta*, in the English Garden of the Royal Palace of Caserta (Italy) in 1792 by Johann Andreas

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Graefer, probably with seeds donated by Sir Joseph Banks. In Italy, the first significant planting outside a garden was at *Abbazia delle Tre Fontane*, Monaci Trappisti (Pavari 1922; Pavari and De Philippis 1941; La Mantia 2013). However, many references document earlier introductions in private gardens, such as the English Garden of the Royal Palace of Caserta (Italy), the greenhouse in San Donato (Planchon and de Demidoff 1854), Tuscany, and in many botanical gardens (Badalamenti et al. 2018). The first recorded mention of eucalypts in France dates back to the early 19th century, when Bonpland described *E. diversifolia* at the Château de Malmaison in 1813. Naudin (1883) believed that this was most likely the first eucalypt species to be introduced to France.

The greatest expansion of eucalypt plantations (mainly *E. globulus*) in the Mediterranean Basin occurred in the second half of the 20th century and was driven primarily by the demand for wood pulp for paper production (Bermúdez et al. 2002; Alegria et al. 2020). Since the 1980 s eucalypts (primarily *E. gunnii* × *E. dalrympleana*) have been cultivated for wood energy or paper pulp production, primarily in southwestern regions (Occitanie, Nouvelle-Aquitaine) and in Corsica. However, these areas (ca. 2,000 ha) are relatively small compared to areas under eucalypt cultivation in neighbouring Mediterranean countries. Eucalypt plantations in southern Europe currently cover approximately 1.3 million hectares, over 80% in the Iberian Peninsula and Italy (Cerasoli et al. 2016). This area has increased fourfold since 1970 (Deus et al. 2019; López-Sánchez et al. 2021; Tomé et al. 2021). Hybrid eucalypt clones (*E. camaldulensis* × *E. viminalis*, *E. camaldulensis* × *E. grandis* and *E. camaldulensis* × *E. globulus* subsp. *bicostata*) selected for biomass production in Mediterranean environments are becoming increasingly popular. Additionally, the phytoremediation of areas contaminated by arsenic and heavy metals using eucalypts as short-rotation woody crops (SRWC) for biomass production served the dual purpose of long-term reclamation and the production of valuable bioenergy (Mughini et al. 2013).

In southwestern Europe, particularly in Spain, Portugal, France, and Italy, the silvicultural and economic importance of eucalypts is closely linked to their early introduction and subsequent use as highly productive forestry species. The cultivation of eucalypts for forestry in France and Algeria began attracting significant interest around 1850 (Chevalier 1952; Silva-Pando 2021). During this period, Gustave Thuret (1817–1875) created the Villa Thuret Botanic Garden in Antibes (France, Alpes-Maritimes), a scientific research site dedicated to botany and acclimatization. Thuret, being in contact with Ferdinand von Müller (director of the Botanic Garden of Sydney and an expert on eucalypts), introduced at least 50 eucalypt species directly from Australia to Villa Thuret (Vilmorin 1893). Most of the eucalypts planted at Villa Thuret were still alive in 1930 (Chevalier 1952). In the Iberian Peninsula, particularly in Portugal and northwestern Spain, *E. globulus* dominates large areas, reflecting its strong resprouting capacity and efficiency in fibre production for the paper industry. In France and Italy eucalypts have also been used for afforestation, for windbreaks, and the recovery of marshy or degraded lands, contributing to rural economies and landscape transformation (Deidda et al. 2016). Ecologically, however, their expansion has generated contrasting effects. While they contribute to carbon sequestration and rapid biomass accumulation, they are also associated with high water consumption, allelopathic effects, reduced biodiversity in monocultures, and increased fire risk in Mediterranean environments (Pereira et al. 2007; Fernandes et al. 2019).

In the eastern Mediterranean region, eucalypts have long been valued for ornamental purposes and their rapid growth. For example, *E. camaldulensis* was planted around the Adana-Mersin railway (Türkiye) starting in 1885, because of its exotic appearance and rapid growth (Özgün 2013), timber production, and for its ability to drain swamps, as seen in the Ottoman territories. Although the exact date of the first introduction of eucalypts to the Ottoman Empire is unknown, historical data confirms their presence in Yemen in 1880. From 1893 onward the Ziraat Heyet-i Fenniye (Agricultural Technical Committee) promoted eucalypt cultivation across the Empire, importing seeds in 1894, 1896, 1897, and 1899 for distribution in Diyarbakır, Adana, Harput, and İzmir (Özgün 2013).

In Egypt, Gastinel-Bey and Figari-Bey were the first to introduce and cultivate eucalypts on the land of Kasr-Nouza, conducting experiments to extract useful products, while Delchevalerie (1871) documented cultivation in the Acclimatization Garden of Ghézireh (Cairo). The role of eucalypts in afforestation and land reclamation became particularly important during the British mandate period in Israel (1917–1948) and in Cyprus, where reforestation programs included multiple eucalypt species (Unwin 1931; Streets 1962). In Cyprus, eucalypt planting began under Ottoman rule with a forestry report commissioned in 1873 (Unwin 1931; Streets 1962). Planting expanded significantly under British administration after 1878. The Department of Forestry, formally established in 1879, introduced *E. camaldulensis* and other species from Australia. Large plantations were established across Cyprus under Mr. Bovili, who directed the Department until 1920 (Unwin 1931; Ciesla 2004). In North Africa, especially Tunisia, eucalypts have been widely used for reforestation, erosion control, timber production, and honey production (Khouja et al. 2024).

