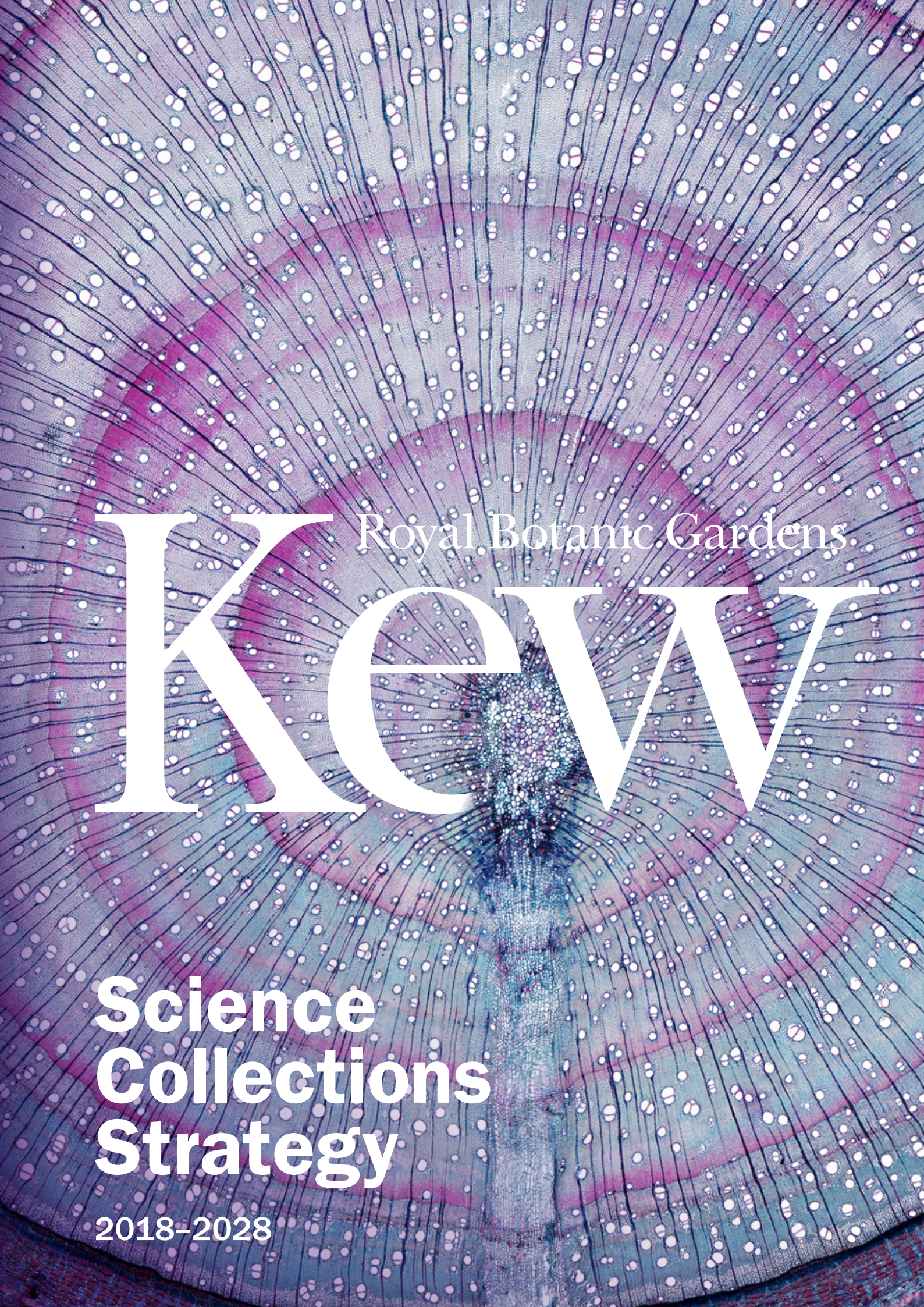


Science Collections Strategy

2018–2028

Foreword

The Science Collections at the Royal Botanic Gardens, Kew, represent an asset that has been growing more or less continuously for the past 170 years. We now have over 8.5 million specimens housed at our two sites at Kew and Wakehurst.

