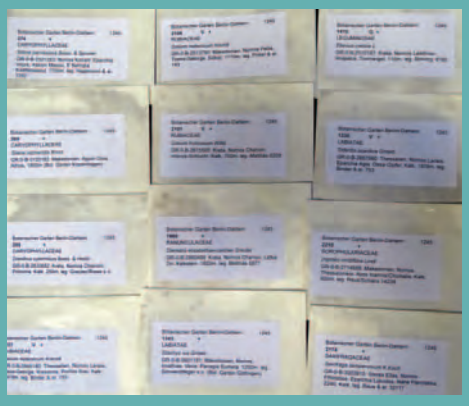
BGCI Technical Review

Purpose and trends in exchange of plant material between botanic gardens



BOTANIC GARDENS CONSERVATION INTERNATIONAL

BGCI Technical Review

Purpose and trends in exchange of plant material between botanic gardens

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Contents

Acknowledgments:

This report grew from an initial study of data from BGCI's PlantSearch database carried out by a team from Cambridge University, UK in 2019. In this respect we gratefully acknowledge the work of: Sam Brockington, Ángela Cano, Brett Wilson, Mar Millan, Peter Atkinson, Penny Coggill, Emma Soh, Margeaux Apple and Jake Powell. In addition, this report includes the results of a questionnaire designed by Ashenafi Ayenew at Addis Ababa University in Ethiopia and Peter Omaswa at Makerere University in Uganda. The report also cites the analysis carried out by these two researchers, to whom we are very grateful. We would also like to thank Ashenafi and Peter's supervisors Professor Sebsebe Demissew and Prof. James Kalema, respectively. This research was supported by the UK Government's Darwin Initiative (project 27-016), which we gratefully acknowledge.

We would also like to thank those who provided case studies for the report and who provided their perspectives on the issues covered.

This report is dedicated to the memory of our colleague and friend Ashenafi Ayenew, who passed away in May 2023

Cover images:

Top left: RBG Kew's Millennium Seed Bank (Suzanne Sharrock)

Top right: Seeds of the threatened Cretan endemic *Tulipa cretica* repatriated from the Gothenburg Botanic Garden, Sweden for *ex situ* conservation at the Balkan Botanic Garden of Kroussia, Greece. (Nikos Krigas)

Left: Alpine plants in a Swiss botanic garden (Suzanne Sharrock)

Left: Collection of seed samples of wild plant species (Krisztián Halász)

Middle: Cambridge University Botanic Garden (Pete Atkinson)

Left bottom: Plant collecting in Tanzania (Costantino Bonomi)

Bottom right: Seed accessions received in Greece from Berlin-Dalhem Botanic Garden, Germany (Nikos Krigas)

The University of Durham Botanic Garden provides information about conifers, including Picea koyamae *(right) grown as part of the International Conifer Conservation Programme (RBGE).*

1. Introduction

Salvia conservation (Yanbo Huang)

There are over 3,000 botanic gardens and arboreta registered around the world, located in 170 countries and their combined living (cultivated) collections represent at least one third of the world's plant species, including over 40 percent of its threatened plants (Mounce *et al*., 2017). Representing a meeting point of conservation, experimentation, education, display, cultivation and germplasm sourcing, botanic gardens are a uniquely powerful resource, serving many purposes.

At the heart of every botanic garden is its plant collection. These collections are an important source of material for collaborative research and practice supporting biodiversity conservation and sustainable development. They serve a particularly key role in species conservation, with some species now persisting only in botanic garden collections. Such Extinct in the Wild (EW) plant species depend for their survival on live propagation by botanic gardens (Smith *et al*., 2023). As well as rare and threatened plant species, gardens also preserve cultivars of cultural, historical and agricultural value and can facilitate experimental testing of taxa in a range of environmental or growth conditions. Plant collections provide material for taxonomic, phylogenetic and pharmaceutical research, as well as material for reintroduction and restoration of wild populations. They also serve an important educational and public awareness role for visitors.

Responsible, legal and effective exchange of plant material and data is essential to support research, conservation and development. Exchange also supports the growth and maintenance of the plant collections themselves and the deployment of their botanical assets. Without such movement, collections exist in isolation and their materials are not available. This can lead to issues such as lack of genetic diversity in collections; vulnerability to loss when species are held in only one or a few collections; underutilisation of genetic diversity due to limited access around the world; lack of exposure of taxa to a variety of cultivation conditions, and therefore lack of experimental data on the habitable range or adaptability of those taxa. Lack of material exchange also presents the practical difficulty that other (e.g. research) institutions cannot obtain the materials they require to conduct their work.

Despite the importance of plant material exchange, and the magnitude of such exchanges for some gardens, there persist numerous constraints which not only limit such movement globally, but also promote a bias towards European and North American involvement. Exchange (particularly international exchange) is governed by a raft of national and international laws and policies and fraught with bureaucracy, which is often demanding to understand and fulfil. Simultaneously, as a result of actual and perceived threats of biopiracy, there can be a lack of trust between providing and receiving parties across the global North-South divide in how material is handled, tracked and used. There are also chronic issues associated with data quality and availability which limit connectivity and material utility.

This review aims to present the existing situation with regard to plant material exchange and inform efforts to improve global connectivity and collection utility across botanic institutions. It provides an overview of the purposes of and trends in botanic material exchange from and between collections and explores the main constraints to such movement and how these might be overcome. It serves also as a demonstration of the ways in which botanic exchange is utilised, and the depth and breadth of its importance. The review also demonstrates how greater connectivity between botanic gardens helps them to become more resilient, better resourced and more able to achieve their missions.

2. Materials and methods

2.1 Principal study methods

The trends and statistics discussed in this review primarily refer to the findings of three studies performed in partnership with BGCI and partly supported by funding from the UK government's Darwin Initiative (Project 27-016). These explore patterns and constraints in demand for and exchange of plant material between botanic gardens and associated institutions.

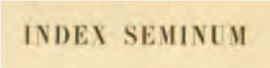
One of the three principal studies in this review derived its data from BGCI's PlantSearch database - a database of taxa represented in the living plant collections of botanic gardens, through which requests for material and information can be made to potential donor institutions. As of March 2023, this database held 1,574,453 collection records, representing 650,080 taxa, across 1,202 institutions. Prior to its relaunch in 2023, BGCI PlantSearch's material request function involved a user submitting an email which went to all holders of a requested taxon, without revealing which collections the request would go to. The collection holders could respond or not, and if in agreement with the request, arrange an exchange. The email request included a short form for the requester to complete, outlining why they were requesting material.

An analysis of data requests from PlantSearch was carried out in 2019 by a team from Cambridge University Botanic Garden[1]. A dataset of exchanges from all the emails received by the BGCI PlantSearch platform during the period 2008-2019 was generated, and using bioinformatic commands in BASH, combined with data processing in Excel, key information from the 17,309 emails was extracted and transferred to a dataframe. This dataframe was enriched with information on geographic location of requesting institutions and type of requests. Further analysis carried out as part of an undergraduate thesis, also addressed the location of donor institutes and the timing of the request. The study aimed to understand which plant taxa were being requested and why, as well as exploring the relationship between plant taxon rarity and endemism with request frequency. It also visualized the network of requestors and potential donors (see Figure 2). One significant limitation of the study was that replies to requests were not recorded, so the outcomes of requests were unknown.

The other two principal studies used for this review (Ayenew *et al*., 2023; Omaswa, 2022, unpublished) focused on the exchange of material between European and African botanical institutions. These studies included on-line surveys and data from *Indices Seminum* and were supported by literature reviews and reports from relevant organisations.

Information in this review is also supplemented with other studies identified by a concise literature review in which search terms such as 'botanic garden exchange', 'botanic material exchange', 'botanic garden transfer' and similar were applied to Google Scholar.

Box 1: What is an *Index Seminum*?



Botanic gardens, arboreta, and research institutions around the world have been exchanging seeds, free of charge, through *Index Seminum* (seed lists or catalogues) for centuries. Participating institutions provide a catalogue of seeds which may be of wild or cultivated origin and circulate this list to other botanical institutions; catalogues are published annually or biennially.

Some of the *Index Seminum* catalogues of the past were quite extensive and were published in booklet format and mailed out. In recent years most participants either provide an online link to their *Index Seminum*, or they distribute it by email.

In 2023, BGCI launched an on-line *Index Seminum* which, for the first time, allows gardens to share their catalogues and make requests for material from multiple institutions through a single platform.

Find out more: Index Seminum | Botanic Gardens Conservation International (bgci.org)

2.2 Case study selection

The PlantSearch data used by Soh (2019) were examined for requests which could serve as suitable case studies. Requests were selected according to request volume and/or to relevance of the intended use of the material as described in the request message. The data were then filtered according to usage class (as labelled by Soh) to identify case studies covering the range of usage examples (conservation, collections, research, education, horticulture, or information). Institutions were contacted at the email addresses used for the requests, as held in the data records. Institution annual reports published at or shortly after the time of the request were also consulted.

Case studies were also sought through outreach via the BGCI newsletter Cultivate, the subscribers to which are mostly botanic garden staff. Email requests were also sent out to BGCI contact groups in Europe, East Africa and Latin America.

For some case studies, garden staff and curators were contacted directly in relation to examples of exchange known to the review authors, particularly those published in BGCI's regular publication *BGjournal*.

[1]**People involved in the BGCI-exchanges project**
Sam Brockington: lead and supervised the project; **Ángela Cano**: generated and enhanced the dataset of email exchanges and overviewed and supported further analyses; **Brett Wilson, Mar Millan, Peter Atkinson**, and **Penny Coggill**: supported data enrichment; **Emma Soh**: participated in the enrichment process and conducted analyses on the resulting dataset as a undergraduate thesis project.

3. Trends in plant material exchange

3.1 Frequency of material exchange

With their long history of collecting and conserving plant diversity, and their on-going focus on collaborative taxonomic research, conservation, restoration and education, the movement and exchange of plant material is central to the work of botanic gardens. Evidence shows that there is considerable demand for, and exchange of plant material within the global botanic garden community. This is mediated either through purpose-built digital platforms such as PlantSearch, or through direct requests, often facilitated by *Indices Seminum*. There were over 17,300 requests made through BGCI's PlantSearch database from 2008 to 2019, with requests in most years averaging around 1,500. Of the 64 institutions surveyed by Ayenew *et al*., (2023) around a third reported exchanging material more than 50 times per year, and another third do so 1-10 times per year.

Figures from individual gardens support these significant levels of exchange, with RBG Kew's Millennium Seed Bank distributing more than 500 seed samples a year and its living collections also providing several hundred samples every year (Case studies 1 and 2). Meanwhile, Bonn Botanic Garden receives an average of 3,600 accession requests through its *Index Seminum* every year and over 600 requests for material from other sources, including PlantSearch. Meise Botanic Garden in Belgium reports that between 500 and 2,000 accessions are shared each year with 1,024 plant specimens being sent out in 2022. Other European botanic gardens also report several hundred exchange interactions per year with studies indicating that those gardens which supply more material also receive more (Ayenew *et al*., 2023). Involvement in exchange pathways is often two-way, indicating that efforts to provide plants are reciprocated, whether directly as repayment or indirectly through greater connectivity across the garden network, or simply that those gardens with the capacity to supply material are also those with the capacity to host it.