In countries such as Croatia, Montenegro, Serbia, and Slovenia, their importance has also been linked to acclimatization efforts and later forestry trials (Vrdoljak 1956), essential-oil studies (Chalchat et al. 1995; Grbović et al. 2010; Damjanović-Vratnica et al. 2011), and the conservation of exotic taxa (Łuczaj and Dolina 2015). Along the Croatian Adriatic coast, early introductions, particularly around Dubrovnik, date to the mid-19th century on Lokrum Island after 1859 (Đurašović 1997; Łuczaj and Dolina 2015; Marić and Vitasović-Kosić 2020). Later inventories recorded numerous species in collections at Lokrum Island, including *E. diversifolia*, documented in the mid-19th century (Đurašović 1997) and the Trsteno Arboretum, where inventories from the mid-20th century onward record *E. camaldulensis* (often cited as *E. rostrata*), *E. globulus*, and *E. viminalis*, and later also *E. albens*, *E. behriana*, *E. sideroxylon*, *E. sieberi*, and *E. pauciflora* (Idžojtić et al. 2019), while additional plantings occurred on the Brijuni Islands (Brijuni National Park 2024).

In Malta, records by Silverwood (1974) and Mazzocchi (1969) indicate that the government initiated large-scale afforestation during the late 1960 s and early 1970 s using *Pinus halepensis*, *Tamarix* spp., *Ceratonia siliqua*, *Acacia* spp., and *Eucalyptus* species (historically referred to as *E. globulus* but actually *E. gomphocephala*). Eucalypts became widespread through ornamental planting and large-scale adoption by the bird-hunting community (Haslam et al. 1977).

However, their ecological role has evolved over time, with concerns emerging in some areas, such as Israel, where *E. camaldulensis* was declared invasive in riparian habitats in the early 2010 s (Dufour-Dror 2012), leading to more restrictive planting policies. Besides the uses of eucalypts in ornamental horticulture and forestry, they were also promoted by several national governments to prevent malaria (e.g. García-Pereda and Rodrigues 2022). They were sometimes referred to as "the malaria tree" and were touted by European scientists as beneficial to health. This was based on the belief that eucalypts could reduce mosquito populations by the repellent properties of their aromatic compounds (Sheikh et al. 2021). It was only much later that it was understood that they could help in the desiccation of swampy land, e.g. in Italy, Türkiye, and Portugal (Vieira 2007), thus reducing the extent of habitats suitable for mosquitoes. In Algeria, Hardy (1859/1860) reports experimental plantings at Hamma, Maison Carrée documented by Cordier and comprising 130 species (Planchon 1875).

Overall, eucalypts have played a multifaceted role, combining economic utility, environmental management, and scientific interest across their introduced range. The most recent literature on eucalypts in the Mediterranean region focuses on only a few species – those that were widely cultivated or which have been under observation due to the risk of naturalization or invasion outside of plantations (Deus et al. 2025). Despite this long and well-documented history of introduction since the late 18th century, the distribution, diversity and establishment status of eucalypts in the Mediterranean Basin has yet to be consolidated in one single inventory. However, some studies have focused on localized assessments of naturalization (e.g. in parts of Italy or the Iberian Peninsula) and highlight knowledge gaps, particularly the absence of an updated overview of species occurrences and invasion dynamics (Badalamenti et al. 2018). More broadly, although efforts have produced large-scale databases for Mediterranean trees (e.g. WOODIV, Monnet et al. 2021), such resources incompletely represent non-native genera such as *Angophora*, *Eucalyptus* and *Corymbia*, and often rely on heterogeneous and fragmented data sources. The aim of this study is therefore to provide the first comprehensive inventory of the eucalypts (*Angophora*, *Corymbia* and *Eucalyptus* species) introduced to the Mediterranean Basin. Specifically, it seeks to: (i) quantify the number of species and hybrids introduced; (ii) collate and harmonize available records into an informative, and spatially explicit inventory; and (iii) depict and visualize the distribution patterns of introduced eucalypts in the Mediterranean Basin using this collected dataset. By addressing this data gap, it is hoped that this work will contribute to a better understanding of the distribution patterns in the Mediterranean context to support future ecological, forestry, and management studies.

Materials and methods

Study area and data collection

Data collection included: (1) available literature on the history of introduction of eucalypts for the following 21 Mediterranean *sensu lato* countries: Albania, Algeria, Bosnia-Herzegovina, Croatia, Cyprus, Egypt, France, Greece, Israel, Italy, Lebanon, Libya, Malta, Montenegro, Morocco, Portugal, Slovenia, Spain, Syrian Arab Republic, Tunisia, and Türkiye, and (2) all Global Biodiversity Information Facility (GBIF) occurrence records of eucalypts. Where possible, records specifically located in the largest Mediterranean islands such as Corsica (France), Sardinia, and Sicily (Italy) were noted separately. Countries that are relatively close to the Mediterranean Basin, but which do not border the Meditteranean Sea (e.g. North Macedonia, Serbia) were not considered during data collection, with the sole exception of Portugal, as this country is of paramount importance for the history of the introduction and use of eucalypts in Europe and the Mediterranean Basin. GBIF occurrence records were used only as a supporting resource during data collection. They helped in identifying the species described in historical records, in pinpointing geographic areas that may have been overlooked during the literature search, and to ensure that no important sources were omitted. GBIF occurrence records were also used to compare spatial patterns between GBIF and literature-derived data. However, GBIF occurrence records were not included in EUCAMED's final inventory, which is based exclusively on information extracted and verified from scientific literature.

The significant changes in borders defining countries were considered and records found in the literature were allocated to present-day countries. As an updated standard for defining current countries and borders the US CIA website (https://www.cia.gov/the-world-factbook/maps/world-regional/) was consulted.