These specimens range from dried plant and fungal material preserved on sheets of paper, to seeds in jars stored at -20°C, to DNA samples stored in freezers at -80°C. They represent a global research resource, enabling the discovery of new knowledge on plants and fungi, their diversity and uses, and their potential to provide solutions to some of the most critical challenges facing humanity today. The collections are used extensively by a global community of researchers and have been ever since they were first established – notable individuals such as Charles Darwin and Beatrix Potter, and those involved in developing trade in tea, coffee, rubber and plant-based medicines, were early users of the collections.

Over the past 170 years, the decision as to what to collect and from where has been largely driven by serendipity and political trends. Large numbers of accessions, for example, were imported from across the British Empire in the 19th century and include material from David Livingstone's expeditions and Speke and Grant's journey to the source of the Nile. Orchid and fern mania in the late 1800s resulted in the addition of many more specimens, and large collections of economically important plants and plant curiosities were imported in time for the Great Exhibition in 1851. As a result of this process, Kew has managed to obtain approximately 95% of the world's vascular plant genera and 60% of fungal genera. The global breadth of the collections is really quite remarkable. What is even more remarkable is the fact that throughout the past 170 years, Kew has never to our knowledge had a collections strategy.

When Kew started, there were relatively few other botanical institutes; there are now more than 3,000 worldwide. There was also little ability to share images and details of the collections with ease; digitisation is now occurring in the vast majority of botanical institutes, reducing the need for over-duplication of samples. The time is therefore ripe to develop a strategy that prioritises what Kew will collect, curate and disseminate. This strategy sets out our vision for the next decade, to ensure that we continue to build collections that underpin our core research activities as articulated in our *Science Strategy* and continue to provide well-curated collections important for botanical and mycological science globally. We also aim to embrace innovation, building on our 170-year-old asset to ensure our Science Collections remain relevant and widely accessible over the next decade and long into the future.

Professor Katherine J. Willis
Director of Science

Dr Alan J. Paton
Head of Science Collections

Executive summary

Kew's Science Collections are a unique and dynamic resource of vascular plants and fungi from across the globe. They document plant and fungal diversity through time and space and underpin Kew's extensive research programmes, providing an exceptional evidence base that can be used to address contemporary issues ranging from climate change to food security and human health.

The aim of this strategy is to guide the development of these collections over the next ten years, enabling us to audit, enhance, manage and share our globally significant Science Collections in line with our scientific priorities and with international policy, such as the Convention on Biological Diversity.

This strategy covers all Kew's major scientific collections: the Herbarium, Spirit Collection, Fungarium, Economic Botany Collection, Seed Collection, DNA and Tissue Bank, Microscope Slide Collection, *In Vitro* Collection, and complementary digital resources. Kew's other internationally significant collections – the Living Collections and the Library, Art and Archives – complement and greatly enhance the Science Collections. Their respective strategies, to be developed subsequently, will closely align with what is set out in this document.

What collections do we currently have?

Kew houses one of the largest and most diverse botanical and mycological collections in the world, containing over 8.5 million items and representing approximately 95% of the world's vascular plant genera and 60% of fungal genera. The strength of Kew's collections lies not only in their extraordinary breadth and depth but also in the unique suite of collections, the synergy between them and the high quality of curation. However, the full details of the holdings are unknown, and a unified system for accessing information on the material in our different collections is lacking. In the next decade we therefore propose to:

- Complete an audit of the Science Collections – generic level by 2020; species level by 2028.
- Provide a unified system for accessing collection information digitally by 2020.
- Share data with our global partners and collaborators to identify critical gaps in collections and reduce duplication of efforts between institutions.

What current and future collections are critical to our research priorities?

The collection and acquisition of new specimens will be aligned with Kew's scientific vision*: to document and understand global plant and fungal diversity and its uses, bringing authoritative expertise to bear on the critical challenges facing humanity today*. We aim to align our collecting priorities with our research priorities, while retaining the flexibility to adapt to emerging opportunities or to support our global partners. Collections will be guided by the four strategic research questions set out in Kew's *Science Strategy 2015–2020*:

1. What plants and fungi occur on Earth and how is this diversity distributed?
2. What drivers and processes underpin global plant and fungal diversity?
3. What plant and fungal diversity is under threat, and what needs to be conserved to provide resilience to global change?
4. Which plants and fungi contribute to important ecosystem services, sustainable livelihoods and natural capital, and how do we manage them?

