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Review / Revisión

Ecosystem services provided by orchids: a global analysis

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Abstract

Background: Orchids constitute one of the most diverse group of plants, they provide a large number of benefits to human society.

Questions: What are the ecosystem services provided by orchids?

Data description: We performed a systematic review based on 413 articles, of which 224 provide relevant information, focusing on publications by ecosystem service category, continent, genus, and quartile of journal.

Study site and years studied: studies of orchids on all continents from 2000 to 2021.

Methods: databases reviewed were BioOne, CONRICyT, EBSCO, EndNote, Google Scholar, JSTOR, Mendeley, ScienceDirect, Wiley library, as well as reviews of specialized books.

Results: We found 75 articles on cultural services, followed by 66 on provisioning services, 64 on supporting and 19 on regulating services. The Epidendroideae subfamily was the most mentioned with 90.9 %, with the genus *Dendrobium* having the most mentions (39.13 %). Most of the orchid ecosystem service research was conducted on the American and Asian continents, where cultural and provisioning services were prevalent, respectively. Of all the publications, 54.7 % belong to quartile 1, and 2.4 % to quartile 4.

Conclusions: This research contributes to our understanding of ecosystem services provided by orchids, which may allow us a more comprehensive understanding of how human society benefits from orchids, and what could be lost if these species are not conserved and used sustainably.

Key Words: biodiversity, conservation, cultural service, Orchidaceae, orchid uses.

Resumen

Antecedentes: Las orquídeas constituyen uno de los grupos más diversos de plantas, y brindan una gran cantidad de beneficios a la sociedad humana.

Preguntas: ¿Cuáles son los servicios ecosistémicos que brindan las orquídeas?

Descripción de los datos: Se realizó una revisión sistemática basada en 413 artículos, de los cuales 224 brindan información relevante enfocándose en publicaciones por categoría de servicio ecosistémico, continente, género y cuartil de revista.

Sitio de estudio y años estudiados: estudios de orquídeas en todos los continentes desde 2000 hasta 2021.

Métodos: Las bases de datos revisadas fueron BioOne, CONRICyT, EBSCO, EndNote, Google Scholar, JSTOR, Mendeley, ScienceDirect, Wiley library, y libros especializados.

Resultados: Se encontraron 75 artículos sobre servicios culturales, seguidos de 66 sobre servicios de provisión, 64 de servicios de soporte y 19 sobre servicios de regulación. La subfamilia Epidendroideae fue la más mencionada con el 90.9 %, siendo el género *Dendrobium* el que más menciones tuvo (39.13 %). La mayor parte de la investigación sobre los servicios ecosistémicos de las orquídeas se llevó a cabo en los continentes Americano y Asiático, donde prevalecen los servicios culturales y de provisión, respectivamente. Del total de publicaciones, el 54.7 % pertenecen al cuartil 1 y el 2.4 % al cuartil 4.

Conclusiones: Esta investigación contribuye al entendimiento de los servicios ecosistémicos proporcionados por las orquídeas, lo que permite una comprensión más completa de cómo la sociedad humana se beneficia de las orquídeas y qué se podría perder si estas especies no se conservan y utilizan de manera sostenible.

Palabras clave: biodiversidad, conservación, servicio cultural, Orchidaceae, usos de las orquídeas.

Ecosystem services (ES) are the benefits provided to human society by nature and are dependent on the functions of organisms within the ecosystem (FAO 2022). The identification and quantification of ES are key in the search for areas which provide a high degree of certain services and need protection to be maintained (Petter *et al*. 2013, Shen *et al*. 2020, Teague & Kreuter 2020). For example, the maintenance of stable and productive soils for obtaining food, and the pollination of the plants which inhabit them.

Recently, research on ES has increased in order to inform decision-making on the use and management of land and natural resources (Balvanera *et al*. 2020) mainly to achieve ecosystem conservation (Matzek *et al*. 2019). The Food and Agriculture Organization of the United Nations (FAO) classifies ES into four categories: provisioning (food, fiber, water, chemicals, and pharmaceuticals); regulating (air quality, water, pests and diseases, pollination and natural risks); supporting (biodiversity, nutrient cycling, genetic diversity and conservation); and cultural (traditional knowledge, aesthetic appreciation, cultural heritage, tourism and recreation) (FAO 2022). It is important to consider that biological diversity is under constant threat, and this is reflected in the ES that humans take advantage of.