Structure of the EUCAMED inventory

The information extracted from the literature (snowball search method, starting with key historical books) was included in the inventory dataframe (hereafter referred to as EUCAMED), with a row for each single record and several descriptive fields.

The compilation of EUCAMED included inputting all species/taxa exactly as they were reported in the reference considered (*verbatim*), with or without Authority (when this information was missing) and including possible orthographic mistakes in the reference.

The following descriptive attributes were added to EUCAMED:

(i) Taxonomy. Nomenclature standardization was performed according to the World Flora Online (WFO) (https://www.worldfloraonline.org/) and Plants of the World Online (POWO) (https://powo.science.kew.org/) classification. Since the manuscript compiles historical records, taxonomic changes and nomenclatural updates were carefully considered during data processing. The original taxon name as it appears *verbatim* in the source was stored. Names were then standardized and updated to currently accepted nomenclature through expert validation, supported by authoritative floristic databases; the corrected name was reported in the inventory in the field "Taxon [VALID_Name]". Both the original name and the corrected name were stored, allowing traceability between historical and current taxonomy. The level of uncertainty in the standardization was assessed via expert opinion and included in one field of the inventory (confidence level = high, medium, low, or very low). Hybrids were also considered. Infraspecific taxa (i.e. subspecies) were only considered when they were solid taxonomic entities (unequivocally accepted subspecies).

(ii) Status. EUCAMED includes the status for each record exactly as it is reported in the reference considered. The set of possible values for this field include cultivated, casual, failed to establish, naturalized, and invasive, following the terminology proposed by Pyšek et al. (2004).

(iii) Locality and first record. Another field in the inventory is dedicated to the date for the species as reported in the reference. The date could be an introduction date, and, when available, the date of the first introduction was provided, or a date of cultivation. For example, a scientific paper on the timber production of *Eucalyptus* species used in forest plots was considered as a reference for the year of cultivation of the species listed in that paper. When the literature reported a time interval (e.g. "introduction in Forestry occurred in the period 1920–1930", "planting in the botanical garden occurred in the period 1780–1920") we stored in the inventory both the first and the last year, respectively. If no specific date or year is given in the reference, we simply considered the publication year of the corresponding reference (e.g. publication year of the book, such as "*Os eucaliptos em Portugal*, V. 1, Ernesto Goes, 1960"). To facilitate the possibility of verification of the references, we inserted a field with the exact page number, or number of the table in the text of the reference pointing to the species. Such information will be useful for locating the information, especially in long books, and for any future verification and updating of the database. For example, "1082:T2" points at Table n. 2 at page 1082.

(iv) Source of information. One of the fields in the inventory was used to categorise the type of reference. The values for this field included, e.g. grey literature, and other labels such as books, reports, *Index Seminum* of Botanic Gardens and Arboreta, Websites of Botanic Gardens/Arboreta, and journal articles.

(v) Geolocation. Whenever the location of the occurrence of the species/taxon was available in the text of the reference considered, or when it was possible to locate the site on Google Earth, the Longitude (E) and the Latitude (N) in decimal degrees (WGS84 Geo, EPSG: 4326) were stored in EUCAMED. When the species was reported for a town, botanic garden or arboretum, the coordinates of the centroid (central point) of the area were adopted (e.g. 9.202493 and 38.699390 for the Tropical Botanic Garden of Lisbon, Portugal). The coordinates stored in the inventory were always associated with a degree of uncertainty (in metres).

All records, including the date, location, and published names of the species, were verified and certified by national experts, although it was not possible to carry out on-site surveys for all populations and locations to assess their survival or persistence and to ascertain the taxonomic identification.

Data analysis

The data stored in the EUCAMED inventory and the data downloaded from GBIF (which was not included in the final inventory), were analysed using dedicated scripts in the R environment (V. 2025.5.1.513) and visually checked on Quantum GIS (V. 3.44.4 Solothurn). The information extracted from GBIF for the same study area was stored for each genus in the form of a flat.csv file as follows: *Corymbia*, https://doi.org/10.15468/dl.99nn8b; *Eucalyptus*, https://doi.org/10.15468/dl.d9qrwd; *Angophora*, https://doi.org/10.15468/dl.8nsg6s (Accessed 1 May 2025) (Supplementary Table S1).

The analysis explores data on eucalypt occurrences, status, and geographic distribution across 21 countries in the Mediterranean Basin. Spatial patterns were explored by mapping literature-derived and GBIF-derived occurrences, identifying unique coordinates, and visualizing species occurrences per location, e.g. identifying the frequency of occurrences in the Arboreta. We quantified the number of records and different species/taxon per status (cultivated, casual, failed to establish, naturalized, invasive) in the different countries. GBIF and literature data were also compared via side-by-side bar plots, revealing differences in taxonomic and occurrence coverage among countries. Temporal dynamics were analysed through histograms and frequency plots showing historical accumulation of records. Collectively, these analyses provide a comprehensive overview of the spatial distribution, temporal trends, and data-source consistency for eucalypts across the Mediterranean region.

Results

Data from GBIF

Data retrieved from GBIF (until 1 May 2025; *cf.* supplementary material for GBIF DOIs) included a total of 2,036,065 global occurrences, of which 146,839 occurrences corresponded to the genus *Corymbia* K. D.Hill & L.A.S.Johnson, 1,830,466 occurrences to the genus *Eucalyptus* L'Hér., and 58,760 occurrences to the genus *Angophora* Cav. (Supplementary Table S1). However, only 435,969 occurrences corresponded to the Mediterranean study area as identified in the present study, of which 99.2% corresponded only to two countries (i.e. Portugal and Spain, Figure 1, Supplementary Table S3). No occurrence data were

Figure 1. The distribution of eucalypt occurrences across 21 countries in the Mediterranean study area (including Portugal). Orange dots represent occurences retrieved from GBIF, while blue dots indicate georeferenced records from the literature search.

available for Bosnia-Herzegovina. We identified a large number of spelling mistakes (including inconsistencies in the way authors' names were written) and some other discrepancies. These were corrected by botanical experts and through standardization of the nomenclature.