Recent patterns of exchange show a steady rate year-on-year with, in some cases, a sudden and considerable change in 2020, likely an artefact of the Covid-19 pandemic when wild collection expeditions were far harder to arrange and when closure to the public may have spurred gardens to overhaul their displays. Conversely, for some collections, capacity to manage exchanges was limited during the pandemic. Opinion among high-ranking garden staff is that exchange rates will probably remain steady, with any future changes likely to be towards a decrease rather than an increase. This is in spite of increasing globalisation and the changing focus of many collections due to shifting environmental conditions. This is likely symptomatic of the limitations to exchange explored in a later section (Section 4: Constraints and Opportunities for Exchange) and a growing preference for wild collections to improve genetic diversity representation in *ex situ* collections.

CASE STUDY: **1. The Millennium Seed Bank**

The Millennium Seed Bank is the world's largest *ex situ* wild seed collection, with 82,556 seed accessions of 36,975 species (39,669 taxa) from 189 countries or territories. Between January 2000 and March 2017, it supplied 11,182 seed samples representing 4,811 taxa to 410 organisations across 57 countries. The majority of supplied seeds were used in research (75%), with smaller portions given for conservation (13%), education (2%) or display (1%); usage of the remainder is unknown. Research utilisation spanned 80 different disciplines from agriculture to archaeology, the former likely the most common considering that demand was highest for commercial species such as *Lotus corniculatus, Trifolium repens, Lolium perenne* (important livestock forage species), *Brassica oleracea, Sorghum arundinaceum* and *Beta vulgaris* (crop ancestors).

Liu *et al*., 2018.

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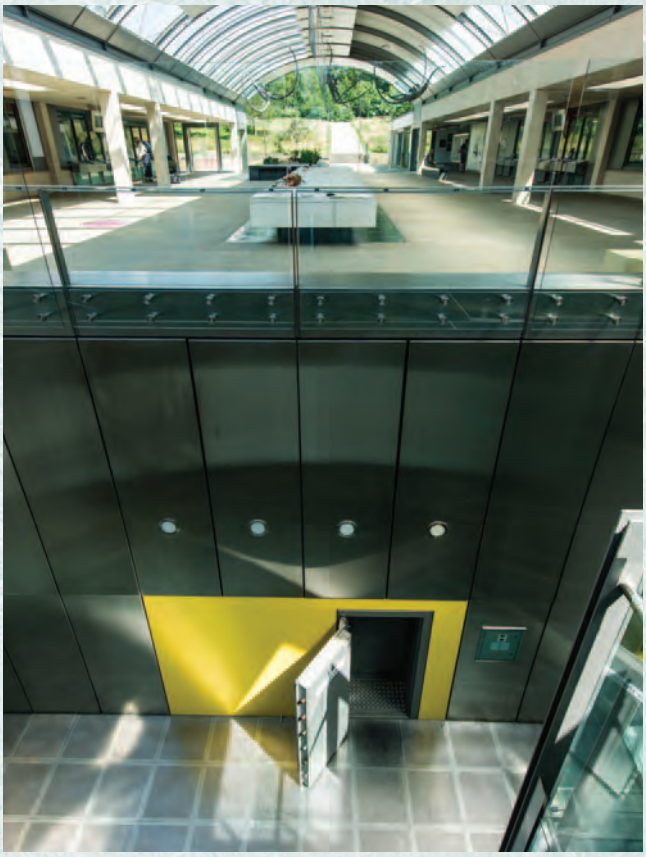


RBG Kew's Millennium Seed Bank (Barney Wilczak)

CASE STUDY:

2. Supplying plant material from the living collections of the Royal Botanic Gardens, Kew

The supply of plant material in various forms (living plants, seeds, bulbs etc.) is an important function of the living collections at Kew.

Data collected over the past 20 years, shows that some 19,656 donations have been made over this period involving a total of 7,516 species from 268 families. The most commonly supplied species is *Populus nigra* subsp. *betulifolia*, (131 shipments) followed by *Nothofagus cunninghamii* (44 shipments). The most commonly supplied families are Araceae, Arecaceae and Rosaceae (Figures A and B)

Plant collections at RBG Kew

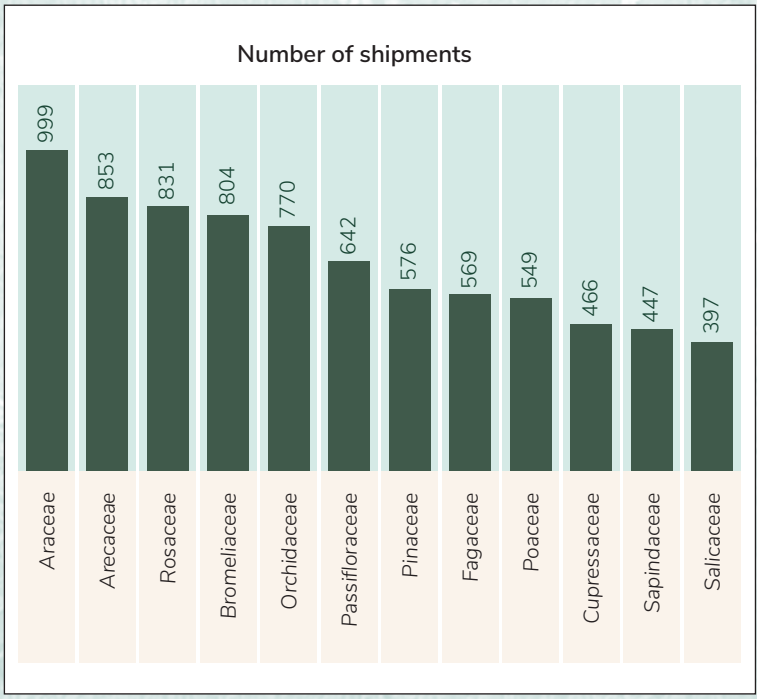


Figure A: Most commonly supplied plant families from 2000-2022.