The orchid group is mainly threatened by such factors as habitat fragmentation, climate change, commercialization as ornamental plants, among others (Wraith & Pickering 2017, Jiménez-López *et al*. 2019a, b). The study of the ES that orchids provide to humans becomes relevant, since despite their wide diversity and adaptive advantage to establish themselves in all ecosystems except Antarctica, several species have a restricted distribution with particular ecological and physiological requirements, such as specific symbiont fungi (Jacquemyn *et al*. 2017, Yeh *et al*. 2019), specialized pollinators (Singer 2009), and microenvironment (Krömer *et al*. 2007). Changes in these requirements, besides the threats faced by the Orchidaceae would lead to many species disappearing, leaving us without the benefits and services they provide us.

The Orchidaceae family has around 30,000 species (Chase *et al*. 2015) and represents one of the most diverse flowering plants. It comprises five subfamilies: Apostasioideae consists of two genera with 16 species, which are native to southeast Asia; Vainilloideae includes 15 genera with approximately 250 species distributed in the tropics; Cypripedioideae, has five genera with 155 species found worldwide with the exception of Africa and Australia; Orchidioideae has 210 genera and 5,000 species, which are distributed worldwide with the exception of Antarctica, and Epidendroideae comprising 80 % of all orchids with predominantly epiphytic members, that have a maximally accelerated diversification in the neotropics (Givnish *et al.* 2016).

Orchids are classified into those that grow as epiphytes, terrestrial and mycoheterotrophic (Watkinson 2016, Zotz *et al*. 2021). Particularly, orchids 75 % of all epiphyte species and 63 % of all genera of epiphytes, being a conspicuous group in the canopy and important components of tropical diversity (Acevedo *et al*. 2020, Taylor *et al*. 2021, Zotz *et al*. 2021).

Given the diversity of this group and its multiple uses, an analysis of the ES provides by orchids to society is required to understand the role of these species in the ecosystems and guarantee the provision and sustainable use of their benefits.

A wide variety of orchid species are identified as providers of ES around the world. For example, Tamang *et al*. (2021) and Wang *et al*. (2021) mention that various parts of these plants can be used for medicinal purposes, highlighting the preparation of teas, infusions, and ointments, as well as for food. Meanwhile, Farrera-Sarmiento *et al*. (2018) and Rosete *et al*. (2019) describe the cultural ES provided by orchids being used in rituals as offerings, ornaments and sacred symbols that are part of the identity of the communities that use them. The regulating ES provided by orchids are related to identifying pollinators and the self-pollination capacity of species that are mainly native or under some category of protection, for the purposes of reproduction and reintroduction into their habitats (Ray *et al*. 2019). Moreover, Thammasiri (2016) focuses on the genetic resources of orchids in Thailand as supporting ES for the success of their cultivation, the trade of cut flowers and potted plants.

This work aims to provide updated and relevant information about ES provided by orchids through a systematic review. Our objectives were 1) to identify and classify the ES provided by orchids worldwide, and 2) to evaluate the state of knowledge about the ES provided by orchids at continental level, and according to quartile of the journal where published.

Materials and methods

We carried out a systematic review of the scientific literature between 2000 and 2021 on the ES provided by orchids. This time range was defined considering that the rise of research and studies on ecosystem services occurred from 1997 onwards and our work began in 2022. The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses; Tricco *et al*. 2018) methodology was followed to obtain more objective and reproducible systematic reviews, with the aim of increasing the transparency and reproducibility of science. Review was performed, searching for coincidences with the keywords: "Orchidaceae" or "orchid" and either "ecosystem services" or "environmental services", "cultural", "ornamental", "tourism", "medicinal", "genetic diversity", "reproduction", "nutrient cycling", "conservation", "ethnobotany", "illegal trade", "habitat loss", "sustainability", "natural resources", "biodiversity", "tropical forests", "protected natural areas", or "conserved areas". These keywords were also searched in Spanish. The articles were selected based on their contributions about orchids and their ES. Unpublished documents such as bachelor's, engineering, master's and doctoral theses, conference abstracts and technical reports were discarded. The search was carried out in the BioOne, CONRICyT, EBSCO, EndNote, Google Scholar, JSTOR, Mendeley, ScienceDirect, Wiley library databases, as well as reviews of specialized books. Data on title, year of publication, authors, journal where published, type of service provided, subfamily and genera of orchids mentioned were taken from each one for further analysis. The number of times subfamilies and genera were mentioned was also considered. EndNote 20 software was used to manage the references and their bibliographic citations. The journals were classified by their quartiles (Q1, Q2, Q3, Q4) data taken from the metrics of each journal consulted, for recognizing productivity on ES, and related at continent level, which can guide us to better understand current research progress, and future research directions.