Data from the literature

The current version of the inventory (September 2025) contains 4,103 "taxon × country × site" entries (Figure 1). The term "taxon × country × site" in the context of this inventory means the number of unique combinations of taxa (species or other taxonomic units), countries, and sites where they are recorded or reported. For instance, the presence of *E. globulus* documented by literature references for five different sites in one country equals five records for that country.

The spatial distribution of records across the 21 Mediterranean countries (including Portugal) was slightly unbalanced, with a pronounced concentration in France, Spain, and Portugal. Bubble sizes (Supplementary Figure S1) indicate the frequency of all records at each location (e.g. Arboreta) and revealed several major hot spots rather than a uniform distribution. The largest bubbles are in the Iberian Peninsula, particularly in central Spain (around Madrid), southwestern Andalusia (Huelva-Seville area), the northwestern Atlantic-influenced region of Galicia, and in Provence region of France. These regions accounted for most observations, reflecting repeated records of multiple *Eucalyptus* and *Corymbia* taxa at identical or nearby coordinates such as large historical arboreta. In contrast, other Mediterranean countries were weakly represented or absent, resulting in small or no bubbles across much of the eastern and southern Mediterranean Basin, with the exceptions of Israel and Lebanon. Overall, Supplementary Figure S1 highlights a strongly localized introduction effort, while large areas of the Mediterranean region show sparse occurrence data. The distribution of cumulative records for the 21 Mediterranean countries per year shows a gradual increase of records throughout the 19th and early 20th centuries and a rapid increase in frequency from the mid-20th century onwards, reaching a peak in the early 21th century (Supplementary Figure S2).

The total number of introduced species (including subspecies and hybrids) is 387, of which 162 records (for 19 taxa) belong to the genus *Corymbia* K.D.Hill & L.A.S.Johnson, of which one is hybrid, 3,936 records (for 365 taxa) to the genus *Eucalyptus* L'Hér., of which 17 are subspecies, 17 autonyms, three varieties, two cultivars and 52 hybrids, and five records (for 3 species) to the genus *Angophora* Cav. (Figure 2). Among the collected species, *Eucalyptus camaldulensis* (437 records), *E. globulus* (425 records), and *E. gomphocephala* (105 records) were the most frequently recorded species in the Mediterranean countries, with records in 20, 19, and 17 countries, respectively (Supplementary Figure S4 and Table S2).

Records of species in cultivation (e.g. forest trials, arboreta, gardens, etc.) dominate the dataset (3,811 records and 387 taxa), followed by casual (205 records and 19 taxa), naturalized (50 records and 17 taxa), failed-to-establish (34 records and 14 taxa), and invasive species (3 records and 2 taxa) (Figure 3). Overall, across all Mediterranean countries, records were dominated by taxa classified as cultivated, which accounted for the largest proportion in each country. France showed the highest number of overall records,

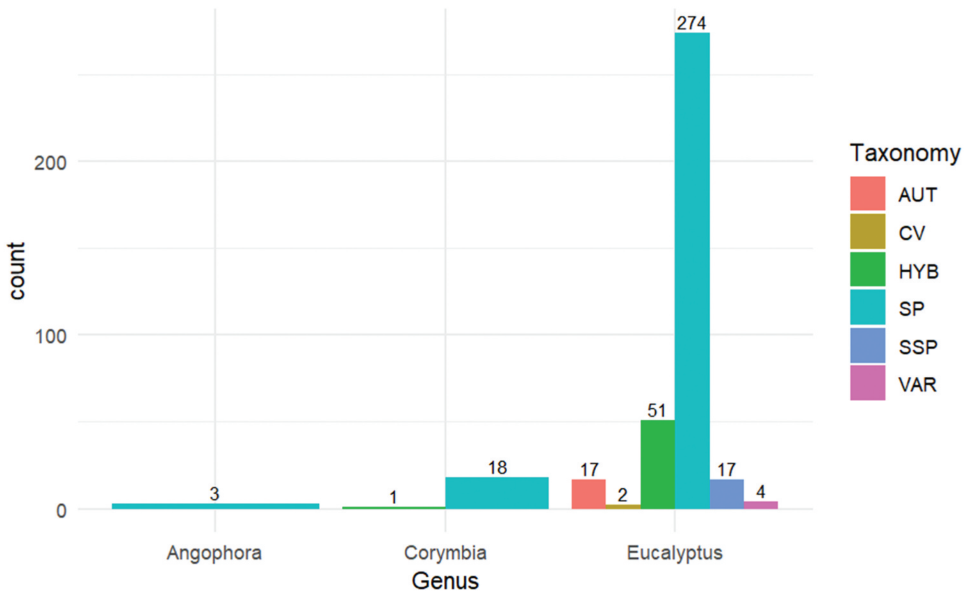

Figure 2. Distribution of taxonomic categories: AUT, autonym; CV, cultivar; HYB, hybrid; SP, species; SSP, subspecies; VAR, variety, across the genera *Angophora*, *Corymbia*, and *Eucalyptus*. Values above bars indicate the number of taxa for each category.

