A New Global Estimation of Medicinal and Aromatic Plant Species in Commercial Cultivation and Their Conservation Status

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A New Global Estimation of Medicinal and Aromatic Plant Species in Commercial Cultivation and Their Conservation Status. Historically, the majority of medicinal and aromatic plant (MAP) species has been harvested in the wild. In recent decades, there has been concern that certain species appear to face threats due to overexploitation related to increasing global demand coupled with loss of habitat due to development and land use change. Earlier studies estimated that about 900 species were produced, to some extent, by cultivation. This study aims to update previous estimates by applying a systematic approach for obtaining data from a large number of different sources of information and knowledge. A broad categorization scheme for forms of cultivation is introduced. Using multiple methods of data collection, we found evidence of commercial cultivation of 3,227 taxa, belonging to 235 different plant families. The most frequently identified forms of cultivation were agroforestry, intensive farming, and controlled cultivation, followed by, to a much lesser extent, extensive farming, and natural fostering. Of the identified species, 954 have a global International Union for Conservation of Nature (IUCN) Red List assessment, of which 82 species (2.5%) are threatened to some degree according to IUCN Red List categories and criteria. Of the 3,227 cultivated taxa, 1,732 (54%) have also been assessed by national red lists, of which 688 taxa are assessed as threatened in at least one country. Additionally, 109 of the 3,227 cultivated species are included in the Convention on International Trade in Endangered Species (CITES) Appendices. The results of this research show that the number of cultivated plants is significantly higher than previously estimated. Potential consequences of threat status on the domestication of MAP species are discussed.

Key Words: Domestication, medicinal crops, natural fostering, sustainable agriculture, threatened species, MAP cultivation, NTFP, enrichment planting, conservation

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Introduction

From historic times until today, the majority of medicinal and aromatic plant (MAP) species have been harvested in the wild. According to the Medicinal Plant Specialist Group of the International Union for Conservation of Nature (IUCN), "the term 'medicinal and aromatic plants' (MAP) includes plants used to produce pharmaceuticals, dietary supplement products, and natural health products, beauty aids, cosmetics, and personal care products, as well as some products marketed in the culinary/food sector" (Medicinal Plants Specialist Group 2007). While declines of some MAP species due to overexploitation already occurred in early history (e.g., Parejko 2003), increasing global demand and rising incomes of a growing human population in recent decades coupled with loss of habitat due to development and land use change have put up new and severe threats to many MAP species (Cunningham 2002; Hamilton 2004; Schippmann et al. 2006; Sharma and Kala 2018). Since at least 1988, awareness of and research into the conservation status of certain wild MAP species has been increasing, brought forward by the historic Chiang–Mai Declaration "Saving Lives by Saving Plants" (Akerele et al. 1991). This declaration articulated an urgent need for conservation and sustainable use of MAPs for primary healthcare globally. It was followed up with publication of the 1993 "Guidelines on the Conservation of Medicinal Plants" (World Health Organization, International Union for the Conservation of Nature and World Wide Fund for Nature 1993), which provided a framework with recommended actions such as transitioning from reliance on wild collection, wherever possible, towards cultivation as the source of supply, ensuring that any wild collection is done sustainably, and conserving populations in natural habitats as well as *ex situ*.

Since the 1990s, an increasing number of MAP species have been brought into commercial cultivation. While the above–mentioned guidelines proposed a transition towards cultivation of medicinal plants to become the primary source of the commercial supply, others juxtaposed the pros and cons of sustainable wild collection and ecosystem management versus domestication, their potential impacts, negative or positive, on biodiversity conservation, raw material quality, and rural economies (Chen et al. 2016; Schippmann et al. 2006). In 2006, a research group estimated that as many as 72,000 MAP species may be in use, of which less than 1% (<720) were sourced from commercial cultivation, and about 3,000 species could be in international trade (Schippmann et al. 2006). From this, Mulliken and Inskipp (2006) suggested that commercial cultivation may be taking place, or occurring at some stage of development, for about 900 MAP species. Up to this point, researchers in this field continue to utilize the estimates that were proposed in 2006 (e.g., Brokamp 2015; Greinwald et al. 2021; Grigore et al. 2016; Li et al. 2010; Moré and Tuğrul-Ay 2017; Rajeswara et al. 2012). With many populations of MAP species decreasing in the wild while the global demand for MAP commodities is increasing as well as technological advances in sectors like biotechnology and agronomy, it can be prospected that cultivation of MAP species will increase in the future (Chen et al. 2016; Lubbe and Verpoorte 2011; Mulliken and Inskipp 2006). Understanding which species are cultivated and where, what the conservation status of their wild populations is, but also how agricultural production of MAP takes place, can thus be an important basis to carry on research in the fields of MAP use and conservation.