Data analysis. The R software (v. 4.3.3, R Core Team 2024) was used for the analyses.

The Chi-square test (χ^2) was applied to find possible differences among (1) the number of articles published by ES, in order to identify the main ES provided by orchids, and (2) period of years of publication of ES provided by orchids, seeking the state of knowledge of this item throughout the years established for this study. In order to identify the state of knowledge about ES at continental level as it relates to diversity, an association test was applied between (1) the type of ES provided by orchids and the continent where each article was published; and (2), between the continent where the ES knowledge was published and the quartile of the journal, this to identify which continent had more mentions according to quartile of the journals; and finally (3), between type of ES provided by orchids and quartile of journals where the knowledge was published. We structured contingency tables with four ES (rows) and five continents (columns); four quartiles (rows) and five continents (columns); and four ES (rows) and four quartiles (columns). Associations were evaluated with a χ^2 test (Vergara-Torres *et al*. 2010). The expected frequency of the number of journals was obtained with the product of the row and column totals, divided by the total number of observations. When the χ^2 test was significative ($P \leq 0.05$) in the contingency tables, a standardized residual analysis was performed (Agresti 1996). Association between ES and continent and quartile, and between quartile and continent was considered positive when observed values were higher than expected values, and standardized residual values were > 2. Negative association was considered when observed values were lower than expected values, and the standardized residual values were < -2 (Agresti 1996).

Results

Ecosystem services provided by orchids. A total of 413 articles were obtained, of which 224 reported information about the ES provided by orchids. The number of articles was significantly different among the ES (χ^2 = 33.81, df = 3, P < 0.05); most of these were on cultural services (75 articles), followed by provisioning services (66), supporting services (64), and regulating services (19). An increase in articles on the ES of orchids was observed from 2010. From 2000 to 2010, the greatest increase in articles occurred in provisioning services (33.33 %, Figure 1). For 2010 and 2020, most of the articles reported on cultural services (37.7 and 33.86 %, respectively) (χ^2= 8.88, df = 12, P > 0.05; Figure 1).

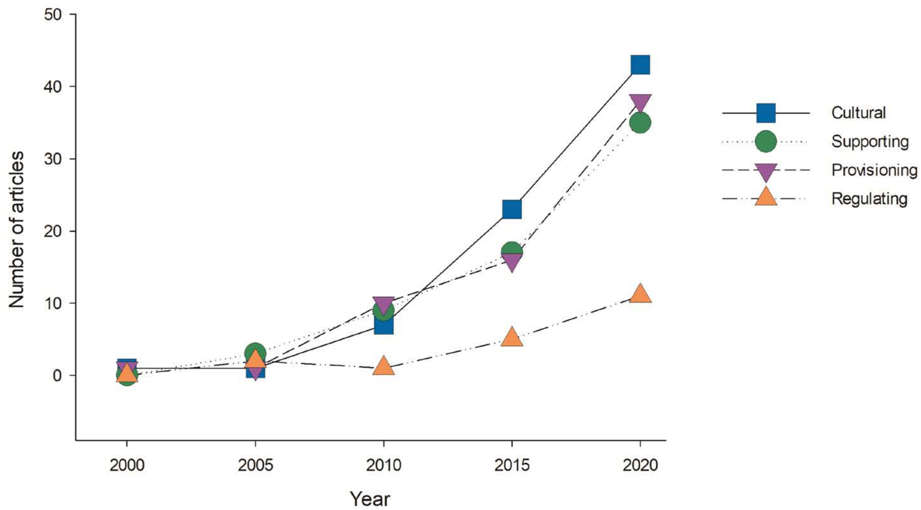


Figure 1. Number of articles that provide information about the ecosystem services provided by orchids between 2000 and 2021. A total of 224 articles were reported.

According to the subfamilies of Orchidaceae mentioned, Epidendroideae comprised 90.9 % of the total, Cypripedioideae by contrast had the fewest mentions (0.1 %). Six orchid genera *were* mentioned more than 50 times in the total number of articles reviewed, the genus *Dendrobium* standing out with 12.31 % (216 mentions), *Epidendrum* with 5.07 % (89 mentions), *Oncidium* with 3.42 % (60 mentions), *Bulbophyllum* with 3.36 % (59 mentions), *Prosthechea* with 3.19 % (56 mentions) and *Vanilla* with 2.96 % (52 mentions) (Figure 2).