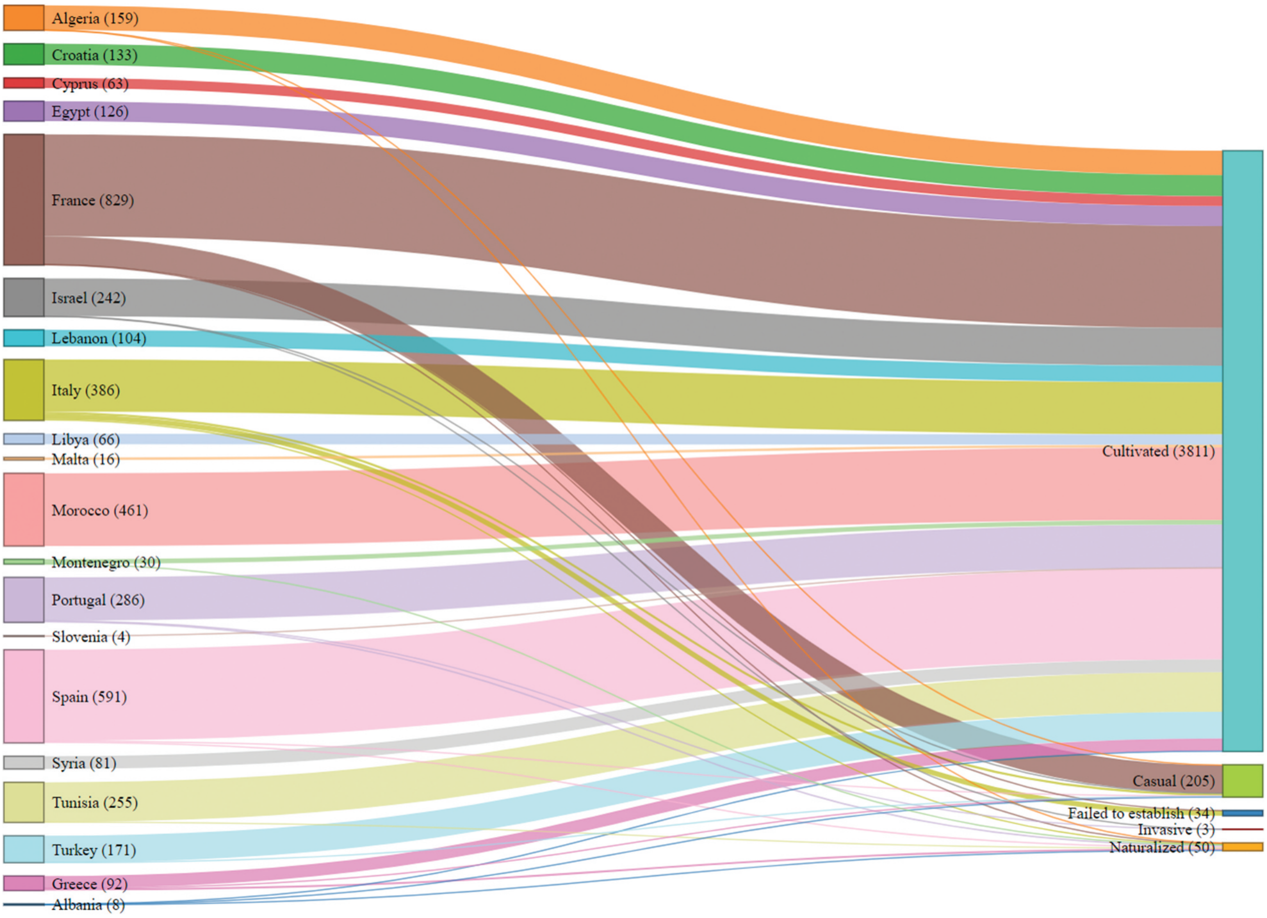

Figure 3. Sankey diagram showing the distribution of the literature-records (taxon × country × site) in the five status classes considered in the inventory (failed to establish, cultivated, casual, naturalized, and invasive). The amplitude of each flow is proportional to the number of records and is linked to the countries (left side) and each of the five status classes. The number in parentheses represents the number of literature-records.

followed by Spain, Morocco, and Italy, indicating a high prevalence of recorded taxa in these countries. Casual occurrences were present at lower but notable levels, particularly in France and Italy, while failed records were high only in Italy. Naturalized taxa occurred rarely in most countries, and invasive records were minimal (e.g. Portugal and Israel) or absent, suggesting that, while many taxa are cultivated or present as casuals, relatively few have progressed to more advanced stages of invasion. Overall, the distribution highlights substantial geographic variation in total counts, but a broadly consistent predominance of the cultivated status across the Mediterranean Basin (Figure 3).

Comparing the data derived from the literature and GBIF, we observed that the countries with the highest number of records and taxa registered in GBIF are France, Portugal, and Spain, while France, Italy, Morocco, and Spain had the highest number of records and taxa registered in the literature. We found no information for Bosnia-Herzegovina (Figure 4, Supplementary Figure S5, and Table S3).

Across the inventory the history of introduction revealed some trends, like France, Italy, Portugal, Spain, and Croatia having the widest ranges (early 1800s to 2020s) while in countries such as Algeria introductions occurred concentrated entirely in the mid-late 1800s. Data from North African and Middle Eastern countries like Morocco, Tunisia, Türkiye, and Syria show introductions mainly from the mid-20th century onward, indicating more recent development or data collection. In contrast, countries like Greece, Cyprus, and Egypt show narrower time ranges, with introductions recorded primarily during the late-20th century (Figure 5). Finally, all the data collected relates to 445 references.