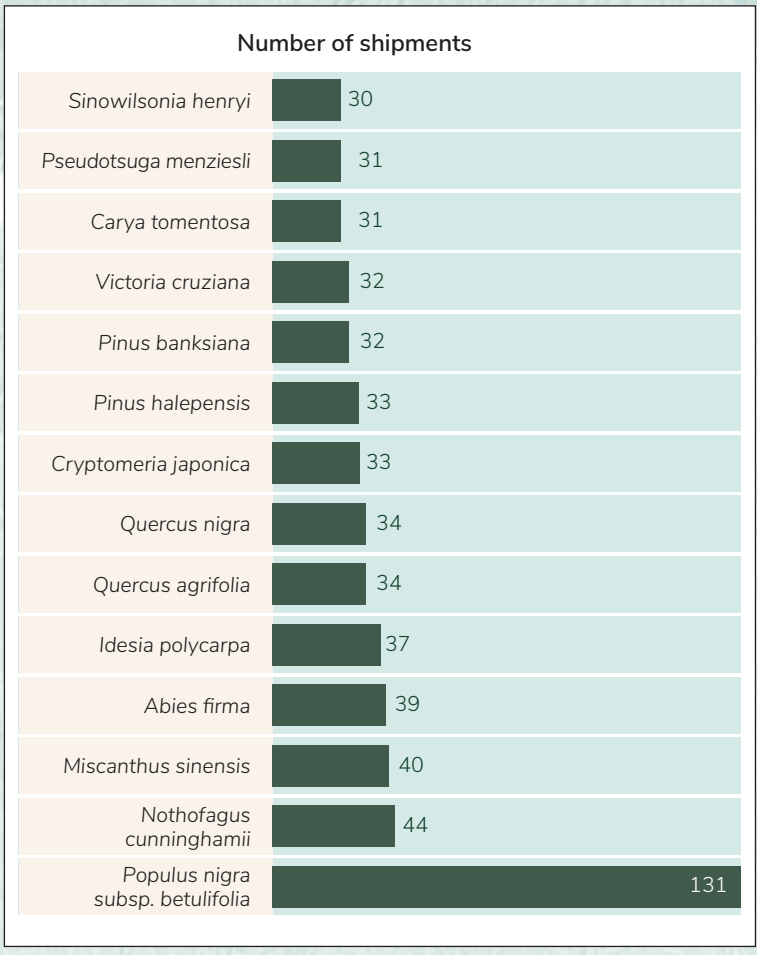


Figure B: Most commonly supplied plant species, 2000-2022

CASE STUDY: **2. Contd.**

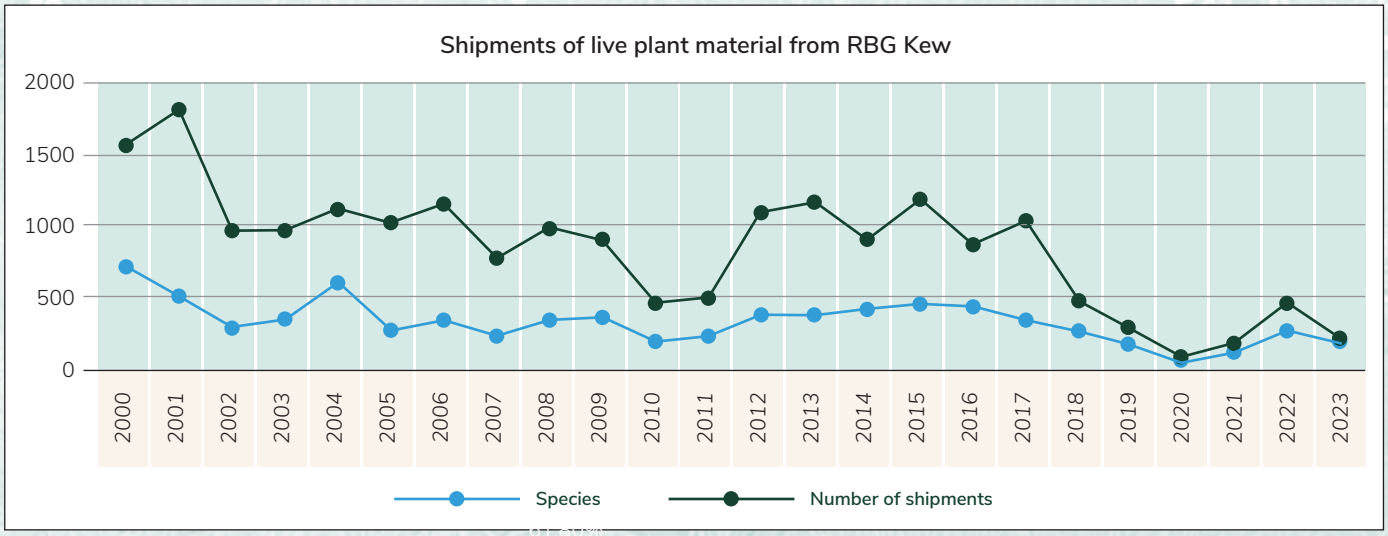


Figure C: Number of species distributed and shipments made per year

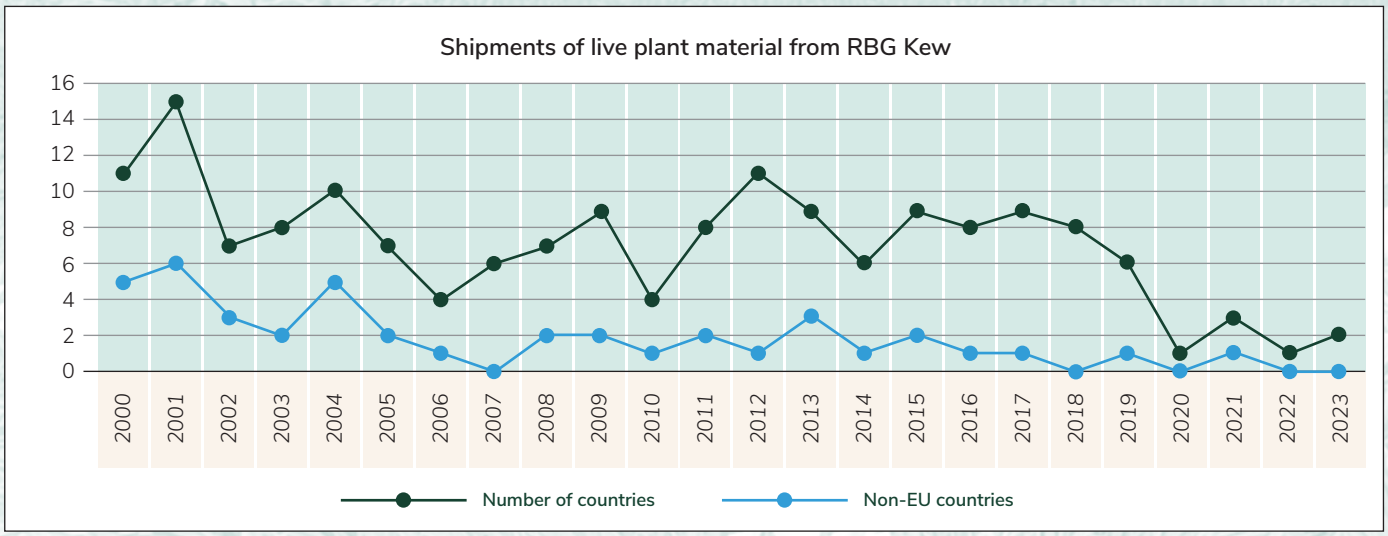


Figure D: No. of countries supplied to (total and non-European), 2000-2022

The number of shipments per year has reduced over the past 20 years, from a maximum of 1,812 shipments in 2001 to around 400 in 2022. A dip was seen in 2010 and 2011, perhaps related to the adoption of the Nagoya Protocol and a lack of clarity around exchange processes at this time. Low figures for 2020 and 2021 are likely due to the impacts of Covid, although shipment rates were already falling from 2017 onwards – Figure C.

The number of different countries material is supplied to averages around 10, with the number falling significantly since 2019. The majority of supply is to European countries, but materials have also been supplied regularly to Russia, China and the USA, with other non-European countries receiving material occasionally (Figure D).

Material is generally supplied as plants (71% of shipments), but other plant parts are also used for supply – Figure E.

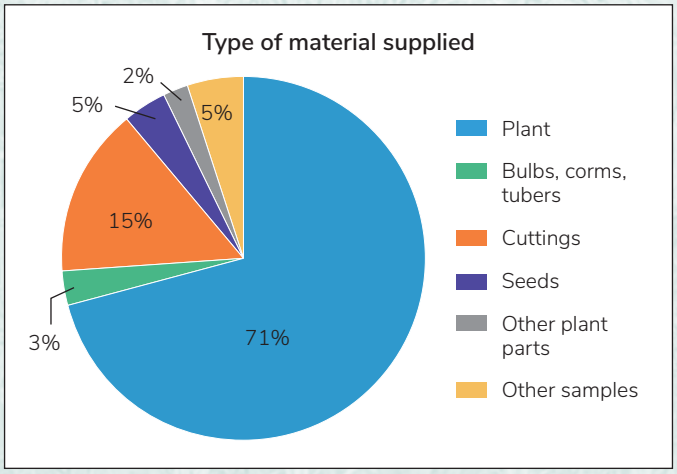


Figure E: Type of material supplied, 2000 – 2022

CASE STUDY:

3 Material exchange at Cambridge University Botanic Garden

Cambridge University Botanic Garden (CUBG) is positioned at the centre of one of the largest concentrations of researchers worldwide, and supporting third party demands for plant material is central to our mission and identity. External stakeholders can request a range of support including material transfers from the garden's documented living collections. We record and document all material exchanges to ensure that we can deal with requests in a timely manner, meet legal obligations controlling collections use, respond strategically to collection use, and collect information to communicate to internal and external stakeholders, and funders.

All requests, including named species and accessions, are entered into CUBG's collections database regardless of whether the request is then fulfilled. This is vital because there are many valid reasons why research requests cannot be fulfilled, yet it is important to record interest, as testament to a collection's perceived value. If a request can be fulfilled, a "Project Description Form" is sent out that asks the user to provide a description of the intended use. Requests are not fulfilled unless this information is received in advance. The careful databasing of these requests allows us to analyse collections utilisation over-time, as well as exploring how users are interacting with our collections, how we can encourage better interaction, and how we can measure our performance in enabling the use of our collections over time.

We distinguish 5 different types of utilisation:

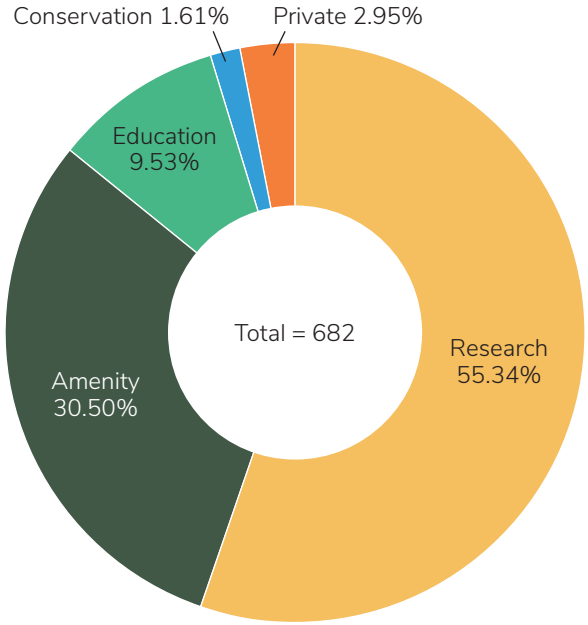
1. **Research** - includes material and/or access to the environment / associated biodiversity to support a specific research project.

2. **Amenity** - includes material provided to another botanical institution for the purposes of cultivation and display, material provided through the seed exchange program *Index Seminum* and material provided to holders of UK National Plant Collections.

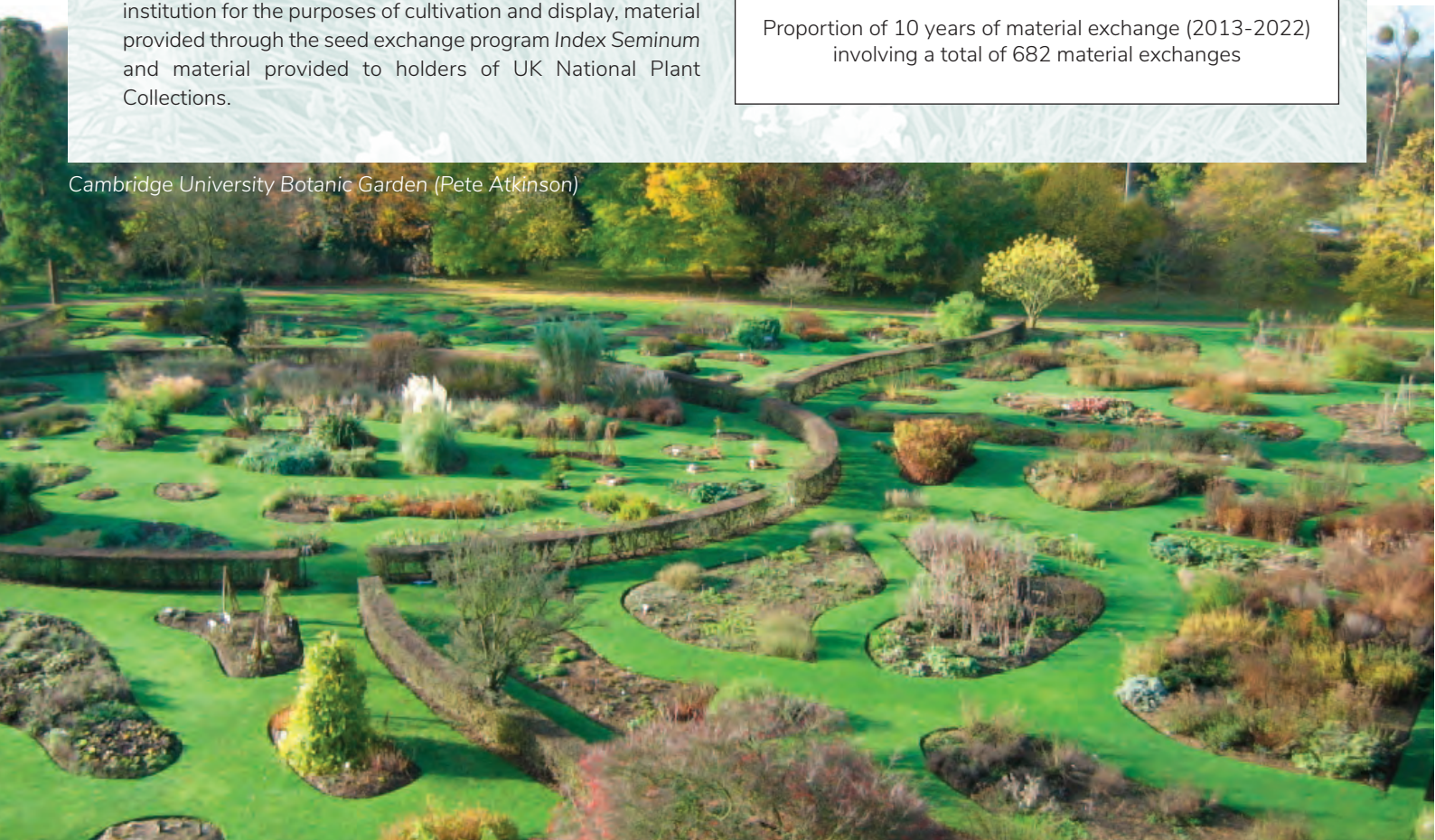
3. **Education** - includes material provided to support learning programs, e.g., material used in CUBG Educational Courses or where teaching material is provided to educational institutions.

4 **Conservation** includes material provided to support ex situ conservation horticulture and reintroduction programmes or other conservation-driven projects.

5. **Private** - includes material and/or access provided to support commercial activity, e.g., collecting plant material for use in the making of special edition gins by local gin makers or material and/or access provided to support National Plant Collections or other private collectors.



Proportion of 10 years of material exchange (2013-2022) involving a total of 682 material exchanges



Cambridge University Botanic Garden (Pete Atkinson)

CASE STUDY: 3. **Contd.**

Patterns of performance have been explored using a dataset of 682 fulfilled material exchanges over the past 10 years (2013-2023). In total, 2,275 accessions were exchanged, representing 21% of the current collection (10,774 accessions) (i.e. a fifth of our total accessions was transferred in a 10 year period). This equates to 1,981 taxa, representing 24% of a total diversity at taxon level. At the level of genus, we exchanged 43% of all the genera in our collection (out of a total of 2,094). At the level of family, we exchanged 70% of all the families in our collection (326 families in total). This examination of the extent of material exchanges at different taxonomic levels emphasises the demand for the full taxonomic breadth of our collections.

The figures below illustrate changes in material supply over time, by utilisation type, particularly highlighting the impact of Covid-19 in 2020 and 2021 (both in terms of demand and our ability to supply).

During the most recent period, Nov 2022-April 2023, we have received 73 material requests in total, of which 43 were fulfilled, and 30 were unfulfilled. Of these 73 requests, 36 were from BGCI PlantSearch, 4 were from our own portal, and the remaining 33 came through other routes. Of the unfulfilled requests, reasons for lack of material transfer were mostly due to unavailability of material (e.g. wrong season), or no response from researchers when contacted. BGCI PlantSearch requests resulted in 14 fulfilled requests to 7 countries (incl. UK). Of the 29 fulfilled requests that were not through PlantSearch, we supplied material to 3 countries (UK, US, Ireland), with 14 requests specific to the University of Cambridge.