Ecosystem services by categories. We found that cultural services fell into three categories: aesthetic appreciation (20 %), recreation and tourism (27 %), and traditional knowledge (53 %) (Table S1). Provisioning services by orchids focused on chemical-pharmaceutical products (75.76 %), and food provision (24.24 %) (Table S2), while regulating services were made up of those articles in which data on pollination (68.42 %) and water quality (31.58 %) were described (Table S3). Finally, articles in the supporting services category comprise those studies in which orchids help to conserve genetic diversity (45.31 %), support biodiversity (46.88 %) and are part of nutrient cycles (7.81 %) (Table S4).

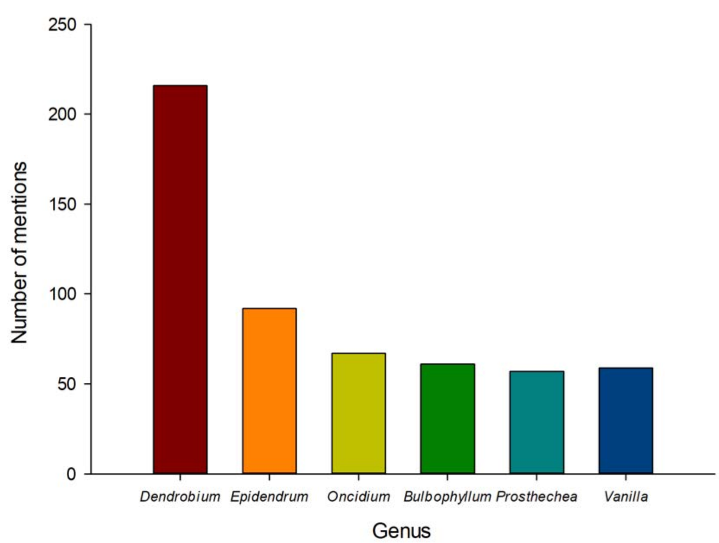


Figure 2. Ecosystem services articles by genus of orchids.

Ecosystem services-continent association. The number of journals on ES was not random among continents ($\chi^2 = 69.56$, df = 12, $P < 0.05$). Residual analysis indicated that journals on cultural ES were more abundant than expected by chance in America with a contribution of 12.09 % of the total (Figure 3A, B). Moreover, provisioning ES was more than expected by chance in Africa and Asia, with a contribution of 21.11 and 13.60 % of the total, respectively (Figure 3A, B). Cultural ES was less than expected by chance in Asia as was provisioning ES in America (Figure 3). For Australia and Europe, the percentage contribution of publications was less than 5 % for most ES (Figure 3B).

Continent-quartile of the journal association. The number of journals by quartile was not homogeneous across continents ($\chi^2 = 22.64$, df = 12, $P < 0.05$). The standard residuals analysis indicated that only journals in Q3 were significantly more abundant than expected by chance on America with a contribution of 18.16 % (Figure 4A, B). Despite journals in Q1 being more abundant in Asia (39.13 %, Figure 4), they were not positively associated. It is important to mention that journals in Q4 were the lowest on all continents (< 3 %).

Ecosystem services-quartile of the journal association. The total number of publications on orchid ES was not significantly different across quartiles of journals ($\chi^2 = 15.9$, df = 9, $P = 0.06$). We found that 54.76 % of publications correspond to journals in Q1 for the four types of ES, with most of the publications on supporting ES (26 journals); publications in Q4 were less than 3 %, with one publication for cultural ES and two for supporting ES (Figure 5).