Discussion

This study provides the first expert-verified inventory on the introduction history, diversity, distribution patterns, and biogeographic status of eucalypts across the Mediterranean Basin, providing more detailed taxonomic and geographical information than has been available until now. Although historical descriptions often highlight a limited set of widely planted species, our results reveal that 387 taxa have been introduced to 21 Mediterranean countries, including

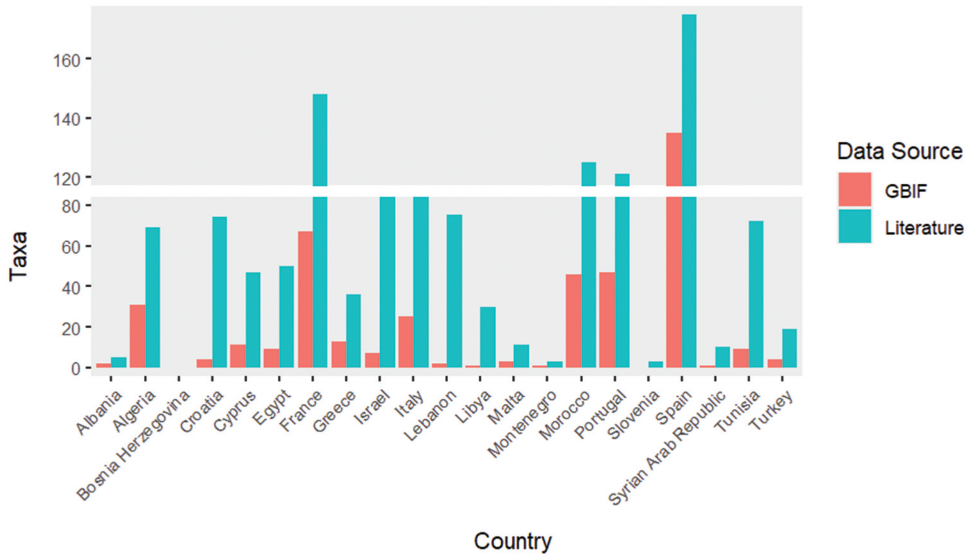

Figure 4. Comparison of the number of recorded eucalypt taxa by country from GBIF (orange) and published literature (green) showing generally higher taxa counts reported in the literature across the Mediterranean study area.

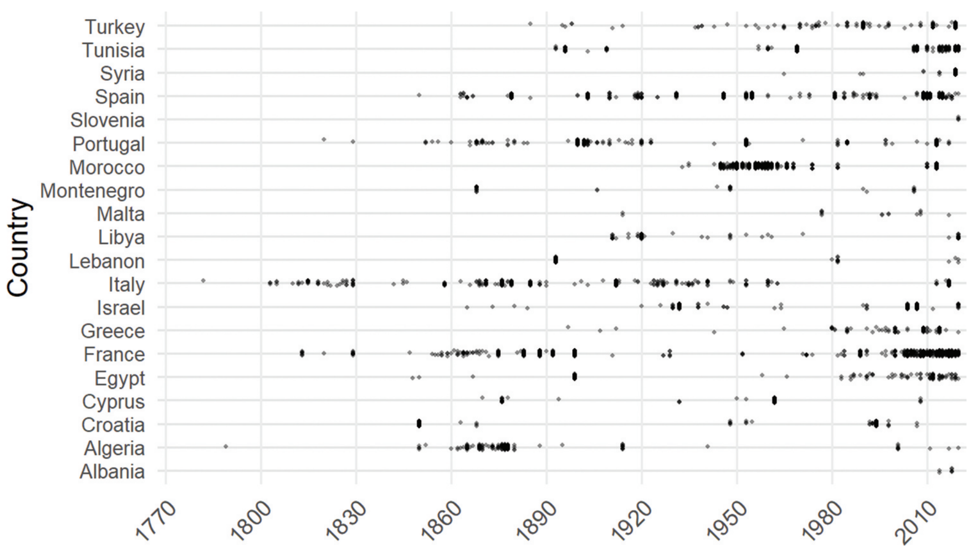

Figure 5. Temporal distribution of eucalypt literature-records (taxon × country × site) in the EUCAMED inventory. Each dot represents one literature record.

Portugal, largely through forestry trials, since the 19th century. The introduction of eucalypts into the Mediterranean Basin constitutes a large-scale natural experiment involving the introduction of hundreds of closely-related species to areas beyond their native range to multiple environments, over different periods, and through different introduction pathways. This offers an opportunity to understand the role of climate adaptation, propagule pressure, human management, and species characteristics in determining the success, failure, or persistence of non-native trees establishment (Richardson et al. 2004; Deus et al. 2025). The results of EUCAMED indicate that in the Mediterranean Basin, ca. one third of all described eucalypts have been introduced at least once, either deliberately for silvicultural and horticultural use, or unintentionally through repeated movement and dissemination of plant material associated with early planting trials (Silva-Pando and Pino-Pérez 2016).

Eucalypts are one of the most widely planted and economically important woody plant taxa worldwide. They provide timber, raw materials for the pulp and paper industries (Tomé et al. 2021), and are widely used in agroforestry (Richardson et al. 2004). Eucalypt plantations have expanded extensively across Brazil, Chile, China, Europe, India, and South Africa, and now cover ca. 30 million hectares globally (Deus et al. 2025). These plantations are growing under different climatic conditions and are facing emerging challenges, including increased wildfire risk (Booth 2013; de Moraes Gonçalves et al. 2013; Urrutia-Jalabert et al. 2018) and growing problems with pests and pathogens (Hurley et al. 2016; Burgess and Wingfield 2026). In many regions, perceptions regarding the benefits and negative impacts of eucalypts has changed rapidly over time (e.g. for *E. camaldulensis* in South Africa; Hirsch et al. 2020). Despite the huge importance, the global information on the introduction of eucalypts has been incomplete and fragmented. In this context, EUCAMED will contribute not only to improving our understanding of the distribution of eucalypts in Europe, more specifically in the Mediterranean Basin, but also to a broader elucidation of the history of their introduction and their biogeographical adaptation globally. EUCAMED will also help elucidate patterns of species performance (e.g. comparing biogeographic status) and resilience under diverse environmental conditions. It will hopefully also provide the impetus to collate the same information and create a global dataset to help explain invasiveness patterns and introduction pathways. Therefore, emphasizing this wider applicability would increase the international impact of the study and place EUCAMED as a valuable resource for forest research worldwide.