In this study, we developed and applied a systematic method to generate a standardized list of MAP species for which references of commercial cultivation exist, including information on the countries or regions where cultivated, the species' threat status, the form(s) of cultivation, and a taxonomic verification that reflects the current systematic status of identified taxa. The relevance of this research to the fields of agronomy of medicinal plants, conservation biology, and economic botany is demonstrated first in our objective to quantify the number of MAP species being brought into commercial cultivation. Second, we aimed to classify forms of MAP cultivation, which can help in better understanding of how domestication impacts conservation of wild species and habitats.

Methods

Background

The research was carried out between June 2017 and October 2020. We followed a

systematic approach using multiple methods of data collection. Mandatory data collected were the species name (the Latin binomial as reported; taxonomically verified after data compilation), country (including region where known) where the species is cultivated, and the type(s) of evidence, such as published literature citations, individual farm crop lists, personal communications, or survey responses. The form of cultivation in each case was classified according to authors' own definitions and agricultural field experience coupled with definitions published in MAP agriculture literature and governmental agriculture glossaries (e.g., European Commission 2018). All found cases of MAP cultivation were documented with reference to the sources of information that were used. Data table and legends thereof provide a detailed explanation of the data categories, as well as a bibliography with complete citations (Electronic Supplementary Material, [ESM] 1).

Our inclusion criteria were botanical species with evidence of medicinal use, where the source(s) of information provided a Latin binomial (even if misspelled, or not the currently accepted plant name) and a geographic location (country name and regions of cultivation within a country, if provided). We excluded species that are used solely as food. However, we did include some species that may be used predominantly as food so long as there was also clear evidence of medicinal use. Sources of information that lacked sufficient details of botanical identity and location were excluded. Much of the excluded literature provided only vernacular names in the local languages. In some cases, where a species name and geographical location were indicated but the form of cultivation was unclear, follow–ups with information providers or additional literature sources were required, along with deliberation by the research team in order to reach consensus on the form of cultivation. To differentiate commercial cultivation from other cultivation, we included species for which we found evidence of cultivation for the purpose of selling raw material as ingredients or for use in processed preparations. Therefore, we included, e.g., home gardening if the species were not only cultivated for subsistence but also for commercialization on local, national, or international markets.

Forms of Cultivation

To categorize the forms of cultivation we developed the classification presented in Table 1. It distinguishes five forms of cultivation plus six potential additional attributes that may further elaborate the form of cultivation. The research team utilized definitions based on their own agricultural field experience that were also supported by definitions published in authoritative or governmental text with agriculture glossaries. The researchers did not find a single internationally accepted agricultural glossary to cite, i.e., one that would include all of the forms of cultivation that are in use for medicinal plant production, some of which are innovative and relatively new. Furthermore, some overlap of farming methods or multiple methods at a single farm site was to be expected. In difficult cases, the research team reviewed the data, deliberated, and decided on the most appropriate classification(s). This aspect is also discussed in the Limitations section of this study.

Taxonomy and Nomenclature

All species identified in our research were subjected to a nomenclatural and taxonomic assessment using the World Checklist of Vascular Plants (WCVP 2021) of the Royal Botanical Gardens, Kew. This was done in order to avoid duplicate entries and to evaluate and sort out potential errors, misspellings, or synonyms used in farmers' crop lists and in other sources of crop data. This happened with the support of the data managers at the Royal Botanical Gardens, Kew.

Conservation Status

We also investigated the conservation status of cultivated MAP species that are classified as threatened in the wild both globally and according to national red list assessments. For the global conservation status, the assessments provided by the International Union for Conservation of Nature were used (IUCN 2021). National red lists of threatened species have been published in 87 of the 162 countries represented in this study. These red lists were analyzed plus red lists of three countries not represented in this study (Guinea, Lesotho, and Luxemburg). We also carved out the international

Table 1. Forms of cultivation used to classify map crops in this study.