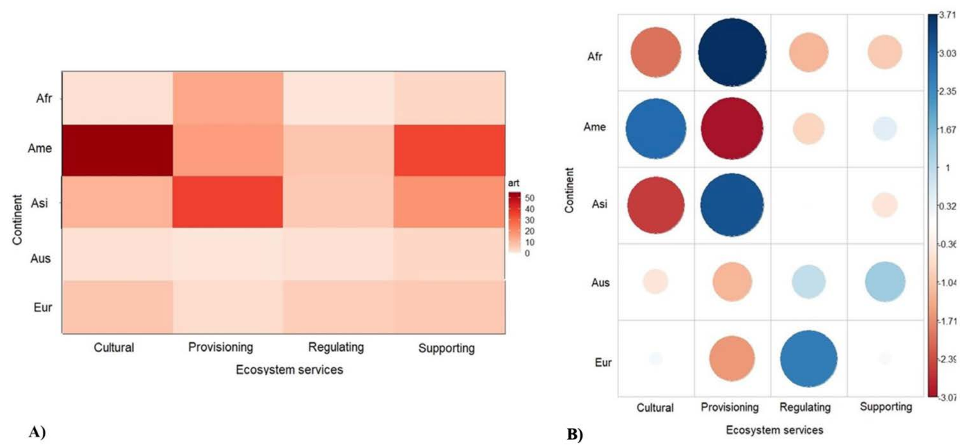


Figure 3. A) Heat map of the number of publications on orchid ecosystem services in relation to the continent in which the study was carried out. B). Standardized residuals of the number of journals by continent in which the ecosystem service of orchids was published. Association between continent and ecosystem service was considered positive when standardized residual values were > 2 and negative when < −2 (Agresti 1996). Afr: African, Ame: American, Asi: Asian, Aus: Australian and Eur: Europe.

Discussion

Ecosystem services provided by orchids. Orchidaceae provide a wide variety of ES around the world. Among the most notable are aesthetic appreciation, recreation and tourism, traditional knowledge, genetic diversity, support for biodiversity, nutrient cycles, chemical-pharmaceutical products, food supply, pollination, and water quality. We found a notably increased interest in studying the ES of orchids in the last ten years, this due to the growing need to find ways to use these plants; although much of the research focuses on medicinal use, chemical-pharmaceutical products and traditional knowledge, there are large open areas for study, particularly related to nutrient cycles, pollination, and water regulation.

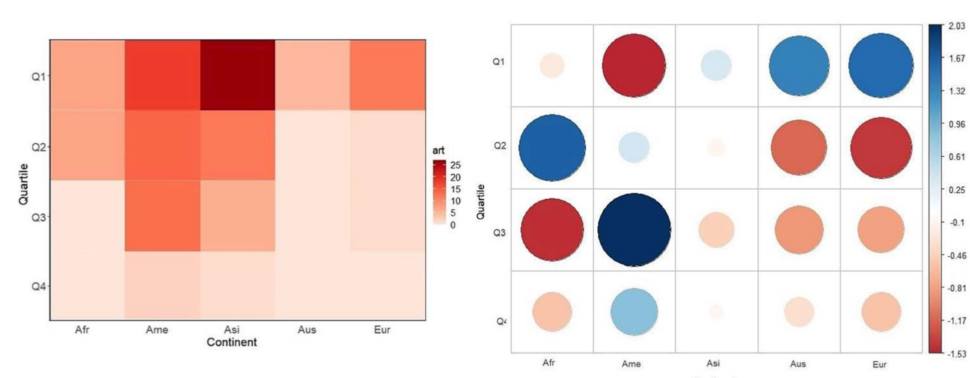
Epidendroideae subfamilies registered around 90 % of the ES mentions reviewed. This result is based on the most diverse subfamilies, with 21,160 species and is noteworthy for having developed one of the most significant diversifications among flowering plants, in terms of pollination strategy and vegetative adaptation (Freudenstein & Chase 2015, Muthukumar & Shenbagam 2018). Furthermore, their wide distribution around the world (Téllez Velasco 2012), allows many of the species to be more accessible and easily used to obtain some ES.

At genus level, *Dendrobium* was the most mentioned; it is widely distributed in the tropical and subtropical regions of Asia and Oceania, where we find the highest number of publications in quartile 1. The research on ES contributed by this particular genus is highly valued, given its wide use in traditional Asian medicine, mainly for its pharmacologically active compounds (Moudi *et al*. 2013, Tang *et al*. 2017). In several countries such as China, India, Nepal and Bangladesh, the use of 22 *Dendrobium* species against skin blemishes and infections has been reported (Wang 2021). Although *Dendrobium* is one of the most important floral crops, studies on this crop as a source for the phytochemicals industry are limited due to low quality of the flower (Kanlayavattanakul *et al.* 2018). The trend is towards developing methods for obtaining high-quality flowers through industrial and quality control practices that ensure mandatory safety and efficacy for the multiple uses of the crop (Kanlayavattanakul *et al*. 2018).