The accuracy of the nomenclature in this work was confirmed through systematic verification by experts in each country or region and cross-checked against existing standard and global plant classifications, namely WFO and POWO. Each record in EUCAMED retains the original name as it appears *verbatim* in the source, while also providing a corrected and currently accepted name according to the above-mentioned classifications, together with an explicit confidence level. This allows us to preserve historical information without hindering modern taxonomic understanding and avoids the perpetuation of misapplied names that frequently bedevil historical studies. However, the accuracy of taxonomy is limited by the quality of the historical sources. Many older literature, catalogues, and early forestry reports lack details on taxon authorities, or contain spelling errors that often cannot be confidently resolved (Coca-de-la-Iglesia et al. 2024). In such cases, the records were treated as “data deficient” and excluded from the quantitative assessment when taxonomic identity or locality information could not be reliably established. Although this leads to a more restrictive dataset, it improves overall validity and confidence in the collated information. Despite these exclusions, the overall confidence level of the literature used in this study was assessed as medium-to-high, reflecting the consistency of independent sources and the validation provided by experts in each country of the Mediterranean Basin.

The differences in taxonomic and recorded data among Mediterranean countries are notable, due to biases documented in global biodiversity databases such as GBIF. These biases result from uneven sampling efforts across countries and spatial scales, often reflecting dissimilarity in research intensity, accessibility, and monitoring (Warton et al. 2013). The differences observed between GBIF data, where a low number of species and a high quantity of occurrences was recorded, and the scientific literature, further highlight the need to integrate historical sources, grey literature, and expert validation (Lozano et al. 2017) when assessing long-term introduction dynamics. GBIF data primarily includes species that have been recorded most frequently, either because they are the best studied, the most-widely planted outside their native ranges (Harwood 2011), or are economically important, resulting in an apparent predominance of a few taxa with many occurrences, while obscuring the long history of introductions (Deus et al. 2025). In our inventory this pattern is particularly evident in eastern parts of the Mediterranean region where limited digitization and weaker botanical monitoring infrastructure likely mask historical introduction efforts, in contrast to the western Mediterranean where greater emphasis has been placed on GBIF data. The clear spatial bias in the concentration of records retrieved from GBIF in the western Mediterranean, especially the Iberian Peninsula and southern France, reflects a long tradition of botanical gardens, and industrial forestry in these regions. This also suggests that introduction efforts were historically patchy and closely linked to regions with established forestry programs, plant exchanges, and well-documented arboretum networks. The importance of eucalypts in these regions is likely influenced by their ecological and socio-economic impact. For instance, in Portugal and Spain, recurrent wildfires frequently occur in extensive eucalypt plantations (Fernandes et al. 2019; Deus et al. 2025) and both their importance in the pulp and timber industry and their ecological impacts drawing attention in scientific studies and monitoring efforts. In contrast, the scarcity of data in parts of the eastern and southern Mediterranean likely reflects insufficient documentation rather than true absences. The biases in GBIF data are well documented, showing unequal sampling coverage globally (García-Roselló et al. 2025).

A limitation of EUCAMED is that the number of records per country cannot be interpreted as a direct measure of introduction intensity or taxonomic diversity. As with many historical biodiversity datasets, the observed spatial and temporal patterns are partly shaped by uneven documentation effort, differences in botanical tradition, accessibility of archives, digitization of records, and the intensity of forestry research and monitoring. This is particularly evident for France, Spain, and Portugal, where the high number of records probably reflects both real historical importance of eucalypts in forestry trials, arboreta, plantations, and industrial production, and a stronger tradition of documenting such introductions. In contrast, the lower number of records from several eastern and southern Mediterranean countries should not be interpreted as evidence of absence or low introduction effort, but rather as potential under-documentation. Importantly, EUCAMED should be viewed as an inventory of documented introductions, not as a direct proxy for propagule pressure, planting intensity, or current abundance. Similar limitations have been widely reported for other databases, where spatial clustering, temporal heterogeneity, and uneven sampling effort can distort apparent patterns of diversity and distribution (Boakes et al. 2010; Warton et al. 2013; Meyer et al. 2016; García-Roselló et al. 2025). Nevertheless, by combining historical literature, grey literature, and expert validation, EUCAMED provides a conservative and transparent baseline that highlights both documented introduction patterns and major geographical knowledge gaps that require further documented work and field verification. As recently highlighted by García-Roselló et al. (2025), differences in data availability and accessibility remain a major source of spatial bias in large-scale biodiversity compilations. Therefore, some countries identified in EUCAMED likely reflect an interaction between historical introduction activity and the availability of documentary evidence. Future efforts aimed at digitizing archives and accessing non-English forestry literature from underrepresented Mediterranean countries may substantially refine the current picture of eucalypt introduction history in the region.