How do we manage and develop our collections?

As a global resource and the foundation for our research, the collections need to be well-managed, curated to high standards, widely accessible and secure. We will ensure appropriate standards are in place across the Science Collections, developing common protocols with our partners and as part of international initiatives such as the European Distributed System of Scientific Collections. In addition, as the legislative framework governing access to genetic resources and benefit sharing evolves, we aim to develop best practice with partners and to adopt new methods to streamline administrative requirements, ensuring a fast, efficient, equitable and transparent process.

To improve our technical infrastructure, we aim to achieve full integration of our data management systems and ensure high quality physical and digital curation of all our specimens and their associated data. We also aim to upgrade the fabric of the buildings holding the physical specimens, to safeguard against hazards such as pests, fire and flooding while allowing appropriate access. In addition, innovations in technology, collecting methodology and analysis will be embraced, to greatly improve the ease of using the collections for research and conservation.

How do we increase access to our collections?

Kew's collections represent a significant global resource, and we aim to enhance the research and information needs of others through increased access to, and engagement with, our collections. We aim to improve both physical and digital access to specimens. We will also promote greater interaction with our collections through public engagement – utilising interpretation spaces, tours of the collections, citizen science, media, social media, and events such as the annual *Kew Science Festival*.

Digital access to the collections will be facilitated by initiating a mass digitisation programme by 2020, to obtain digital images of all herbarium specimens and capture the essential data from 80% of our Science Collections. We aim to complete the databasing of the collections by 2028 and to also obtain digital images of all fungarium type specimens, the labels of all fungarium specimens, and selected microscope slide, seed and economic botany specimens. We aim to disseminate these digital collection data through major online portals on the Kew website – Plants of the World Online and Fungi of the World Online – and through international data sharing portals.

Contents

Fragment of barkcloth from Kew's Economic Botany Collection – collected in the Solomon Islands by Lady Robinson in 1876 and conserved as a Master's project by Elizabeth Palacios, Centre for Textile Conservation, University of Glasgow

Introduction

Kew's Science Collections contain more than 8.5 million items, representing an estimated 95% of vascular plant genera and 60% of fungal genera

Vascular plant genera

Fungal genera

Kew's Science Collections are a unique and dynamic resource of vascular plants and fungi from across the globe, and they provide an exceptional evidence base for addressing some of the critical challenges facing humanity – from climate change to food security and human health.

Together they contain more than 8.5 million items, representing approximately 95% of vascular plant genera and 60% of fungal genera. They incorporate both living and preserved material and document plant and fungal diversity through time and space. The strength of Kew's Science Collections lies not only in their extraordinary breadth and depth but also in the unique suite of collection types, the synergy between them and the high quality of curation. The collections lie at the heart of our strategic aim to be the global resource for plant and fungal knowledge, forming the central objective in Kew's corporate strategy: *Our collections are curated to excellent standards and are widely used for the benefit of humankind*.

The Science Collections include some of the largest collections of their kind in the world, and they provide the foundation for our scientific work and that of research institutions worldwide. These valuable resources therefore require careful management and curation, and this document aims to set a clear strategy to guide the development of the collections over the next decade.

Table 1 gives a summary of the collections that are the focus of this strategy. Currently, just over 21% of these collections are digitised (i.e. have at least partial specimen data in Kew's databases and are accessible externally) and just under 8% have images available. This digital collection information, along with our extensive set of databases covering names, taxonomy and taxon-based information, forms a valuable resource that also requires careful curation and development, as we describe later.

Kew's other internationally significant collections are the Living Collections, in the 300-acre site at Kew in West London and 560-acre estate at Wakehurst, West Sussex, and the Library, Art and Archives, which form one of the world's largest collections of plant and fungal science publications and illustrations (see Table 2). These collections complement and greatly enhance the Science Collections and provide essential resources for scientific research and conservation (see Box 1). Their respective strategies, to be developed subsequently, will closely align with what is set out in this document.