Case study provided by Sam Brockington with data analysis by Margeaux Apple, Ángela Cano and Jake Powell.

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3.2: Geographic trends in exchange

Data from all sources confirm the considerable concentration of exchanges within and between North America (particularly the USA) and Europe, both in terms of material sent and material requested. Germany, Italy and the USA are the nations most commonly involved in international transfers, both sending and receiving, and within Europe, there is a tendency to exchange with other European institutions. This concentration in the North is partly explained by a greater density of botanic gardens in these regions but it is also here that the highest rates of material transfer per garden are found (around two thirds of those surveyed exchange material more than 10 times per year) (Ayenew et *al*., 2023). This may be due to ease of transport to nearby collections or due to a greater capacity for exchange.

Further analysis of data on the exchange of plant material from seventeen institutional *Index Seminum* records indicated that the exchange of plant material between European and African institutions occurs very rarely (Figure 1). It accounted for less than 1% (0.49%) of the total proportion of material exchanged at the institutions concerned. Only four African countries were involved in material exchange; these were Algeria, Egypt, South Africa and Tunisia. Plant material exchange occurred most frequently among European institutions, with 77% of the plant material exchanged being within Europe. Plant material exchange between European and non-European institutions accounted for 22.2% of the material exchanged (Ayenew et *al*., 2023).

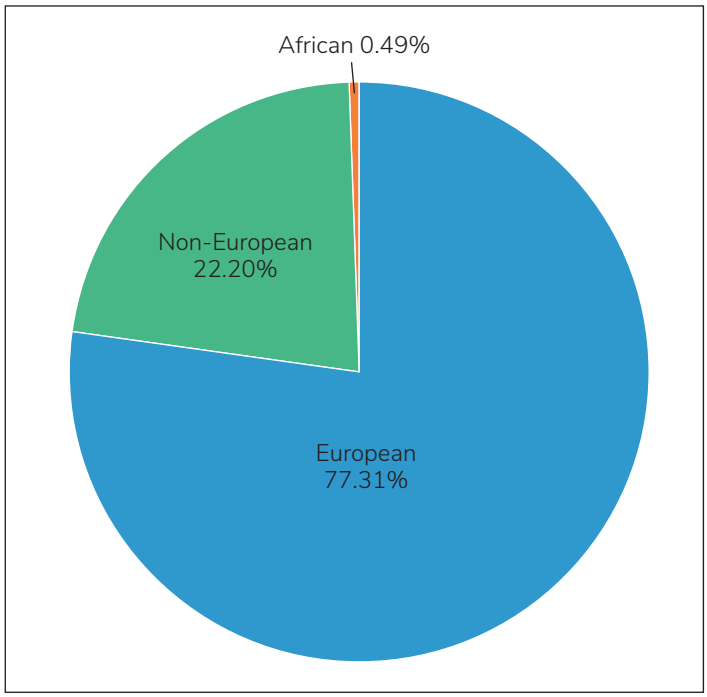


Figure 1: Analysis of data on the geographical exchange of plant material from seventeen institutional Index Seminum *records.*

The concentration of exchanges between northern countries is also likely to be closely linked to the heavy northern bias in the species known to be present in the global botanic network, as represented in digital exchange platforms. For example, 93% of taxa recorded in PlantSearch come from temperate regions (Mounce et *al*., 2017) and the vast majority of gardens that produce an *Index Seminum* catalogue are located in northern countries. It is therefore unsurprising that temperate taxa are much more widely requested through these platforms than tropical species.

The bias in species available for exchange, compounded by a greater concentration of institutions in temperate Northern countries results in a greater availability of plants suited to temperate environments. Temperate species are not likely to be of interest to gardens in warmer areas, the majority of which, being located in areas of higher biodiversity, tend to focus their research and conservation efforts on native flora rather than exotic species.

An exception to this does exist in Asia, where PlantSearch requests show a significant demand from India and East Asian countries, particularly China, for materials for research purposes This could be related to overall economic growth in these countries that provides more opportunities for plant research to be undertaken (Soh, 2019). Disproportionately little material is available from this region, possibly due to national Access and Benefit Sharing (ABS) regulations (or lack of clear guidance on this) that restrict the export of genetic resources from these countries.

Figure 2 provides a representation of the network of research request movement between continents using PlantSearch data, where the width of lines corresponds to the number of requests moving from one continent to another, scaled by Number of requests/10,000. Line colour corresponds to the continent of the request origin. (From Soh, 2019).

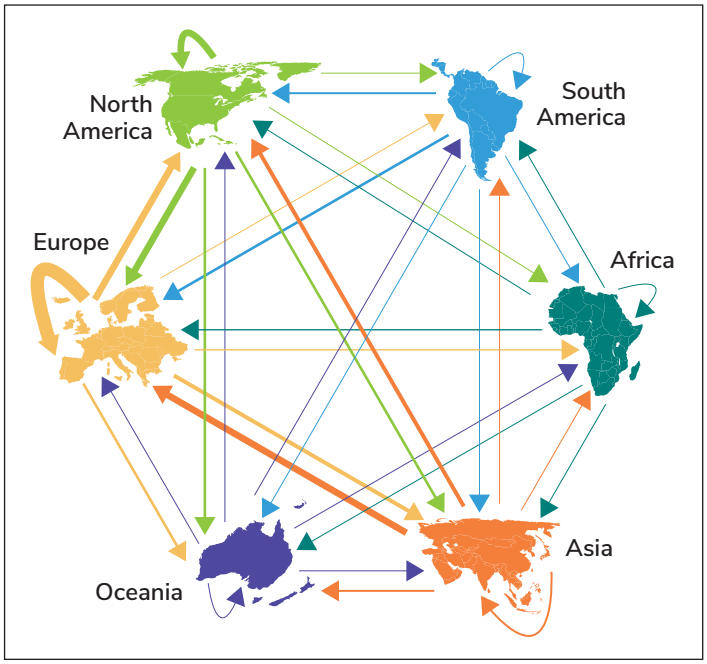


Figure 2: Continental network of requests for material for research purposes made through PlantSearch between 2008 to 2019

The concentration of exchange requests and supply in North America and Europe is also demonstrated in Figures 3 and 4 from Missouri Botanical Garden and Figure 5 from Cambridge University, as well as Case Study 2.

Survey results from Ayenew et *al*. (2023) indicate that European institutions export around as much material beyond Europe as they receive from outside the continent, if not slightly more: Europe is therefore neither a net plant source nor net sink. Results for North America are less well quantified but appear similar. This indicates that material is not commonly crossing the global North-South divide in spite of the North holding diverse, globally-sourced historical collections and having important horticultural expertise in managing a diverse range of species.

There have been calls for Global North institutions to utilise their greater wealth and resources to fund and support the growth of botanic collections in areas of high biodiversity, rather than transferring material to their home institutions. This could help to ameliorate uneven global capacity and gaps in plant ex *situ* representation. Increasingly this is the model being followed, with many of the larger European and North America gardens establishing in-country conservation sites and focussing on local capacity building initiatives. The ultimate goal is the establishment of independent, economically-sustainable gardens in underrepresented areas and their integration (functional, informational and financial) into the global botanic garden network. (Case Study 4).

Newly-arrived plant material in Hawaii (Ruth Aguraiuja)

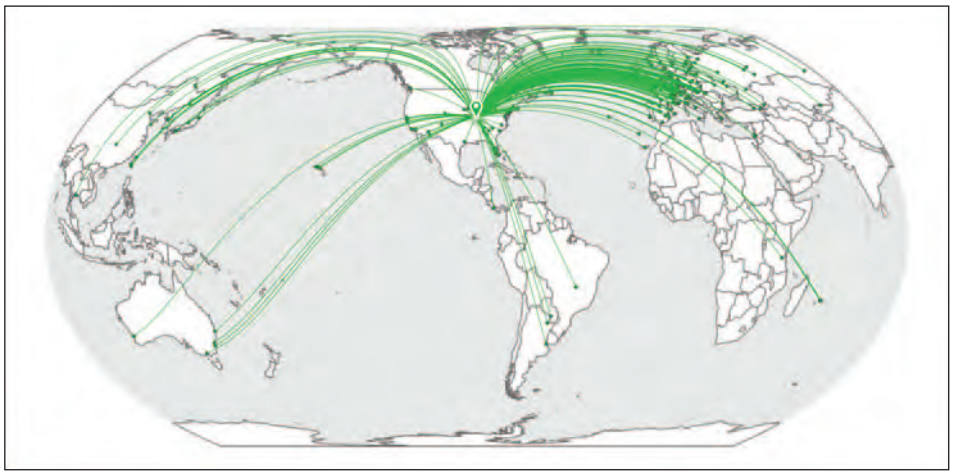


Figure 3: Location of institutions supplying material to Missouri Botanical Garden over the past 10 years. This represents 2,065 transfers of 7,856 accessions coming from 252 institutions in 52 countries.

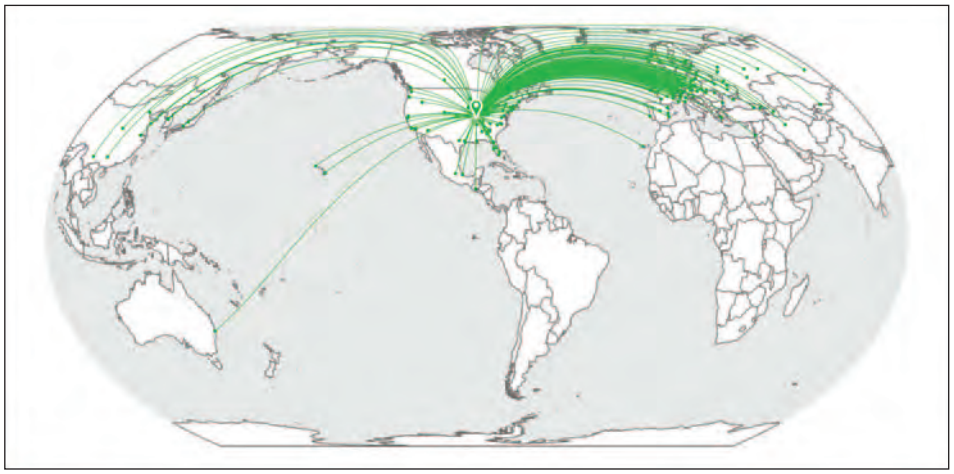


Figure 4: Location of institutions receiving material from Missouri Botanical Garden over the past 10 years. This represents 550 transfers to 239 institutions in 46 countries.

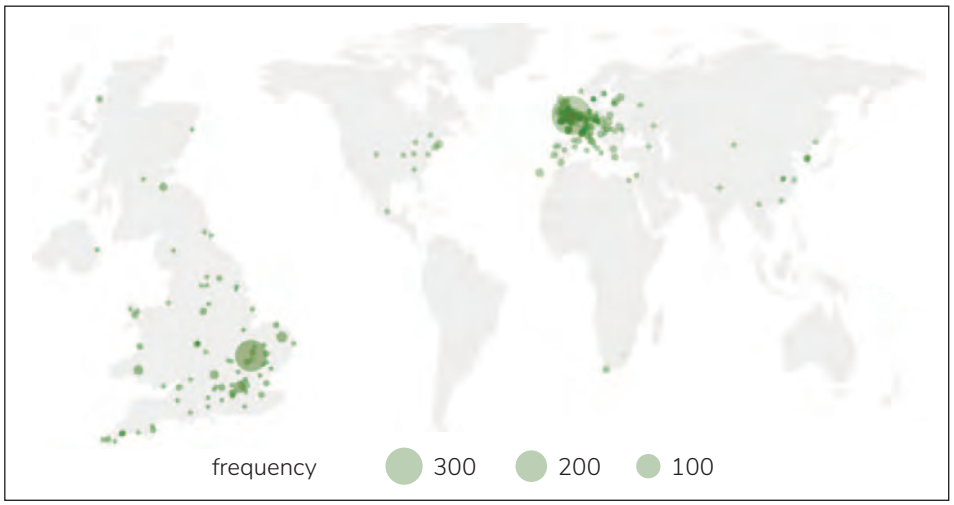


Figure 5: Between the years 2013-2022, Cambridge University Botanic Garden sent material to 35 different countries. On the right is a world map depicting the frequency of the exchanges to different locations as a bubble plot. where the size of the bubbles represents the frequency of the destination in material exchanges.