EUCAMED provides an historical baseline not only of successful forest taxa such as *E. globulus* and *E. camaldulensis*, but also of numerous less studied species or hybrids that were cultivated or failed to establish. The predominance of cultivated records and the rarity of naturalized or invasive records across the Mediterranean Basin suggest that, despite repeated introductions, only a small subset of species successfully escape cultivation under Mediterranean conditions. This pattern may reflect constraints such as limited seed dispersal or high juvenile mortality (Rejmánek and Richardson 2011), although other recent research shows the opposite (Silva et al. 2021; Costa et al. 2022). At the same time, distinguishing between naturalized and invasive species remains a challenge. We adopted a conservative approach and referred primarily to natural regeneration rather than invasion, while recognizing that many of the sampled populations could be considered invasive following the citeria proposed by Richardson et al. (2000). Some evidence shows that the introduction of eucalypts across Europe was far from consistently successful, with numerous early failures, probably linked to unsuitable conditions such as climatic constraints, soil conditions, disturbance regimes, limited silvicultural knowledge, and management intensity that severely limit establishment outside of plantations (Deus et al. 2019; Silva-Pando 2021). These constraints probably act as environmental filters, limiting the establishment and future invasion patterns. Fire regime, however, can strongly influence escape from plantations, as shown by widespread invasions in Portugal and Galicia, Spain (Deus et al. 2025). For instance, *E. globulus* produces a large number of seeds that germinate rapidly after disturbances such as fires, leading to extremely dense populations. Its rapid growth, high survival rate, and ability to compete with native vegetation, reduce biodiversity, and alter the ecosystem structure. Furthermore, its continuous regeneration and resprouting make it difficult to control once established. However, its establishment depends on local conditions, as it can be kept under control in less favourable environments (e.g. water scarcity) (Silva et al. 2021). In this context, particular attention should be paid to potential shifts in the current fire regime that may trigger increased and more frequent recruitment from planted trees across the Mediterranean Basin, as has already been observed in several regions of the Iberian Peninsula (Calviño-Cancela et al. 2018; Deus et al. 2025). In this context, EUCAMED could support future risk assessments by linking the results of historical introductions with drivers such as changes in fire regimes, thus making it possible to manage strategies and policy decisions aimed at preventing new invasions.

However, the main aim of the EUCAMED inventory was not to assess establishment success, long-term persistence, or invasion risk, but to document the historical and spatial distribution patterns of introductions in the Mediterranean Basin. A limitation of this kind of historical study is the difficulty of verifying the persistence of the species through field research, particularly when introductions occurred decades ago. Therefore, the absence of recent records for some taxa does not necessarily suggest failure, and the continued reporting of occurrences does not guarantee population establishment. Furthermore, recognizing this uncertainty is preferable to inferring establishment outcomes without empirical support (Zenetos et al. 2017).

By integrating historical sources, grey literature, and expert validation, EUCAMED addresses a methodological gap identified in invasion ecology, which is the lack of long-term, regionally contextualized datasets of introduction effort (Deus et al. 2025). The inventory therefore represents not only an updated taxonomic inventory, but also a baseline for evaluating future invasion risk under climate change, when warmer temperatures, increased drought tolerance selection, and expanding disturbance regimes may alter current establishment constraints, and provides a central framework for informed eucalypts management in a region facing rapid climate and land-use change (Liu and Yang 2022). Finally, EUCAMED is not a static inventory and dataset, and it will incorporate increased availability of data. There is also the possibility to increase the level of data not only in the Mediterranean basin but also for other Mediterranean regions and globally.

Conclusions

EUCAMED represents the first comprehensive inventory that combines both recent and historical sources, improving the coverage that would not be possible through any single data source. EUCAMED shows spatial and historical biases in eucalypt introductions across the Mediterranean, concentrated in western countries and specific experimental sites, with unequal data availability elsewhere. Although taxonomic diversity is high, introductions are dominated by a few widely planted species, and most records remain restricted to cultivation, suggesting limited but potentially emerging invasion risks. This inventory provides the baseline for future research, particularly in macroecological and biogeographical analyses, highlighting the importance of combining datasets and expanding data collection to better understand long-term distribution and ecological dynamics. Finally, while GBIF data remain highly valuable and indispensable, it is essential to make continued efforts to increase sample sizes by generating new and original data and publishing existing datasets to further improve data integrity and reliability.

Disclaimer

The country designations used in this study and the way the material is presented do not imply any opinion on the part of the authors regarding the legal status of any country, territory, city or area, or its authorities. Nor do they imply any opinion on the part of the authors regarding the delimitation of its frontiers or boundaries.

Author contributions

CRediT: **Giuseppe Brundu:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing; **Necmi Aksoy:** Data curation, Validation, Visualization, Writing – original draft, Writing – review & editing; **Ioannis Bazos:** Data curation, Validation, Visualization, Writing – original draft, Writing – review & editing; **Antonio Brunori:** Data curation, Validation, Visualization, Writing – original draft, Writing – review & editing; **Jean-Marc Dufour-Dror:** Data curation, Validation, Visualization, Writing – original draft, Writing – review & editing; **Guillaume Fried:** Data curation, Validation, Visualization, Writing – original draft, Writing – review & editing; **Vanessa Lozano:** Data curation, Formal analysis, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing; **Stephen Mifsud:** Data curation, Validation, Visualization, Writing – original draft, Writing – review & editing; **Ana Novoa:** Data curation, Validation, Visualization, Writing – original draft, Writing – review & editing; **Lucia A. Santoianni:** Data curation, Validation, Visualization, Writing – original draft, Writing – review & editing; **Joaquim S. Silva:** Data curation, Validation, Visualization, Writing – original draft, Writing – review & editing; **Najla Sayari:** Data curation, Validation, Visualization, Writing – original draft, Writing – review & editing; **Nataša Šibanc:** Data curation, Validation, Visualization, Writing – original draft, Writing – review & editing; **Marjana Westergren:** Data curation, Validation, Visualization, Writing – original draft, Writing – review & editing; **David M. Richardson:** Conceptualization, Data curation, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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