Box 1: Science and horticulture – sowing the seeds for research and conservation

Kew's extensive collections of living plants are used widely in our scientific research. Seed collections provide important opportunities to incorporate new species into the Living Collections, bringing science and horticulture together and providing material for research, display, education and conservation. Many threatened species are maintained as live plants at Kew and are part of active species recovery programmes. Horticulture protocols (the documented formula for growing plants successfully from seed through to mature flowering and fruiting) are developed at Kew and shared with our partners. The image shows our UK Overseas Territories Programme Officer completing the protocol for *Rondeletia buxifolia*, a critically endangered endemic forest shrub from Montserrat. The protocol has been shared with the Montserrat Government and the Montserrat National Trust, who have established a *Rondeletia* hedge at the island's botanic garden. This species is banked in the Millennium Seed Bank and is on display in the Princess of Wales Conservatory at Kew.

Table 1: An overview of Kew's Science Collections

Collection	Approximate size*	Description
Herbarium	7,000,000	Preserved dried vascular plant specimens[1]. The number of species represented is unknown but the current Herbarium catalogue, which covers 12% of the collection, represents 187,500 species.
Spirit Collection	76,000	Specimens[1] of plants, plant parts and fungi preserved in spirit, representing almost 30,000 species.
Fungarium	1,250,000	Preserved dried fungi, lichens and fungal analogues such as oomycetes and myxomycetes. An additional 1,100 fungal cultures are stored in liquid nitrogen. The number of species represented is unknown but the current Fungarium catalogue, which covers 40% of the collection, contains 52,000 species.
Economic Botany Collection	100,000	A broad range of samples[2] documenting the use of plants by people, including 42,000 wood collections. Approximately 20,000 species are represented.
Seed Collection	86,000	Living seed collections[3] held in the Millennium Seed Bank, with over 2 billion individual seeds representing around 38,600 species. An additional 20,000 preserved seed samples from herbarium sheets are held for taxonomic reference.
DNA and Tissue Bank	58,000	48,000 samples[2] of plant genomic DNA stored at -80°C, and 10,000 silica-dried tissue samples at room temperature – together representing around 35,000 species.
Microscope Slide Collection	150,000	Microscope slides documenting plant and fungal anatomy, including c. 40,000 slides of pollen, c. 36,000 slides of wood and c. 10,500 slides of fungi. The number of species represented is unknown but the current database, which represents 37% of the collection, contains 30,600 species.
In Vitro Collection	6,000	Living plants and fungi cultured on agar. Comprises 1,000 *in vitro* plants of over 20 species of orchids, and 5,000 cultures of mycorrhizal and non-mycorrhizal fungi corresponding to 600 genetically distinct isolates covering c. 200 identified species.

* The exact size of the larger collections and the precise number of species contained within them is unknown, and the sizes given for these therefore represent an estimate based on our knowledge of the collection and those specimens that have been digitised

[1] A specimen = material collected from a single plant or fungal species at a given location and a given time

[2] A sample = tissue or DNA collected/extracted from a single plant at a given time

[3] A collection = a group of related specimens. In the case of seed collections these represent seeds gathered from the same individual or same population at the same time

Table 2: An overview of Kew's other major collections

Collection	Approximate size	Description
Library	300,000	Printed books, journals and pamphlets covering the worlds of plant and fungal science and horticultural history, including: naming, classification and uses of plants and fungi; plant ecology and conservation; wild plants of the world; botanic gardens and herbaria worldwide; the history of gardening and garden design; and the development of botanical illustration.
Art	200,000	Prints and drawings assembled over the last 200 years and ranging in date from the 18th century to the present day. Additional works on paper, portraits, photographs, and three-dimensional objects.
Archives	7,000,000 sheets of paper in 4,600 collections	Unpublished material comprising correspondence, field notebooks and photograph albums, records of plants received at Kew and sent out from Kew, and maps and plans tracing the development of the Gardens.
Living Collections	68,000 accessions*	Living plants in the Gardens and glasshouses at Kew and Wakehurst, representing over 22,000 taxa.