Cultural ecosystem services. The cultural ES provided by orchids in America showed a contribution of around 12 % of the total articles reviewed, while in Australia, they constituted less than 5 %. This is related to low diversity and limited distribution of many orchid species in the large desert areas of Australia (van der Cingel 2001) that have not yet been explored.

The cultural use of orchids over time has been part of spiritual and religious rituals, being used as offerings and ornamental flowers in many countries. In India, the Lepcha tribe, is recognized for its great knowledge about the use and exploitation of plants. This tribe has an ancient and exclusive tradition of manually making artifacts based on leaves of *Cymbidium*, and its hybrids (Singh *et al*. 2019). Its main products are hats, fruit and vegetable baskets, tea trays, containers, rugs, and flowerpots, among others. This tribe uses their own artifacts specifically in certain socio-religious rituals, which has allowed them to increase the search to preserve and transmit this knowledge and traditions into the tribe.

In other countries such as Mexico, *Erycina hyalinobulbon* (Lex.) N.H.Williams & M.W.Chase, *Guarianthe sp*., *Laelia autumnalis* (Lex.) Lindl, *L. albida* Bateman ex Lindl, *L. furfuracea* Lindl, *L. speciosa* (Kunth) Schltr, *L. anceps* Lindl, *L. superbiens* Lindl, *Lycaste skinneri* Lindl, and *Prosthechea karwinskii* (Mart.) J.M.H.Shaw (Jiménez-López *et al.* 2019a, b, Jorquera García & Brenes Cambronero 2019, Flores-Tolentino *et al*. 2020, Martínez-Meléndez *et al.* 2020, Emeterio-Lara *et al*. 2021a, b, Gutiérrez-Zavala *et al*. 2021, Ibarra-Contreras *et al*. 2021), are reported as highly exploited species and are used mainly for their visual appearance and ease of extraction from nature. Many of these species represent a source of family income and are an important part of the traditional culture of the populations where the species is found (Menchaca García *et al*. 2012); however, the practice requires authorization and constant monitoring by the corresponding authorities to be considered good utilization. Although these traditions are culturally important, they can lead to an important reduction in population numbers and genetic diversity, as the plants are often collected during the flowering period and in large quantities. Several strategies could be implemented to minimize these impacts, such as restoration-friendly crops in small-scale communities, and the establishment of



A) B)

Figure 4 A) Classification of journals by their quartiles in relation to the continent where published B). Standardized residuals of the number of journals by quartile (Q) in which the ecosystem service of orchids was published by continent. Afr: Africa, Ame: America, Asi: Asia, Aus: Australia and Eur: Europe. Association between quartile and continent was considered positive when standardized residual values were > 2 and negative when < −2 (Agresti 1996).

shade gardens and community nurseries, where species are propagated to satisfy the demand for rare, native and more wanted species (Wilkinson & Daley 2014, Hinsley *et al*. 2015), and managed under guidelines that operate within every country legislation (Velázquez Juárez 2019, Bazzicalupo *et al.* 2023).

Provisioning ecosystem services. Studies on the properties and medicinal uses of orchids are developed mainly in Asia. Due to the great biological diversity of orchids, some countries such as China and India (Singh *et al*. 2014, Shao *et al*. 2017, Vaidya 2019, Islam *et al*. 2021, Khajuria *et al*. 2021, Wang *et al*. 2021) are relevant for their geographical areas where more than 140 tribal communities use around 1,350 plant species, including some orchid species such as *Acampe rigida* (Buch. -Ham. exSm.) P.F.Hunt, *Dendrobium densiflorum* Lindl, and *D. nobile* Lindl (Tamang *et al*. 2021), passing down knowledge of herbal medicine from generation to generation (Tamang *et al*. 2021). Research on the provision of orchids as medicinal species becomes relevant mainly in developing countries, derived from the increase in the side effects of synthetic and modern medicine and its high cost (Tamang *et al*. 2021); therefore, people opt for cheap, efficient, and safe traditional herbal medicines (Śliwiński *et al*. 2022). Our results show that many orchids are used for their anti-inflammatory, antimicrobial, antioxidant, and anti-aging properties, which are developed into pharmaceutical and naturalistic medicine (Wang 2021).