Initial	Form of Cultivation and Description	
AF	Agroforestry	Cultivation of agricultural crops with trees, whether exotic or native species, and whether inside a managed forest area or outside of the forest.
CC	Controlled Cultivation	The farming systems are science–based, specifically designed for controlling and optimizing the content of active constituents (e.g., secondary metabolites or other pharmacologically active compounds) of pharmaceutical herbal drug crops. It is controlled, in part, by an intentionally selected environment/site (whether indoors or outdoors) with a range of analytical tools, and by specified production practices that are designed to optimize a desired composition, content of active compounds and uniformity of the crop for pharmaceutical use. Controlled cultivation is not limited to the field but could be implemented in other settings including aquaculture or greenhouse. It can be small–scale or large–scale and it aims to avoid the use of pesticides and herbicides wherever possible.
EF	Extensive Farming	Cultivation with a low use of capital and labor (e.g., fertilizers, pesticides, machinery) relative to land area. For example, a small organic farm with no machines, no or very low input use, and sowing and harvesting by hand, whether in desert, field, or forest conditions, would illustrate extensive farming.
IF	Intensive Farming	"Intensive farming is a farming system characterized by the significant use of capital and inputs relative to land. Large amounts of capital are necessary to the acquisition and application of fertilizer and pesticides to growing crops.... Capital is also particularly important to the maintenance of high–efficiency machinery for planting, cultivating, and harvesting, as well as irrigation equipment where that is required. Optimal use of these inputs produces significantly greater crop yields per unit of land than in extensive farming systems …. However, the actual effect of the use of inputs on the environment is not only depending on the amount of inputs used but also on how and when they are applied." (European Commission 2018)
NF	Natural Fostering	Augmenting wild populations by cultivating a native species in the same area where it naturally grows or can grow. This is also known as enrichment planting, semi–imitational cultivation, wild simulated cultivation, or wild nursery, and may include introduction of seeds, seedlings, or propagules into habitats, and replanting or transplanting of harvested roots, rhizomes, bulbs, or other subterraneous regenerative plant parts. There is a continuum between wild harvest and natural fostering, and many cases are, probably, unreported.
	Potential additional attributes	
AC	Aquaculture	Cultivation of marine plants, freshwater aquatic plants, or algae, whether in open water or in land / on–shore tanks.
DF	Dryland Farming	Arid–zone or desert cultivation of crops without irrigation.
HG	Home Garden Farming	Cultivation of plants in and around the home for domestic use and for trade.
IC	Intercropping	Cultivation of two or more crops together.
SA	Sustainable Agriculture	Cultivation in accordance with voluntary sustainability standards or regulations that define biodynamic farming, organic farming, permaculture farming or regenerative agriculture.
TC	Trial Cultivation	Experimental crop domestication to determine feasibility and agro–techniques.

protection status of the cultivated species listed in the Appendices of the Convention on International Trade in Endangered Species (CITES) (UNEP–WCMC 2022).

Data Sources

We obtained relevant MAP crop data by way of traditional desk research, online desk research, as well as catalogues and directories, database research, crop survey interviews, and direct experience and knowledge of members of the research team based on their decades of fieldwork inspecting MAP production operations around the world. One member of the research team also had an existing large collection of relevant publications on MAP cultivation, collected over many years, which augmented the literature retrieval process.

Representative types of cited publications include MAP crop–specific Good Agricultural Practices (GAP) (e.g., Jat et al. 2015; World Health Organization 2006), handbooks on agro–techniques for MAP crops (e.g., Hoppe, 2007, 2009, 2010, 2012, 2013; National Medicinal Plants Board 2008, 2014), scientific papers evaluating methods of MAP production such as natural fostering (e.g., Li et al. 2015), papers listing and quantifying MAPs cultivated under GAP regulations (e.g., Zhang et al. 2010), and surveys quantifying MAP production and export trade from specific countries (e.g., Evstatieva et al. 2007).