CASE STUDY: **4: Kisanto Botanic Garden rehabilitation**

Kisanto Botanic Garden, in the Democratic Republic of Congo, was a regionally important institution for the first half the 20th Century, its scale and scientific activity peaking between 1946 and 1960. However, the garden fell into disrepair under decades of dictatorial rule culminating in a civil war. In 2004, the European Union, the World Wildlife Fund and the Belgium National Botanic Garden (now Meise Botanic Garden) agreed to fund and support a rehabilitation programme for Kisanto. Within a few years, buildings were again operational (including new shop, guesthouse and conference room), trails were re-opened and collections were built up again. Meise Botanic Garden sent a sizeable set of cacti to stock the restored greenhouse, likely becoming the largest and best-documented Cactaceae collection in Africa at the time.

(Lanata, 2007)

3.3: Mechanisms of exchange

The exchange of plant material and data is essential to support collaborative research and sustainable development. However, it is essential that any such exchange is carried out in a way that is responsible, legal and safe.

The exchange of plant material by botanical institutions is governed by the principles of the Convention on Biological Diversity (CBD) and particularly the Access and Benefit Sharing regulations of the Nagoya Protocol (CBD Art. 15 and Nagoya Protocol Art. 5-9). Material exchange should be covered by Material Transfer Agreements (MTAs) that stipulate how plant material can be used and how any benefits derived from the use of such material should be shared.

As a collective response of botanic gardens to CBD provisions, the International Plant Exchange Network (IPEN) was established in 2002. It is a registration system for botanic gardens worldwide with a Code of Conduct that ensures that exchange of plant genetic resources by members is in compliance with the CBD. The objective of IPEN is to foster the non-commercial use of plant resources, and to provide a sound basis for cooperation, documentation, transparency and communication, taking into account the concerns and needs of both the providers and the users of genetic resources. Over 200 gardens have so far become members of IPEN, the vast majority being European gardens, but increasingly, gardens from outside Europe are also joining.

Responsible exchange also requires that, where necessary, botanic gardens comply with the obligations and permit requirements of the Convention on International Trade of Endangered Species of Wild Fauna and Flora (CITES) and have a good understanding of which plant species are listed on the CITES Appendices. Furthermore, responsible exchange also requires gardens to follow best practices in biosecurity and adopt phytosanitary standards for all material that enters and leaves their collections.

Given the importance of ensuring that plant exchange is carried out in a responsible manner, it is encouraging that most of the respondents surveyed by Ayenew et *al*., reported using MTAs or other types of agreement to obtain and provide plant material. Free access without formal agreement was granted in some cases, but it is likely that such exchange was between European countries, many of which do not require access permits. The wide variety of agreements in use to exchange plant material is symptomatic of differences in national and institutional policy, complicating networking efforts and collaboration. Indeed, institutional guidelines are more common than national legal frameworks in Africa (Ayenew et *al*., 2023), indicating a placement of onus and initiative on the institutions rather than national authorities. Standardisation, in a manner compliant with global ABS instruments could help to facilitate exchange, but such a response must be careful in its implementation so as not to merely introduce yet another exchange mechanism and must also allow for flexibility in the face of differing national frameworks.

Being able to track the use of, and future exchanges of material provided, is an important element in building trust between providers and users of plant resources. Most institutions utilise tracking measures to monitor and record their exchanges, though there remains a sizeable minority who do not. Digital spreadsheets or databases are widely used as an easy means of recording details of material sent and received. Participation in IPEN, whereby accessions are allocated an IPEN number for tracking purposes, is restricted largely to Europe, and is so far underutilised on the global stage. Paper records remain disproportionately popular in Africa, a result of lower budgets and less technological capacity, but there appears to be enthusiasm for digitisation. There is a large capacity for improvement in tracking to boost global confidence in plant material exchange.

Some examples of botanic garden data management systems that allow tracking of accessions are provided on the BGCI website: Implementing Access and Benefit Sharing | Botanic Gardens Conservation International (bgci.org)

Box 2: The International Plant Exchange Network (IPEN)

IPEN facilitates ABS-compliant non-commercial use and transfer of plant material by its members. To join IPEN, botanic gardens must sign and implement the IPEN Code of Conduct, a harmonized policy that clearly defines the rules for acquisition, maintenance, and supply of plant material as well as sharing the benefits from its use. When acquiring new material from outside IPEN, an IPEN garden assigns an "IPEN number" to each accession that will be exchanged within the network. That number stays with the accession as it moves within the network. The IPEN number encodes information on the country of origin and any restrictions on use, replacing the need for material transfer agreements (MTAs) within the network. The allocation of IPEN numbers also allows the tracking of material as it is exchanged between member gardens.

For more information: The International Plant Exchange Network | Botanic Gardens Conservation International (bgci.org)

3.4: Type of material exchanged

Seeds are by far the most common form of material exchanged due to a greater ease of preparation and transport, and lower biosecurity risk compared to other types of plant material. Moreover, seed catalogues, *indices seminum*, have long been the principal way to advertise plant availability between gardens. However, two fifths of botanic institutions surveyed by Ayenew also trade living plant material and there is a growing demand for DNA samples for phylogenetic and other types of research. Many institutions engage in the exchange of herbarium specimens, and some may also exchange plant extracts, such as oils, gums and resins. The type of material exchanged may be related to the institution providing the samples. For example, 71% of the shipments made from RBG Kew's living collection between 2000 and 2022 were live plants, while seeds were exclusively supplied by its Millennium Seed Bank.

In order to maintain the value of exchanged material for conservation and research, it is essential that it is accompanied by the necessary documentation. This should include basic passport data, such as taxon name (local and/or scientific) and provenance data (location and date of wild collection or cultivation), as well as, if relevant, copies of original collection permits and transfer and use agreements, so that any ABS obligations and restrictions can be adhered to. Despite their importance, such data are not always automatically sent during material exchanges and may be lacking if the recipient institution fails to request it. Greater care is clearly needed in this regard, and the establishment of a standardised exchange policy could perhaps reduce the risk of miscommunication. Associated traditional knowledge may also be exchanged with the living plant material, but it is important to recognise that, unlike passport data, this is considered a resource distinct from the plants to which it may refer and has a standalone value.

3.5: Preferences across taxa

Although there is enormous diversity in the plants requested and exchanged between institutions, for a whole host of purposes (see Section 3.6), there remain patterns of preference.

The review of requests made through PlantSearch revealed, somewhat surprisingly, that overall, there is a greater demand for cultivars than for natural species (Soh, 2019). Cultivars may be broadly preferred because they have been developed for specific purposes and have established utility. Indeed, the six species most commonly supplied by the Millennium Seed Bank between 2000 and 2017 have agricultural utility either as livestock forage or as crops and crop ancestors (see Case Study 1). Their economic value also provides greater incentive for research, the most common utilisation of exchanged material. An alternative explanation is simply that cultivars cannot be obtained from the wild so there is greater reliance on garden collections as a source of material, although nurseries, horticulturalists and forestry institutions can also provide this.


(Barney Wilczak)


Seed samples from Gothenburg Botanic Garden (Nikos Krigas)

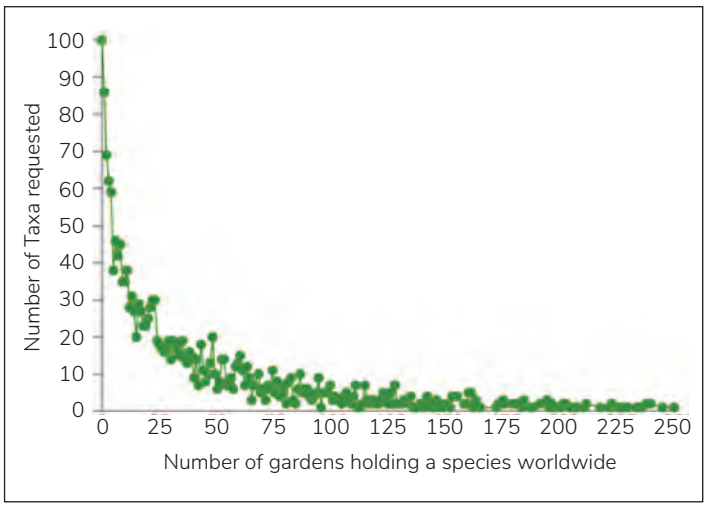


Figure 6: Graph depicting the horticultural rarity of taxa requested by external stakeholders from the University of Cambridge Botanic Garden (Brockington et al., pers comm)

Analysis of demand for taxa from the Cambridge University Botanic Garden shows a strong skew towards taxa that are horticulturally rare in global collections (Figure 6)

Where material is requested explicitly for conservation purposes or to expand living collections, the focus is on species rather than cultivars. Given that conservation actions require plants of local provenance, these are best collected locally from the wild rather than acquired through exchange with other collections. This is no doubt the reason that rarer taxa are not in higher demand despite their conservation value. In fact, the greatest influence on demand versus rarity in collections may be statistical: the majority of plants requested are neither the rarest nor the most common.

In the same vein, endemic species are under-represented in exchange requests compared to their proportion in global diversity, despite being of particular conservation concern. This is of note considering that many endemic species are likely undescribed and endemic biodiversity is therefore underestimated. Predictably, endemic species are in greater demand among material requests for the sake of conservation; a greater proportion of southern or tropical taxa being requested are endemic, suggesting that these taxa are sought over other tropical species because of their conservation value. Overall, there is a greater proportion of endemic species being cultivated than being requested, indicating that gardens cultivate endemic species for conservation purposes, but there is no need or demand to exchange these.

3.6: Utilisation of material

Requests for material show an enormous range of intended uses. While research and collection development are by far the most common reasons for requesting material through PlantSearch, conservation, horticulture and education are also cited (Figure 7).

Results of the survey by Omaswa show a different pattern of usage, with conservation, research and education being the most commonly cited purposes for plant material exchange (Figure 8).

This difference can perhaps be explained by the fact that the term 'collections' was not provided as an option by Omaswa, and collection establishment and enhancement could be considered to be mainly for conservation or educational purposes. The difference in intended use of material may also reflect the utilisation of PlantSearch by people beyond the botanic garden community, especially researchers from Universities. More unusual requests received through PlantSearch include material for restaurant supplies, zoo animal fodder, filming for nature documentaries and diplomatic symbolism (Case Study 5). Intended purposes are rarely mutually exclusive, with research feeding conservation strategies, displays assisting public awareness, cultivar development supporting sustainable industry and collections expansion serving to build repositories for all of these uses.