In order to minimize excessive orchid extraction, artificial propagation techniques of orchid seeds have improved, helping to reduce the demand for wild plants (Nongdam *et al*. 2023). However, drawbacks have been found in the use of artificially grown medicinal orchids, mainly in Asia, where they are considered inferior in quality to ornamental orchids and have a much lower market price than their wild counterparts (Liu *et al.* 2014). Additionally, the establishment of protected areas and the reintroduction of species form a comprehensive conservation plan that contributes to the restoration of orchid populations and the maintenance of their ES (Segovia-Rivas *et al*. 2018, Wraith & Pickering 2019).

Within the great diversity of the Orchidaceae, the herbaceous perennial vine *Vanilla planifolia* Andrews stands out as one of the most recognized and researched worldwide since it provides ES for food and medicinal purposes as well as the essence used in the perfumery market, being highly employed worldwide (Salazar-Rojas *et al*. 2012, Watteyn *et al*. 2020). This species is endemic to Mexico and Central America, the orchid species has been used since the first Mesoamerican cultures (Bythrow 2005). Some authors report its use in the tribes of the Totonacas and the Aztecs around 1427-1440, who distributed it throughout the Gulf of Mexico and Central Mexico (Torquemada 1723). For these tribes, vanilla was one of the most important plants and its use expanded among other Mesoamerican tribes, who called it *Xhanat*, and the Aztecs gave it the name *Tlilxochitl* (Hágsater *et al*. 2015). Subsequently, it continued to be cultivated and towards the end of the Mexican colonial period, from 1767 was highly recognized

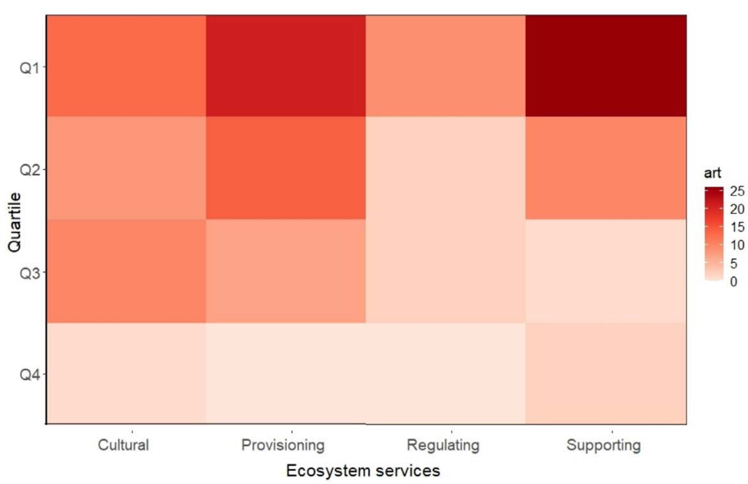


Figure 5. Heat map representing the classification of the ecosystem services according to the journal quartile (Q).

as an important species mainly for the preparation of flavored beverages (Menchaca García & Lozano Rodríguez 2021). Due to the long history of vanilla use in Mexico, the exploitation of its wild populations has caused it to be recognized as a species now subject to special protection (NOM-059) SEMARNAT 2010 and considered in various sustainable management and conservation plans (Flanagan & Mosquera-Espinosa 2016, Archila *et al*. 2019, Andriamihaja *et al*. 2020).

Regulating ecosystem services. Our results show a low number of studies on regulating services (8.5 %, 19 articles), where the topic of pollination has been one of the most researched categories due to the highly specialized orchid pollination systems, and the need to conserve endangered or endemic species, such as *Broughtonia cubensis* (Lindl.) Cogn or *Dendrophylax lindenii* (Lindl.) Benth. Ex Rolfe (Vale *et al*. 2013, Houlihan *et al*. 2019).

The orchid-pollinator interaction is mainly threatened by habitat loss, deforestation, and the expansion of urban areas (Gutiérrez-Rodríguez 2022). Thus, it is necessary to promote the conservation of both habitats and orchids, and their pollinators, considering that the disappearance of one would lead to the disappearance of the other or both, affecting the ES they provide (Gutiérrez-Rodríguez & Hernández-Rivera 2022).

For the above, it is important to involve specialists who focus on the analysis of pollination and orchid reproduction systems in conservation programs. Thus, proposals such as manual pollination of flowers by recruiting and training people must be implemented, in order to increase seed production within botanical gardens and nature reserves (Ticktin *et al*. 2020). In addition, promoting conservation education is essential to spread the relevance of conserving and protecting orchids, their habitats, and the different organisms to which they are related (Bernhardt *et al*. 2017).