Our data collection strategy involved using a group of search terms translated into multiple languages. Searches were carried out separately in each of the selected languages including Chinese, Dutch, English, French, German, Japanese, Korean, Persian, Portuguese, Russian, and Spanish. Search terms included *botanical*, *herbal*, *medicinal and aromatic plants*, *natural fostering*, *agroforestry*, *agronomy*, *crop*, *cultivation*, *farm*, *forest farm*, and *sustainable agriculture.* Different combinations and/or order of selected terms also could achieve differing results in different search engines. In some cases, there was no clear translation of an English term such as "natural fostering." Terms that could serve as a proxy for the concept also were used, such as "conservation agriculture." We used the online academic search engine Google Scholar, and ResearchGate, a professional network for scientists and researchers, as well as the online databases of standards setting organizations and inspection and certification bodies for access to evidence of MAP crops that are produced in accordance with voluntary sustainability standards including the USDA Organic Integrity Database (https://organic.ams.usda.gov/integrity/), Demeter International Datenbank (https://database.demeter.net/welcome), FLOCERT Customer Database (https://www.flocert.net/about–flocert/customer–search/), and the ECOCERT Fair For Life Certified Products Database (https://www.fairforlife.org/pmws/indexDOM.php?client_id=fairforlife&page_id=certprod&lang_iso639=en). Websites of MAP farms and traders, listed in the certification online databases, were also reviewed to verify species listed in the databases. Information on 491 farms was collected and evaluated. We accessed data including crop lists, price lists, and catalogues of commercially available cultivated MAP crops in websites of farms and of trading companies (e.g., Organic Herb Trading Company 2017; Pacific Botanicals 2017). To identify and communicate with other relevant information providers, we also searched LinkedIn, a business professional social networking site.

In addition, we developed a survey to obtain information on MAP crops from farms and trading companies. Selected interview partners were contacted with a request for information including name of crop (common name and Latin binomial), country, form of cultivation, and year when cultivation began. Interviewee selection criteria were based on existing personal and professional relationships that researchers have established with MAP producers, traders, and sector experts living in Africa, Asia, the Americas, Australia, and Europe.

Results

MAP crop data were obtained through multiple methods. Of the approximately 2,800 publications reviewed, 867 publications met our inclusion criteria (citations provided in ESM 1). There was a low response rate to the MAP crop list survey (only two were returned). Thus, most informants provided MAP crop information in other ways, mainly in response to email communication or LinkedIn private messaging,

but also through direct communication (e.g., via telephone, Skype, or WhatsApp). Of the 29 informants who confidentially provided MAP crop information, 14 informants either worked for MAP farms or for companies that procure MAPs from farms, 7 were independent MAP experts, 5 worked for research institutes involved with MAP crops, and 3 worked for biodiversity conservation NGOs that have MAP programs. The 29 informants lived in 11 countries (but generally had MAP crop experience in more than one country), including Brazil (1 informant), Canada (2 informants), China (1 informant), Germany (3 informants), India (2 informants), Iran (3 informants), Mexico (1 informant), Nepal (1 informant), South Africa (3 informants), United Kingdom (5 informants), and United States (7 informants).

We identified 13,371 distinct examples of commercial cultivation. MAP taxa cultivated at different sites, whether in same country or different countries were entered as separate line items and evaluated separately. After the taxonomic review and the identification of unclear datasets, 2,428 entries were excluded for various reasons, of which 77 entries provided only genus level information or the species name was not reconcilable, and 2,351 entries did not provide country or "form of cultivation" data. Of the remaining 10,943 entries, 7,271 provided the botanical name, country where grown, and either a form of cultivation or at least a potential additional attribute. Of these 7,271 entries, 5,018 entries provided sufficient information on the form of cultivation. And of these 5,018 entries, 3,092 entries provided some information on additional attributes such as "sustainable agriculture" (e.g., evidence of biodynamic or organic farming certification).

From the 10,943 entries, the taxonomic review carried out by Royal Botanic Gardens, Kew delivered 3,227 different accepted scientific names; 128 taxa are on infra–specific level: 66 sub–species, 61 varieties, and 1 forma. The cultivated MAP taxa identified in this study belong to a total of 235 different plant families. The plant families with the highest species numbers are Asteraceae (272 taxa), Fabaceae (263 taxa), and Lamiaceae (241). Our results include species with reported commercial cultivation in 162 countries of the world (Table 2). We classified the Russian Federation as its own region rather than segregating data of Asian Russia and European Russia. We found evidence in 31 countries of more than 100 MAP taxa in cultivation. Of those, the predominant countries by region included those of Asia (India, China, Iran, Nepal, Indonesia, Vietnam, Myanmar, and Laos), Africa (South Africa, Ethiopia, Egypt, Uganda, Tanzania, Nigeria, DR Congo, Kenya, and Togo), Europe (Germany, Italy, France, Hungary, Portugal, and Spain), the Americas (United States, Peru, Brazil, Chile, Mexico, Argentina, and Ecuador), and Oceania (Australia) (Fig. 1).