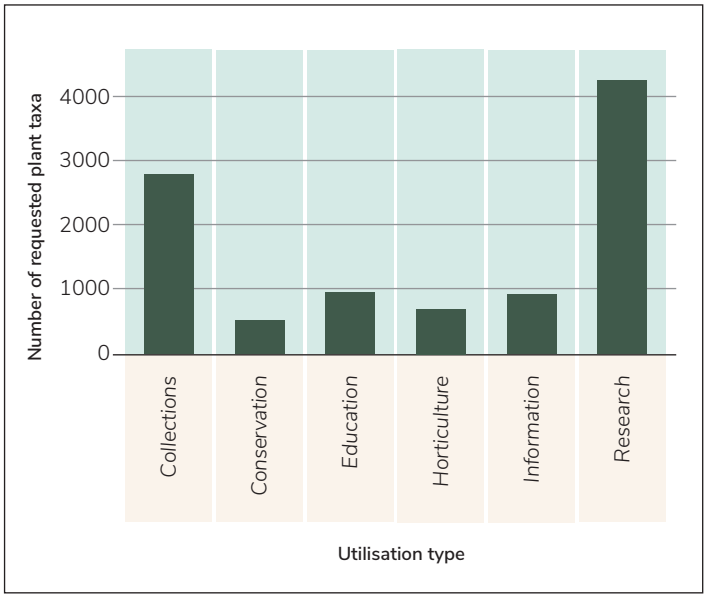
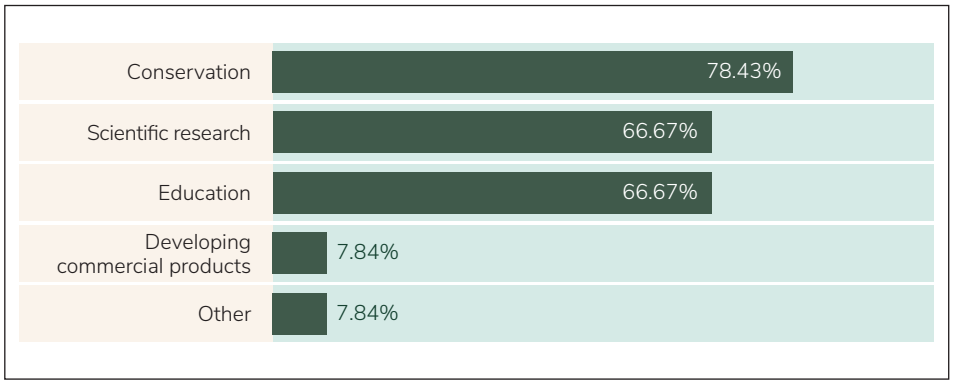


Figure 7: Number of requests for different utilisation types made through PlantSearch between 2008-2019 (Soh, 2019).

Figure 8: The purpose of plant material exchanges with foreign institutions- Results of a survey of 64 botanical institutions (Omaswa 2022).

Cultivation of conifers at RBGE nursery for ex situ conservation planting (RBGE)



The Millennium Seed Bank (Suzanne Sharrock)

CASE STUDY: **5: The diverse uses of plants in collections**

Demand for material from botanic gardens comes from a great diversity of needs. PlantSearch records show that a restaurant in France requested material of *Lilium* species for their gardens which they use to build awareness and as a source of fresh food. Toronto Zoo and Rotterdam Zoo requested plants as fodder for endangered Lord Howe Island stick insects and okapis respectively. There have been repeated requests for examples of plants, particularly in flower, held in the global botanic garden network to be filmed for BBC Earth documentaries.

One of the more curious demonstrations of the diverse value of botanic exchange involves Shanghai Botanic Garden's plants as symbolic tools for diplomacy. Shanghai opened its Penjing Garden in 1978, developed from the work of Japanese immigrants and the accumulation of materials from schools along the Yangtze River delta which resident Penjing masters would gradually mould into a unique 'Hai-Pai' style. The Garden provided Penjing to the Montreal International Horticultural Exhibition in 1980, donating them to the city where they found a more permanent place in Montreal Botanic Garden. This donation set the stage for further exchange, not just of plants but also expertise in the running of the botanic garden, a connection which supported Montreal's naming as a sister city to Shanghai in 1985. Similarly, upon becoming a sister city to Shanghai in 1973, a delegation from Yokohama visited Longhua Nursery (predecessor to Shanghai Botanic Garden) and donated 'Somei-Yoshino' cherry blossoms; this became a commemorative tree for diplomatic ties between the cities, with 138 trees presented by the Japanese side in total. Cherry blossoms, orchids and peonies were frequently exchanged in 1981, 1984 and 1988 as a symbol of connection, this period of diplomatic restoration culminating in the unveiling of the Sino-Japanese Cherry Blossom Friendly Forest in Shanghai Botanic Garden in 1997.

3.6.1: Collection establishment and enhancement

Material exchange provides an accessible and fast method of acquiring material to establish or grow a collection, or to acquire specific taxa in line with an existing collection. Amassing samples for the establishment of new collections, or for their meaningful expansion, demands the fast acquisition of many plants in a short timeframe (Case Studies 4 and 6); According to Soh (2019) around a third of material requests are for establishment, expansion or maintenance of collections as a primary purpose (Figure 7).

By obtaining material already in *ex situ* collections, the fieldwork required to obtain wild germplasm is effectively outsourced to the donating institution(s), reducing the costs of acquisition. Requests for material can be made across the botanic garden network, diluting effort and drawing from the sum global availability of deliverable material. These methods are especially useful where an otherwise prohibitively large number of accessions are to be sourced rapidly (e.g. when establishing a new bed or collection), or where only specific taxa are required and wild collection would be disproportionately costly (e.g. replacing lost accessions). It is also a common (and recommended) strategy to provide duplicate material of an accession to other gardens to establish replicates in case the original plant is lost (Case studies 7, 8 and 9).


(Cambridge University Botanic Garden)


(Suzanne Sharrock)

CASE STUDY:

6: Missouri Botanic Garden's entrance landscaping project

Missouri Botanic Garden is redeveloping its entrance alongside the construction of a new visitor centre. The project involves acquiring and planting some 30,500 individuals of 332 different taxa across the 14,000m^2 landscape area. This has demanded a multifaceted approach as private nurseries offer only a restricted range of species and wild collection is too resource-intensive to be relied upon completely. With a focus on active species conservation and research, species were chosen around two themes: woodland biomes and dry grassland biomes. Plants were also selected to illustrate the garden's programs in many regions of the world and to introduce visitors to the scope of this work from the outset of their visit. Having developed a list of plants wanted for the project, Missouri Botanic Garden sent out a request to those botanic gardens with which it already regularly trades material and across *Index Seminum*, to a good response: 144 taxa were obtained in this way from 57 institutions. The resulting plantings are a combination of wild-collected, privately-sourced and garden-exchanged materials. Over time, plants of lesser research or conservation significance (e.g. from commercial nurseries) will be strategically replaced with plants of higher collections value, sourced through in-country partnerships. In this way, development of the collection remains directly tied to supporting conservation, research and capacity building. Propagation and cultivation data is shared with partners in the country of origin to support *in situ* conservation, and the advanced permissions tracking system ensures compliance with the CBD and the wishes of those who share material.

(pers comm A Wyatt/Missouri BG)

Planting In Entrance Landscape South: (Kayla Flamm)

CASE STUDY:

7: The Plant Collecting Collaborative

The Plant Collecting Collaborative is a group of mainly North American botanic gardens which collaborate in wild plant acquisition expeditions, combining their resources to provide funding, find in-country contacts and assist in the movement of materials. This grants multiple institutions the capacity for wild material collection even in areas where there are few or no local botanic gardens and allows them to obtain taxa which are not available in the existing exchange network. Under this programme, the representatives are able to acquire seed for their own institutions in the field or, post-expedition, through transfer. Material is shared quite freely across the Collaborative, whether this is seed collected during the expedition or plants grown out from that seed and shared once propagated. This collaboration, then, provides gardens with greater access to wild material through resource pooling and subsequent distribution of acquired germplasm across member institutions.

(pers comm C Newlander/Denver BG)

Above: Entrance plants growing in MBG's nursery (Andrew Wyatt)

CASE STUDY:

8: Marie Selby Botanic Garden's replacement *Scadoxus* progeny

In 1997, Denver Botanic Gardens received germplasm of *Scadoxus cinnibarinus* from Marie Selby Botanic Garden. Some 20 years later, Missouri Botanic Garden requested germplasm of that species from Denver for their programme on displaying and conserving tropical species. The request spurred Denver to revisit and improve their data on the taxon by contacting Marie Selby Botanic Garden, who revealed that their original plant was now sickly. The latter therefore requested the same material from Denver, thus acquiring as a replacement for their dying *Scadoxus cinnibarinus* the clonal progeny of that very individual. Denver Botanic Gardens has also been exchanging material from its rock alpine collection with other American gardens to establish duplicates both for the safeguarding of those species and to request replacement material should their own accessions perish. Benefits are mutual: Denver ensures accessions are backed-up while other gardens acquire further specimens for their collections.

(*pers comm* C Newlander/Denver BG)

Scadoxus cinnabarinus (Ken Kuhar)

CASE STUDY:

9: Hortus Botanicus Amsterdam's post-Brexit South African material exchange

Hortus Botanicus Amsterdam recently transferred material to the National Botanic Garden of Wales, consisting of 153 plants (representing 127 species) of mostly South African origin. The exchange was performed to establish duplicates of these species, some of which are rare, between multiple institutions and countries. At the time of writing, the material is currently in quarantine in the Welsh recipient garden, after which some material will remain in the collection while some will be transferred to Cambridge Botanic Garden and to the Royal Botanic Gardens Kew. This was likely the first post-Brexit international exchange with a British institution, presenting an extra bureaucratic challenge as the new processes were designed for commercial, rather than non-profit, import. Phytosanitary inspections were required for both export and import and the plants have to remain in a quarantine greenhouse for one year before being released.

(*pers comm* H Veldman/HB Amsterdam)

Nursery at NBG Wales (Suzanne Sharrock)

3.6.2: Research

Research is probably the most common primary purpose for requesting botanic materials (Figure 7). Exchange spreads taxa across a wider geographic range, thus enabling the study of their growth patterns and tolerances to different environmental conditions – information which is growing in importance in the face of changing climates. It also greatly improves sample availability and reduces geo-economic inequities in research capacity, as institutions are not dependent on the availability of samples from their own or nearby facilities. A very wide range of research activities are supported by material from botanic garden collections, with for example, 75% of seed exchanges from the Millennium Seed Bank being requested for research purposes across 80 different disciplines. This point is further illustrated in Case Study 10, while Case Study 11 highlights the particular importance of collections (including herbaria) in supporting phylogenetic research.

CASE STUDY: **10: Selected Missouri Botanical Garden exchanges for research**

Missouri Botanical Garden provided material from 143 species for 19 projects (all but 5 for research) in 2019, and 147 species for 13 research projects in 2022. The foci of research projects using supplied specimens included: an Iranian doctoral study in Lithospermeae physiological and biochemical traits; cytotoxic treatment for epithelial ovarian cancer in Asian women in Hong Kong; a Swiss study on biosynthesis of vitamin E in plants; a Ukrainian study on the growth patterns of *Quercus* trees; DNA molecular analysis of cultivated Callery pear conducted in Tennessee, USA; and the provision of chestnut galls to a project in New York State, USA, studying the Asian chestnut gall wasp and its biocontrol. All researchers are asked to sign Material Supply agreements and no material is shared that would be counter to agreements with those who originally provided material.