Orchids are recognized for fulfilling a fundamental and important function in the cycles of water capture and filtration, thanks to both physiological and anatomical adaptations that allow a great diversity of species, mainly epiphytes, to establish in habitats with limited water, and optimize hydrological functions by improving water capture and filtration (Mendieta *et al*. 2020, Pan *et al*. 2021). For example, the genus *Cymbidium* has been studied to determine its adaptive capacity and the strategies that both terrestrial and epiphytic species develop to establish themselves and survive in their habitat (Zhang *et al*. 2015).

In this sense, climate change is one of the factors that most threatens the hydrological processes carried out by orchids, which impact their survival and conservation along with their habitats (Gutiérrez-Rodríguez 2022). Due to this phenomenon, changes in precipitation patterns and cloud formation will affect orchids, which could lead to a decrease in humidity, affecting seed germination and seedling development, in addition to indirectly influencing the availability of symbiont fungi and carbon sources (Johnson & Kane 2011, Rasmussen *et al*. 2015). However, further investigation is needed to analyze trends of the impact of climate change and epiphyte survival, among others (Wraith & Pickering 2019).

Supporting ecosystem services. In the last decade, a variety of studies have been reported focused on the role of orchids as an important reserve of genetic resources, mainly through studies on genetic variability, such as Lima-Morales *et al.* (2021), who evaluate the intraspecific variation of *V. planifolia* (Orchidaceae) in Mexico, finding a natural intraspecific variation in the labella of native specimens, suggesting the possibility that this species contains genetic variability and information for breeding the species. This represents a fundamental component to understand the life history of the species and determine actions aimed at the conservation of this genetic resource.

Studies on seed viability are also included in supporting ES, given that some orchids, such as *Cypripedium japonicum* Thunb, are reported to have a low germination rate due to biological and ecological traits: the size of their populations and the limited dispersal of seeds has led to the modification of the genetic diversity of this species (Tian *et al.* 2018). One technique to study seed germination includes *in vitro* cultivation, the most developed micropropagation technique for quickly and successfully obtaining orchid seedlings, mainly with threatened species or of commercial interest (Mayo-Mosqueda *et al*. 2010, Salazar-Mercado 2012, Aguilar-Morales & López-Escamilla 2013). Mayo-Mosqueda *et al*. (2020), developed this technique with *L. speciosa* (subject to special protection under Mexican law) obtaining 100 % germination, showing that *in vitro* micropropagation has high potential in the quest to reduce the impact of plant subtraction and maintain genetic diversity as a supporting ES.

Studies on how orchids contribute to maintaining biodiversity are mainly carried out to conserve species that are under some risk category or are endemic through prediction models (Kolanowska *et al.* 2020, Li *et al.* 2022). Deb *et al.* (2017) apply a distribution prediction model and a climate suitability model with *Vanda bicolor* Griff, highly used for horticulture and endemic to India, in order to provide knowledge and tools for its conservation. They propose that the use of these models will allow us to determine the climatic parameters that define the survival of species and thus successfully predict the state of wild populations with a success rate of around 70 %. Our results propose the continued study of genetic diversity, biodiversity, and ecology, allowing the maintenance of support ES provided by orchids around the world.

Concluding remarks. The economic valuation of orchid ES allows us to calculate the socio-environmental costs and benefits of human activities, to make decisions about conservation methods, specific policies in the environmental field, and evaluate projects and payment programs for environmental services, on the assumption that the ES fulfill the function of being the support between ecosystems and human society (Cabrera Murrieta 2012). Although there has been an increase in studies related to orchid ES in the last two decades, it is essential to increase the amount of research to further analyze this topic. We propose to research mainly the regulating ES provided by orchids, since there is a large knowledge gap in such factors as soil processes, nutrient cycle and mineralization, water cycle and energy transfer (trophic chains), where species form an essential part of these processes, without leaving aside that, in turn, all ES go hand in hand with seeking the balance of nature.

The knowledge provided in this review can guide us towards future studies and strategies to integrate efforts in favor of conservation through the mitigation of threats to ecosystems, creation of protected areas, establishment of legal trade in orchids, development of micropropagation techniques and reintroduction of species, focusing on the species listed as under threat or endemic in each country, and giving greater weight to environmental education, always in light of the ES.

Finally, we believe ES will be considered an essential aspect of a country's development and through planning and economic and social development processes, their value, conservation and sustainable use will be guaranteed.

Supplementary material

Supplemental data for this article can be accessed here: https://doi.org/10.17129/botsci.3478

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