Figure 2 shows the number of MAP taxa reported to be cultivated in number of countries. There were six species found to be cultivated in at least 40 countries: *Matricaria chamomilla* L. (Asteraceae) with 46 countries, *Calendula officinalis* L. (Asteraceae) and *Ocimum basilicum* L. (Lamiaceae) with 41 countries each, and *Melissa officinalis* L. (Lamiaceae), *Mentha* × *piperita* L. (Lamiaceae), and *Salvia rosmarinus* Spenn. (Lamiaceae) (syn.: *Rosmarinus officinalis* L.) with 40 countries each.

Forms of Cultivation

Forms of cultivation in order of predominance were agroforestry, intensive farming, controlled cultivation, extensive farming, and natural fostering (Table 3).

Table 3 shows that agroforestry accounted for 2,148 entries (42.8% of 5,018 entries), intensive farming accounted for 1,574 entries (31.4% of 5,018 entries), controlled cultivation was identified for 911 entries (18.2% of 5,018 entries), extensive farming accounted for

Table 2. Overview of number of countries covered in this study by region.

Region	Number of Countries	Number of Cultivated Species
Asia	43	2,618
Africa	40	1,522
Europe	40	2,199
The Americas	29	1,694
Oceania	9	293
Russian Federation	1	74

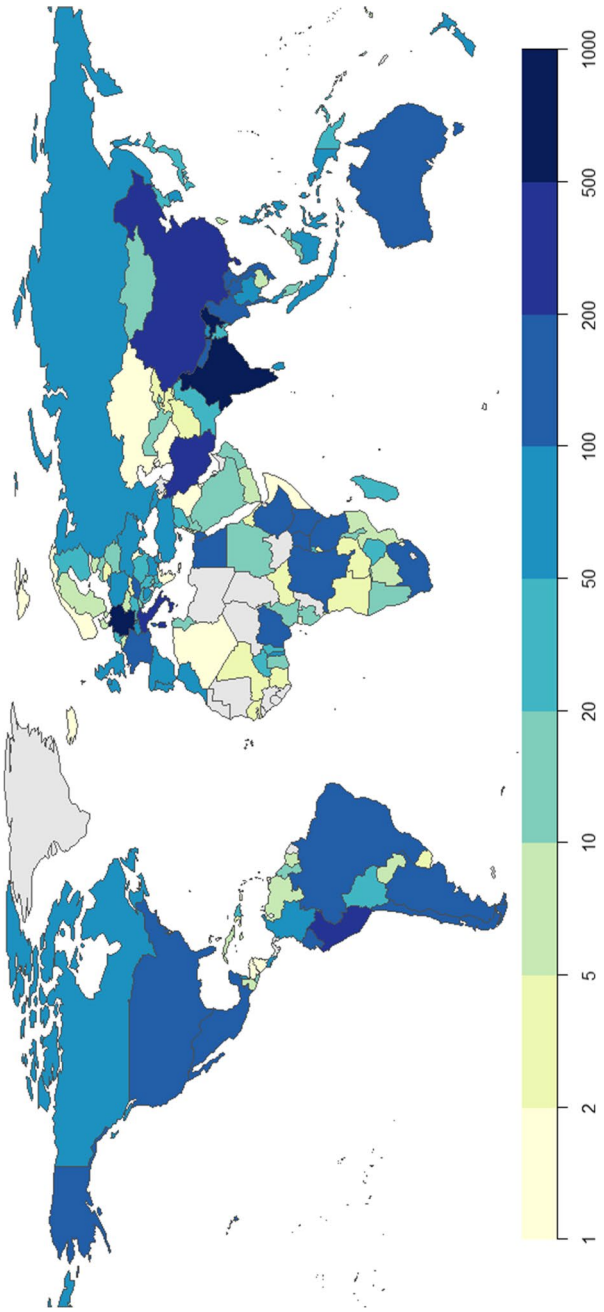

Fig. 1. World map showing the number of MAP taxa reported to be cultivated per country. Gray coloring indicates that no reports of cultivation were found for the respective country.