(pers. comm. A. Wyatt/Missouri Botanical Garden)

CASE STUDY: **11: Specimens for University of Puerto Rico Thespesia phylogeny research**

In 2010, the National Tropical Botanic Garden in Hawaii, USA, provided material from their accessions of *Lebronnecia kokoides*, *Kokia kauaiensis* and *Thespesia populnea* for a University of Puerto Rico study on *Thespesia phylogenetics* and biogeography. The former two species are endemics and were considered of particular value, with *L. kokoides* monotypic in its genus and extremely rare both *in-* and *ex situ*. Though only some are botanic gardens (many are herbaria), the resulting study acknowledges a total of 20 institutions for providing specimens or DNA, spanning Cuba, the United States of America, the Netherlands, Denmark, Germany, the United Kingdom, South Africa, Thailand and Australia.

(*pers comm* JD Ackerman/Uni PR, and Areces-Berazain & Ackerman. 2016)

(Barney Wilczak)

Cultivation of conifers for ex situ conservation planting (RBGE)

3.6.3: Conservation

Plant exchange is a vital mechanism in effective ex *situ* conservation. Whether it is making seed available for reintroduction and restoration programmes, or to bolster wild populations, or exchanging plant material between gardens for duplication purposes, exchange is essential. This is especially important for species known to be held in botanic gardens which are extinct in the wild, for which the loss of ex *situ* representation means total extinction.

Demand for plant material for conservation purposes through PlantSearch is surprisingly low, representing the rarest of the use cases (Figure 7), although conversely, gardens surveyed by Ayenew identified this as the most common reason for exchanging material. It is true that the acquisition of material from the wild for conservation and to improve species representation is often considered more important than the movement of established plants between gardens. Nevertheless, the importance of exchange in duplicating material or in establishing an ex *situ* supply of germplasm near or within the species' native range (as in Case Studies 12 and 13) should not be overlooked and must become more common.

CASE STUDY:

12: Royal Botanic Garden Edinburgh's International Conifer Conservation Programme

The International Conifer Conservation Programme (ICCP) was established at the RBGE in 1991. It combines taxonomic, conservation, genetic and horticultural research with international capacity building to further conifer conservation. A central part of the programme is a 'safe sites' component, in which some 240 sites (at time of writing) have committed to hosting trees long-term, monitoring them and reporting any issues for the ICCP. The safe sites network assures the ex *situ* conservation of the species, some of which are threatened in the wild, and provides hosts with a source of rare or interesting conifers with meaningful conservation benefits. Some 15,000 plants are currently included in the safe site network, representing 288 different species, of which around 141 are considered globally threatened.

The programme has also been involved in the repatriation of catkin yew *Amentotaxus argotaenia*, in partnership with Kadoorie Farm and Botanic Garden (KFBG) in Hong Kong. Very few individuals of this species were known to exist in the wild in Hong Kong and it was unknown whether these rare specimens would be good subjects for propagating without risking damage. Therefore, KFBG contacted RBG Edinburgh through PlantSearch, discovering that RBGE's accessions had been collected from an area close to Kadoorie's reforestation site. Forty cuttings were sent from Edinburgh and planted to bolster the genetic diversity of the heavily depleted population. Further individuals have since been discovered in Hong Kong, and limited cuttings taken for the propagation effort. This species is slow-growing, so the success of the programme has yet to be determined, but there are now many young *Amentotaxus argotaenia* trees under the care of KFBG both *in*- and *ex situ*.

(*pers comm* S Gale & C Williams/KFBG; H Wilson/RBGE and RBGE, 2020)

Collection of seed samples of wild plant species (Krisztián Halász)

Larix griffithii *being propagated at RBGE (RBGE)*

CASE STUDY:

13: Repatriation of Greek plants in the Balkan Botanic Garden of Kroussia, Greece

The Balkan Botanic Garden of Kroussia (BBGK) Greece, is a new botanic garden dedicated to the native plants of Greece and the Balkans. Since its inauguration in 2001, seed exchange with other European botanic gardens was initially limited (46 accessions in total received until 2006). However, during the 5th Planta Europa Conference in Cluj-Napoca (Romania) back in 2007, the associated plant taxonomist Dr. Nikos Krigas presented the "Odyssey" of the Greek plants, launching at the same time a call for the repatriation of well-documented seed material of important Greek plant species from European botanic gardens to the BBGK. This initial call has resulted to date in almost 500 well-documented seed accessions repatriated from 13 European botanic gardens located in eight countries. These seed accessions correspond to 300 native plant species and subspecies collected in Greece by foreign botanists and horticulturists at different time periods. Most of these seed accessions came from the Berlin-Dalhem Botanic Garden in Germany (197) and the Gothenburg Botanic Garden in Sweden (103), thus reflecting their long tradition in studying the Greek flora. Almost 100 accessions of these valuable materials belong to currently threatened plant species of Greece, either Critically Endangered, Endangered or Vulnerable (Kougioumoutzis *et al*., 2021, Phitos *et al*., 1995, 2009); 163 belong to rare range-restricted plants; 106 are Greek endemics (single-country endemics) and 114 are local Balkan endemics or sub-endemics extending to adjacent countries; at least 70 accessions included crop wild relatives and 195 accessions referred to medicinal and aromatic plants. All these precious plant materials have been utilized accordingly at the grounds of BBGK for *ex situ* conservation purposes as well as for the implementation of various research programmes, such as the Critical.GR project focusing on Greek plants assessed as Critically Endangered (Krigas *et al*., 2023); the Tulips.GR project targeted at *ex situ* conservation and sustainable exploitation of 15 wild-growing Greek tulips (Krigas *et al*., 2021) and several others.

Tulipa cretica *(Nikos Krigas)*

Tulipa goulimyi *(Nikos Krigas)*

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Phitos, D.; Konstantinidis, T.; Kamari, G. 2009. The Red Data Book of Rare and Threatened Plants of Greece. Hellenic Botanical Society, Patras.

Case study provided by Nikos Krigas, BBGK, Greece.

CASE STUDY:

14: Tallinn Botanic Garden and Kauai-endemic Ferns

To support dwindling wild populations, Tallinn Botanic Garden successfully propagated three critically-endangered fern species endemic to Hawaii: *Asplenium dielpallidum, A. dielmanii* and *A. deillaciniatum*. Spores were collected for all known wild populations of these species, from which gametophytes were grown and then fertilised. Specimens of every life stage from every species were sent to the National Tropical Botanic Garden in Hawaii, then on to Kauai Mesic Elevation Nursery, for cultivation and planting; a low in-transit mortality rate spurred the delivery of further batches of mature germplasm. In all, 276 individuals were planted *in situ*: 143 of *A. dielpallidum*, 114 of *A. dielmannii* and 19 of *A. diellaciniatum*, with exceptional first-year survival rates of 91.6%, 96.5% and 100% respectively.

Aguraiuja, 2014

Ferns re-potted at NTBG (Ruth Aguraiuja)

(Suzanne Sharrock)

3.6.4: Education

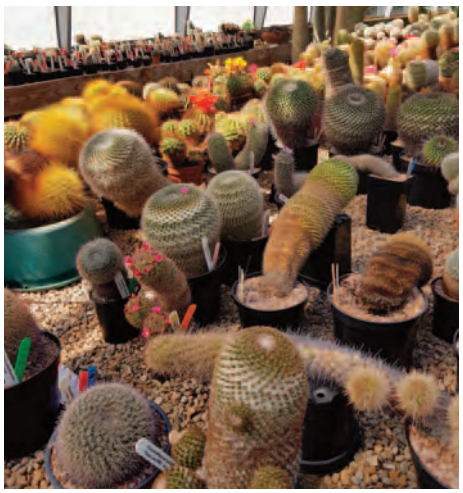
Botanic gardens serve an important role in education inherent in the exposure of the public to the diversity of flora held in their collections; this is magnified where interpretive materials and signage are provided, or through tours and workshops. Often, research utilising botanic garden material is conducted by students as part of their academic advancement (for example, Case Study 11). However, these educational benefits are not usually considered primary functions of the collection or of acquisition through material exchange. Botanic gardens will also receive requests to deliver material to schools, universities and similar educational institutions for lessons and demonstrations; these cases are fairly unusual, as such places will often have their own plant beds or greenhouses, or make do with more accessible material from shops and nurseries. Therefore, demand for material through PlantSearch for education is far less common than for research or for collections, though similar to horticultural demand (Figure 7).

3.6.5: Horticulture

Botanic gardens host cultivars as well as wild species for display, preservation and to serve as a repository. Botanic exchange allows botanic gardens to both receive material for displays or cultivar conservation and to provide material from their own collections to horticultural and commercial projects. Present around the world, featuring staff with specialist knowledge and equipped with advanced infrastructure, botanic gardens will host plants to trial them under the garden's environmental conditions. Gardens will also develop their own cultivars for use in agriculture or horticulture which can then be transferred to nurseries or distributary parties (Case Study 15): cultivar development is usually controlled but the maintenance of so many species within a single institution also provides opportunities for novel crosses.

Paradoxically, though still preferred over wild taxa, cultivars are in no greater demand for this usage class than for any other, indicating that there is also demand for natural species for horticultural purposes or that cultivars for horticulture are more readily available from other sources, or both. Europe and North America dominate this usage class but there is a clear global exchange of material, excepting Africa (Soh, 2019).

Plant nursery (Stéphane Buord)



Cactus collection (Suzanne Sharrock)

CASE STUDY: **15: Denver Botanic Gardens and Plant Select**

Plant Select is a non-profit programme run by Denver Botanic Gardens and Colorado State University to develop non-invasive cultivars with resilience to climate change (especially drought), resistance to disease, lower water demand and improved suitability to the difficult climatic situations present in the Front Range of the Rocky Mountains, a steppe environment. The rationale behind this is that such resilient, resource-flexible cultivars make for more sustainable gardens. The project relies on botanic exchange to deliver germplasm to Denver Botanic Gardens which grows the material in its trial beds, and again when the Garden sends successful cultivars to the Plant Select organisation for wider dispersal.

(*pers comm* C Newlander/Denver BG, Plant Select 2023. Link)

CASE STUDY: **16: Economic benefits of germplasm exchange**

The Adapting Agriculture to Climate Change Project, led by Kew's Millennium Seed Bank and the Crop Trust, set out to improve the diversity, quantity, and accessibility of germplasm collections of Crop Wild Relatives (CWR). Between 2013-2018, partners in 25 countries undertook seed collecting expeditions targeting CWR of 28 crops of global significance for agriculture. A total of 4,587 unique seed samples from at least 355 CWR taxa were collected, conserved *ex situ*, safely duplicated in national and international genebanks, and made available through the Multilateral System of the International Treaty on Plant Genetic Resources for Food and Agriculture. A study commissioned by Kew at the project outset, and carried out by PWC, concluded that the current and potential value of benefits from CWR traits derived from the CWRs targeted by the project was US$42 billion and US$120 billion, respectively.

3.7: Sharing benefits

The Nagoya Protocol of the Convention on Biological Diversity requires the users of genetic resources to share any benefits derived from their use with the provider country. While the details of the Nagoya Protocol or Access and Benefit Sharing more generally are beyond the scope of this review, it is evident that for successful material exchange, benefit sharing must be seen not only as a compensatory measure but as a worthwhile function of material exchange in itself and as such, an important mechanism to build trust among institutions.

The sharing of benefits is not universal, but surveys indicate it has been taken up widely. The most commonly shared benefits are perhaps the simplest, involving exchange of knowledge, participation in research and joint authorship of publications. Capacity building benefits such as training and technical support are provided in some cases, but financial support is relatively rare. Agreements on benefits to be shared are usually established as part of formal MTAs signed before any material is exchanged and as such, it is important that all those involved in developing such agreements understand their benefit sharing obligations (Ayenew *et al*., 2023).

Seed collecting in South Africa (Sthembile Zondi)

4. Constraints and Opportunities for Exchange

4.1: Constraints to plant material exchange

It is widely acknowledged that there are many constraints to plant exchange which can make the practice expensive and time-consuming, sometimes prohibitively so, and which contribute to the unequal global patterns discussed in this review.