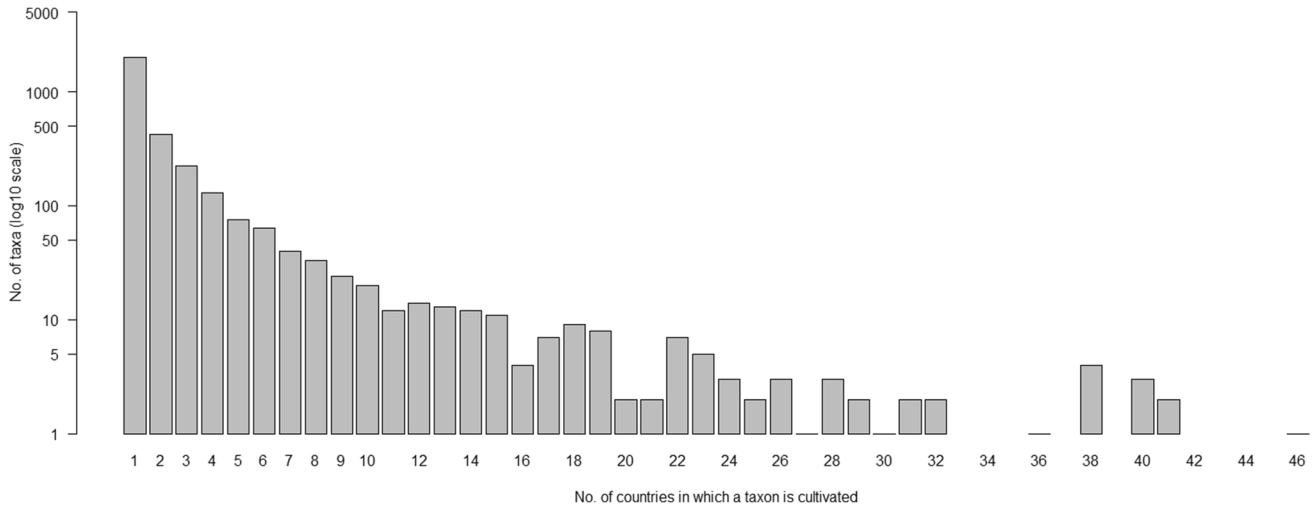

Fig. 2. The number of MAP taxa reported to be cultivated by the number of countries in which a taxon is cultivated. For example, 2018 taxa are cultivated in only one country, respectively, and one taxon is cultivated in 46 countries.

Table 3. Summary of Forms of Cultivation and Additional Attributes.

Forms of Cultivation (FoC)		Number of Taxa		
		Total		In CITES
AF	Agroforestry	2,148		71
IF	Intensive farming	1,574		5
CC	Controlled cultivation	911		38
EF	Extensive farming	287		0
NF	Natural fostering	98		8
Additional attributes		Number of Taxa		
		with FoC	w/o FoC	in CITES
SA	Sustainable agriculture	1,552	1,042	33
HG	Home garden	992	739	36
TC	Trial cultivation	387	472	37
IC	Inter–cropping	128	61	7
AC	Aquaculture	30	0	0
DF	Dryland farming	3	21	0

287 entries (5.7% of 5,018 entries), and natural fostering accounted for 98 entries (1.95% of 5,018 entries). There were another 2,335 entries, for which the form of cultivation was undetermined while an additional attribute (e.g., sustainable agriculture) was determined. Of these 2,335 entries, 1,042 entries (44.6% of 2,335) provided evidence of a sustainable agriculture production system, 739 (31.7% of 2,335) were home garden farming, 472 entries (20.2% of 2,335) were classified as trial cultivation, 61 entries (2.6% of 2,335) mentioned an intercropping system, and 21 entries (0.9% of 2,335) represented dryland farming.

It is important to note that the form of cultivation indicated for a species may be different for farms in one region versus another or even between different farms within the same region. Therefore, no broad generalization can be made linking a MAP crop with a specific form of cultivation globally. If two different forms of cultivation of the same taxon were reported from one country, two separate line entries were made in the original data table (ESM 1). For example, turmeric rhizome (*Curcuma longa* L.), widely cultivated in India, was coded as IF (intensive farming) in cases where it is grown as a high input conventional monocrop. However, at some farm sites in India, turmeric was coded as AF (agroforestry), with additional attributes of IC (intercropping) and SA (sustainable agriculture), denoting an agroforestry setting with several understory crops and certified as an organic farm. To illustrate, some certified organic forest farms that were visited during the course of this study (Fig. 3) used betel nut palm (*Areca catechu* L.) as the main crop with climbing vines attached to the *Areca* trees, long pepper (*Piper longum* L.) and black pepper (*Piper nigrum* L.), interspersed with other trees such as naga sampige (*Mesua ferrea* L.), nutmeg (*Myristica fragrans* Houtt.), paradise tree (*Simarouba glauca* DC.), and sapota (*Manilkara zapota* (L.) P.Royen), with turmeric (*Curcuma longa* L.) growing in the understory.

Cultivation of Threatened Species

To date, IUCN has assessed over 56,000 plant species worldwide (IUCN 2021). Many more species are included in national red lists provided by other authorities who often use their own threat assessment methodology and threat categories.

We found that 954 of the commercially cultivated species in our list (representing 29.6% of the 3,227 taxa) have a global IUCN Red List assessment:

- 82 taxa (or 2.5% of the 3,227 taxa cultivated) fall in the "Threatened" category

Fig. 3. Intercropping system forest farm of Uttara Kannada District Regional Organic Farmers Federal Co–operative Ltd. (UK–COOFED), Sirsi, Karnataka, India. The main crop in the foreground is betel nut palm (*Areca catechu* L.), with climbing long pepper (*Piper longum* L.) and black pepper (*Piper nigrum* L.) attached to the Areca trees. Different other tree species (*Mesua ferrea* L., *Myristica fragrans* Houtt., *Simarouba glauca* DC., and *Manilkara zapota* (L.) P.Royen) are interspersed, as well as *Curcuma longa* L. growing in the understory. Prior informed consent for use of this photo of UK–COOFED farmer Mr. Dattatreya S. Hegde was provided. Photos: J. A. Brinckmann 2017.

sensu stricto because they have been globally assessed as either Critically Endangered (CR), Endangered (EN), or Vulnerable (VU) in the wild;

- 798 taxa (24.7% of 3,227) are considered Least Concern (LC) or Lower Risk (LR);
- 45 taxa have been assessed but were found to be Data Deficient (DD) (1.4% of 3,227);
- 24 as Near Threatened (NT) (0.74% of 3,227); and
- 5 species have been assessed as "Extinct in the Wild" (EW), all of these in the genus *Brugmansia*, which are known only from cultivation.

Of the 3,227 cultivated taxa, 1,732 (54%) have also been assessed by national red lists, many of which do not use IUCN criteria. It should be noted that many of these assessments resulted in "Safe" (= Least Concern) or "Unknown" (= Data Deficient). Of the 3,227 cultivated taxa, 688 (21%) have been assessed as "Threatened" at a national level in at least one country, equating IUCN threat categories of Critically Endangered (CR), Endangered (EN), or Vulnerable (VU). Of the 3,227 cultivated taxa, 36 (1.1%) have been reported as "Extinct" (EX) at the national level in at least one country. We found 15 national red–listed taxa associated with a Natural Fostering form of cultivation, 8 of which occur in China (Table 4). Although we found relatively few examples of natural fostering, we saw particular relevance in looking at this method of natural population augmentation being applied to threatened species in their natural habitat areas. Natural fostering stands out from the other forms of cultivation, as it aims to support wild populations of commercially used MAPs in their natural environment, thus not only fostering the commercial use but also protecting the habitats and all the other species of wild fauna and flora living in these habitats. Hence, natural fostering

Table 4. MAP Species with National Red List Assessment in the Country of Cultivation and identified as Natural Fostering.

Accepted Name (without author)	Country of Cultivation	Threat Category	Country of Red–listing
Astragalus mongholicus	China	VU	China
Cistanche deserticola	China	EN	China
Ephedra intermedia	China	NT / VU	China
Ephedra sinica	China	NT / VU	China
Epimedium brevicornu	China	NT	China
Fritillaria cirrhosa	China	NT	China
Podophyllum versipelle	China	VU	China
Saussurea involucrata	China	EN	China
Warburgia salutaris	Mozambique	VU	Mozambique
Nardostachys jatamansi	Nepal	VU	Nepal
Paris polyphylla	Nepal	VU	Nepal
Swertia chirayita	Nepal	VU	Nepal
Vitellaria paradoxa	Uganda	VU	Uganda
Agathosma betulina	South Africa	Declining	South Africa
Warburgia salutaris	South Africa	EN	South Africa

can be, if well done, the most sustainable form of cultivation with the lowest negative impact on the environment.