4.1.1 Geographic bias

We have seen a considerable bias towards the Global North, particularly Europe and North America, both in providers and recipients of exchanged material (Section 3.2: Geographic Trends of Exchange). Demand itself is currently uneven, a greater concentration of botanic institutions in the north results in a greater demand for and supply of the temperate species which can survive there. Major online exchange platforms PlantSearch and *Index Seminum*, from which data in this review and most botanic exchange studies derive, also have an overrepresentation from Europe and North America. Some institutions, particularly those in biodiversity hotspots or tropical climates, have a greater focus on the collection, conservation and display of local materials usually collected from the wild, and little need for temperate species. Technological, financial and other capacity limitations in low to middle income countries also restricts involvement in research and development, further capping demand in those areas (Ayenew et *al*., 2023).

4.1.2 Regulations, legislation and bureaucracy

Complexity of regulation and cumbersome bureaucratic procedures are considered the leading constraint to plant material exchange. Concerns over fair usage, biosecurity and *in situ* conservation have resulted in the gradual build-up of a regulation and certification complex which is deemed prohibitive for even the largest and best-funded botanic gardens. Discussions held in the course of preparing this review indicate that the regulations themselves are not problematic so much as the level of bureaucracy and paperwork they demand, and the costs involved in securing certificates. Regulations are also not consistent, different nations requiring different certificates or permits for plant export and import which can change over time (Case Study 9).

CASE STUDY:

17: MUSE - Turning to Europe to obtain Tanzanian seed

MUSE Science Museum of Trento recently completed a new glasshouse and aimed to display plants representing the flora of Tanzania. However obtaining plant material from Tanzania was fraught with difficulty. Foremost amongst their problems, was the lack of a botanic garden in Tanzania to partner with, so MUSE instead made an arrangement with Dar University and the Tanzanian Tree Seed Agency. However, the cost MUSE was quoted for collecting and supplying seed lots of 100 species was considered hard to justify, and local partners disagreed over who was required to sign the necessary permits. A trip was organised to scout expertise and facilities but this went poorly. Seeds of 40 species were eventually collected and left with Tanzanian partners for cleaning, packing and phytosanitary certification. However despite making all the necessary payments, no seed was ever sent on to Italy. After all of these complications, efforts to obtain seed from Tanzania were abandoned and plants were instead secured from other European botanic gardens.

(*pers comm* C. Bonomi/MUSE)

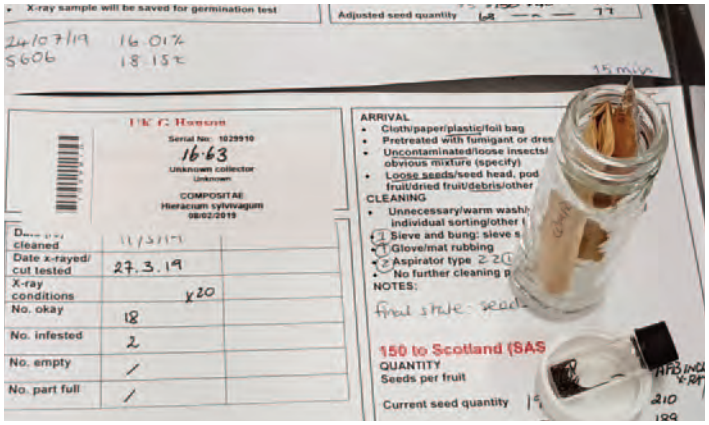
Plant collecting in Tanzania (Costantino Bonomi)

A particular issue that concerns exchange, especially with institutions in biodiverse-rich countries, is the enforcement (or lack of) ABS regulations. Although transfer agreements may clearly state how any material supplied can be used (e.g. not for commercial use), there are still fears that materials will be used inappropriately and that any eventual commercialisation will not result in commensurate benefit sharing. These concerns have led some countries to restrict access to their genetic resources, constraining exchange of material, even for non-commercial use. While, in line with the principles of the Nagoya Protocol, some countries have implemented simplified application processes for non-commercial use, in other cases, quite high fees are charged for applications. The increasing financial, bureaucratic and administrative burdens arising from the many specific ABS-related obligations are problematic for many (especially smaller) botanic gardens because of a lack of personal or financial capacity. Even for larger institutions with long-standing international partnership agreements in place, they can have negative consequences. A recent survey in German-speaking research institutions showed that nearly one third of research projects based on the transfer of plant material could not be carried out as planned because of problems arising from ABS regulations (Kiehn *et al*., 2021).

4.1.3 Data quality

While collections quality is not reported as a factor, poor data quality is quoted by Omaswa (unpublished, 2022) as a major constraint to plant exchange. Data are an important constituent of accessions which enhance the value of plant specimens for conservation, research and other functions. Because plant material is far less usable without associated data, the ability of institutions to keep and provide good records on their collections is vital for effective plant exchange. Poor quality data may result from inexperience (whether individual or institutional), poor storage, language barriers and facilities limitations. Besides provenance data, material tracking is also an issue, with only a third of institutions surveyed by Ayenew *et al* (2023) able to rely on their records to say where material had been received from or sent to. Lack of data on collections from the Southern Hemisphere, symptomatic of a more general lack of membership there, is a shortcoming of the global network and its material exchange platforms at present. More complete data representation ought to help inform and stimulate activity outside Europe and North America, drive greater investment, facilitate research and assist local *ex situ* (or *in situ*) conservation efforts. As well as involvement on the global stage, more complete request and demand data and information may also help gardens to provide and fulfil local demands.

Seeds stored at Berlin Botanic Garden and Museum (André Obermüller)



Checking seeds at Kew's Millennium Seed Bank (Suzanne Sharrock)

Plant collecting in Tanzania (Costantino Bonomi)

4.1.4. Biosecurity

There is a growing recognition of the value of plants to national economies, from agricultural and horticultural production to timber and medicines. The UK Government, for example, has estimated that the total annual value of plants to the UK is £15.7 billion per year (Plant biosecurity strategy for Great Britain (2023 to 2028) - GOV.UK (www.gov.uk). In recent years there has also been an increasing global awareness of plant pests and diseases and their impacts on plant health. Biosecurity is increasingly recognised not just as an important tool in the fight against climate change, but also in reducing poverty and hunger and boosting economic development. As a result of this, many countries are reviewing and revising their biosecurity measures and insisting on ever stricter controls on the movement of plant material. Even seeds, previously thought to be relatively 'safe' from a biosecurity perspective, often now require phytosanitary certification, both at point of import and export. Such certificates can be expensive and slow to obtain – putting another constraint on the international movement of plants (See Case study 9). Gardens may be required to keep introduced material for up to a year in quarantine facilities – and for smaller, poorly resourced gardens, this may be difficult, if not impossible to achieve. Ironically, restrictions on moving plant material also have the impact of impeding research into controlling and managing invasive alien species, pests and diseases.

4.2: Opportunities for improving exchange

While there is a clear consensus that exchange of plant material should be subject to regulation, the existing complexity of such regulations is widely considered the greatest constraint to exchange. The implementation of ABS, CITES and biosecurity regulations pose significant challenges to even the largest and most well-resourced institutions. Simplification and standardisation of such processes therefore presents the clearest opportunity to improve exchange.
With regard to ABS, Kiehn et *al* (2021), note that the main problems encountered include the bureaucratic and administrative burdens arising from the many different ABS-related regulations at the national level; difficulties in identifying and engaging with national authorities designated as competent signatories for the Nagoya Protocol (NP) in user and provider countries; and problems arising from ambivalent and inconsistent use of terms in the NP and in national ABS legislation. Such inconsistencies across countries mean that those with clear and affordable regulations for the permitting and exporting process are now favoured targets for basic research, while research (and research cooperation) with other countries has been considerably reduced.

Parties to the NP are encouraged to implement "*simplified measures on access for non-commercial research purposes*" (NP Article 8a) and to develop and use codes of conduct, guidelines and best practices, or standards for building trust in non-commercial research (NP Article 20 (1)). Botanic gardens have been proactive in developing such codes of conduct and best practices (e.g. IPEN) with the aim of creating confidence in the ABS compliance of the applicants for material transfers. These attempts, however, are so far only partly successful. Many provider countries still have doubts because of the voluntary nature of these systems and because they are transnationally organised and thus not legally recognised bodies at the national level. Further efforts are clearly needed to build trust between 'provider' and 'user' countries and institutions, with the official recognition of systems such as IPEN that ensure best practice processes are followed.

For provider countries to benefit from the use of their genetic resources, regulating physical access should be fluent and easy. It should focus on collecting minimum data – what is being collected, when, where, by whom, and why – and aim to make access flows as easy as possible to encourage research, to increase knowledge, and to find solutions. At the same time, there is also much potential for botanic gardens to document and highlight the wide range of non-monetary benefits they generate and share. If non-monetary benefits are not recorded, and such information shared with national governments, they will continue to be under-appreciated and under-valued (Williams, et *al*., 2023).

Transparency as well as complete documentation are prerequisites to comply with laws and regulations associated with genetic resources and to build trust among users, suppliers, and collaborators. Botanic gardens therefore need to have robust and transparent processes in place for handling not only their materials but also all the associated documents and data.

As a mechanism to demonstrate that best practices are being followed, BGCI provides a certification scheme for botanic gardens in ABS, CITES and biosecurity. Gardens are encouraged to take


(Suzanne Sharrock)

advantage of such schemes as a further means to build trust with potential suppliers of material and to show compliance with national policies legislation and guidelines. Working together at national level can provide a stronger 'voice' for gardens in influencing national policies and guidelines, as well providing opportunities to share resources, such as quarantine facilities, as well as expertise and knowledge.

Furthermore, BGCI's new digital plant material exchange tools, *Index Seminum* and PlantShare, require the providers of plant material to stipulate whether that material is subject to ABS, biosecurity or CITES regulations and to set the terms related to the use of that material. In addition, transactions are all recorded and logged. Our hope is that if botanical institutions use these tools that promote best practice in material/data exchange, then the botanical community will be in a stronger position to seek exemptions from regulations that are primarily aimed at commercial growers.

Another key issue highlighted in this report is the imbalance in the plant material exchange network between the global North and the South. This supposedly 'global' network is heavily biased in favour of the North; the species represented in the network are by and large temperate species and the institutions participating in exchange are mostly northern. It is important that this imbalance is addressed for a truly global network to develop. This will require significant effort in several areas. Firstly, botanic institutions in the South need to be convinced that they stand to benefit from exchange with the North and have sufficient trust in the system to become active participants. Secondly, capacity needs to be developed in data and information management systems so that information on collections can be easily shared through platforms such as PlantSearch, and thirdly institutions in the north need to demonstrate transparency in handling material and document benefit sharing activities that relate to material exchange.

5. Conclusions

The ability to exchange plant material between botanic institutions around the world underpins global conservation and development activities. While large numbers of exchanges are currently taking place, significant constraints remain. There is huge bias towards northern taxa and northern institutions in existing exchanges, and regulations, legislation and bureaucracy are becoming increasingly burdensome.

It is essential that botanic gardens work together at local, national and international levels to overcome these issues. Efforts are required to build capacity where it is lacking and build trust between countries. Botanic gardens need to engage with policy makers at the national level, advocate for simplified exchange mechanisms and demonstrate the efficacy of sector-specific approaches. It is only by working together as a global network that the required benefits for biodiversity and people can be assured.

Collecting cuttings in South Africa (SANBI)

Plant nursery (Suzanne Sharrock)

Plant collecting in Tanzania (Costantino Bonomi)

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