Additionally, we found 109 cultivated species that are included in the Appendices of the Convention on International Trade in Endangered Species (CITES) (UNEP–WCMC 2022). Two species are included in Appendix I: *Araucaria araucana* (Molina) K. Koch and *Aucklandia costus* Falc. One species, *Lodoicea maldivica* (J.F.Gmel.) Pers., is listed in Appendix III, and the remaining 106 taxa are included in Appendix II.

Discussion

The results of this study provide a new global estimate of the number of MAP species being commercially cultivated. We obtained documentary evidence of 3,227 MAP taxa under some form of cultivation, which is over three and one–half times higher than the previous and most oft–cited number of about 900 cultivated MAP crops globally. Furthermore, we provide analysis of the numbers of threatened species being cultivated and discuss the role that threatened species may play in cultivation efforts.

Threatened Species and Conservation

In the system of red list categories used by IUCN, together the categories Critically Endangered (CR), Endangered (EN), and Vulnerable (VU) form the group of Threatened species (IUCN 2021). Estimates for the overall proportion of threatened species in the global number of plant species, derived from the Sampled Red List index for plants—SRLi—which was developed by the Royal Botanic Gardens, Kew, (Brummitt et al. 2015) state that 22% of all vascular plant species are threatened with extinction. According to the SRLi, 65% of the global vascular plant species are assessed as Least Concern (LC) and have a low risk of extinction. These estimates are based on a taxonomically random sample of species and the number of assessments included (7,000+ species) is a statistically verifiable sample.

With 8.6% (as per IUCN assessment) or 21% (as per national assessments), the proportion of threatened species in our sample is smaller than in the global vascular plant flora (22%). On the other side of the threat spectrum, 83.6% of our cultivated species are assessed as Least Concern (LC) or Lower Risk (LR), while in the global population this value is lower (65%). From these aggregated numbers, overharvesting of species

cannot be deduced as an immediate and general driver to take a wild collected species into a domestication program. Companies, inclusive of farming operations, and research institutes may often use other criteria when decisions are made on which species are adequate candidates for bringing into cultivation. The most important criterion may be economic feasibility (Sher et al. 2010). It is usually economically more viable to bring species into cultivation that are in large–scale demand rather than plants that provide "niche" ingredients. Other criteria are biological characteristics of target species (e.g., very long time to reach harvestable age of plants and unfavorable revenue perspectives) and the complexity and costs of the domestication process and availability of personnel. The latter becomes more and more relevant for wild collection, because in some of the main source regions, e.g., Eastern Europe, the number of wild plant collectors has decreased substantially, while the average age of the remaining wild collectors is increasing (Childs et al. 2014; Rodina et al. 2014; Sucholas et al. 2021). An absence of young people engaged in wild collection as a means of livelihood in rural areas has been observed in the field by members of this research group.

Limitations

It is important to note some limitations to this research. As a funded project, there was a specified timeframe for completion of the assignment and extending the study period would likely lead to more identified cases of MAP cultivation. Of the 13,371 entries, only about 54% (7,271 entries) provided the minimum level of data needed for inclusion in the analysis. We identified cultivation of MAP species in 162 countries, which is also a study limitation due to the fact that there are 195 countries in the world. While we believe this study to be the most comprehensive on the topic thus far, and while it provides a new global estimate of MAP crops, along with forms of cultivation and conservation status, follow–up studies using the same methodologies are recommended in order to comprehensively include information on MAP cultivation in all countries of the world.

Besides this limitation on the scope of research, the availability of information in published sources or farm lists is probably more limited on some forms of cultivation than on others. While information on agroforestry, intensive farming, and controlled cultivation is often publicly accessible, information on extensive farming and natural fostering seems less frequently available, because (academic and private sector) research does not usually focus on these cultivation forms. In this study, we analyzed available data on the link between the threat status of MAP species in the wild and the cultivation of these species. While it has become evident that the threat status of species does not systematically lead to increasing levels of domestication and cultivation of these species, further investigation into the reasons for and mechanisms of including species in domestication programs was not part of this research study. However, it would be useful to take a closer look at it in the future, in order to provide more insight into the dynamics that lead to domestication and cultivation of MAP species as well as into processes that could make cultivation beneficial not only from an economic but also from a conservation point of view and provide guidance on how cultivation can actively contribute to the conservation of the wild relatives of cultivated species and their habitats.

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