* An accession in this context consists of one or more living plants derived from the same collection

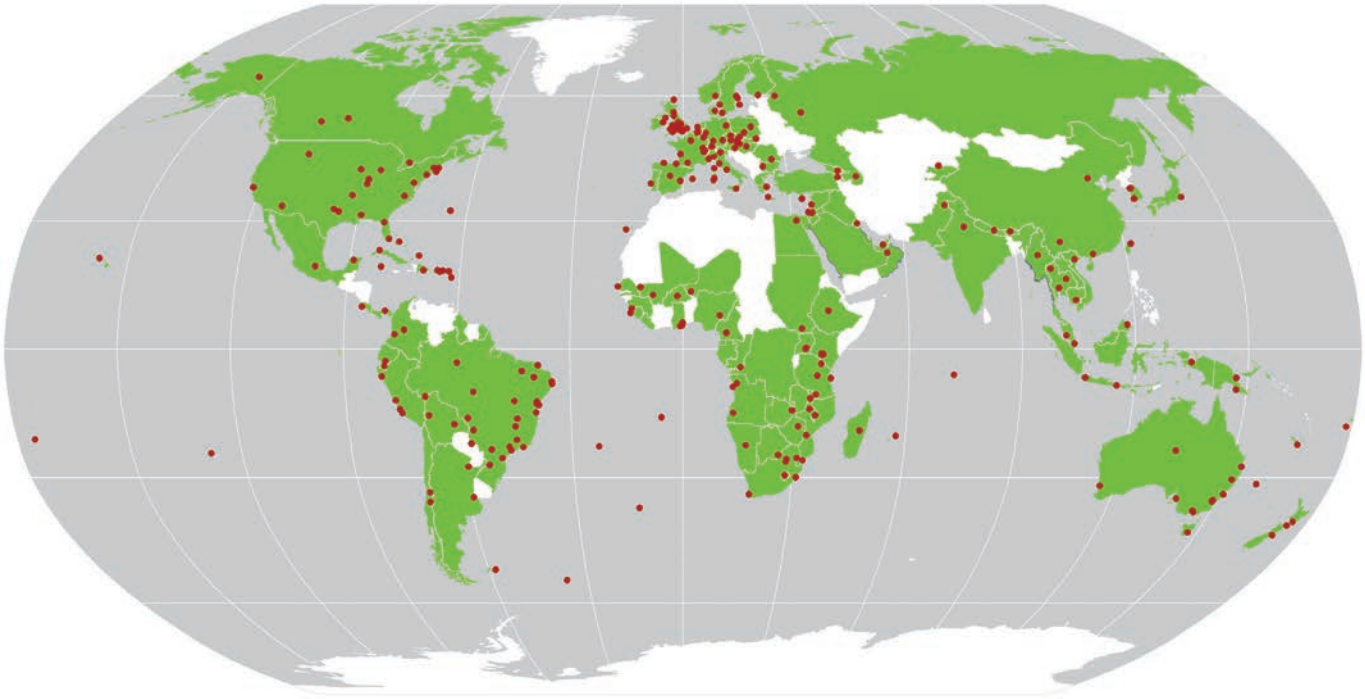
Working in partnership

Kew's scientists work with collaborators in over 400 institutions from more than 100 countries across the globe (Figure 1), and these partnerships are essential to the success of our research and collecting activities. We will continue to collaborate widely, and to work with local partners to maximise the impact of our work and the benefits to our partners, while also developing new ways to avoid unnecessary duplication of collecting effort.

In addition to supporting our own research agenda, Kew's Science Collections are used for research conducted in other institutions worldwide, and they provide a globally important, quantitative evidence-base for determining progress towards agreed international initiatives, including the Sustainable Development Goals, the Aichi targets and the Global Strategy for Plant Conservation. Looking forward, it is therefore important that we develop ways to enhance access to our collections, both physically and digitally, to enable maximum usage. It is also imperative that we actively support current and newly emerging European and global partnership initiatives, such as the European Distributed System of Scientific Collections and Global Biodiversity Information Facility, in order to share information and best practice.

We are internationally recognised for the development of effective access and benefit sharing procedures, and these underpin our collection partnerships worldwide. In the next decade, we will continue to comply with the Convention on Biological Diversity, the Nagoya Protocol, Convention on International Trade in Endangered Species (CITES) and national laws of partner countries on access to genetic resources and benefit sharing. We will streamline our processes governing collection, transfer, research and supply of material to ensure that our agreements can be implemented effectively and efficiently.

Figure 1: Map showing the global reach of Kew's work
Kew's scientific work from 2010–2018 spanned more than 100 countries (shaded green) and involved collaborators from over 400 institutions worldwide (locations denoted by red dots).



Our global partnerships are essential to the success of our collecting activities and research

From the past to the future

Kew's Science Collections provide an exceptional record of plant and fungal diversity through time and space.

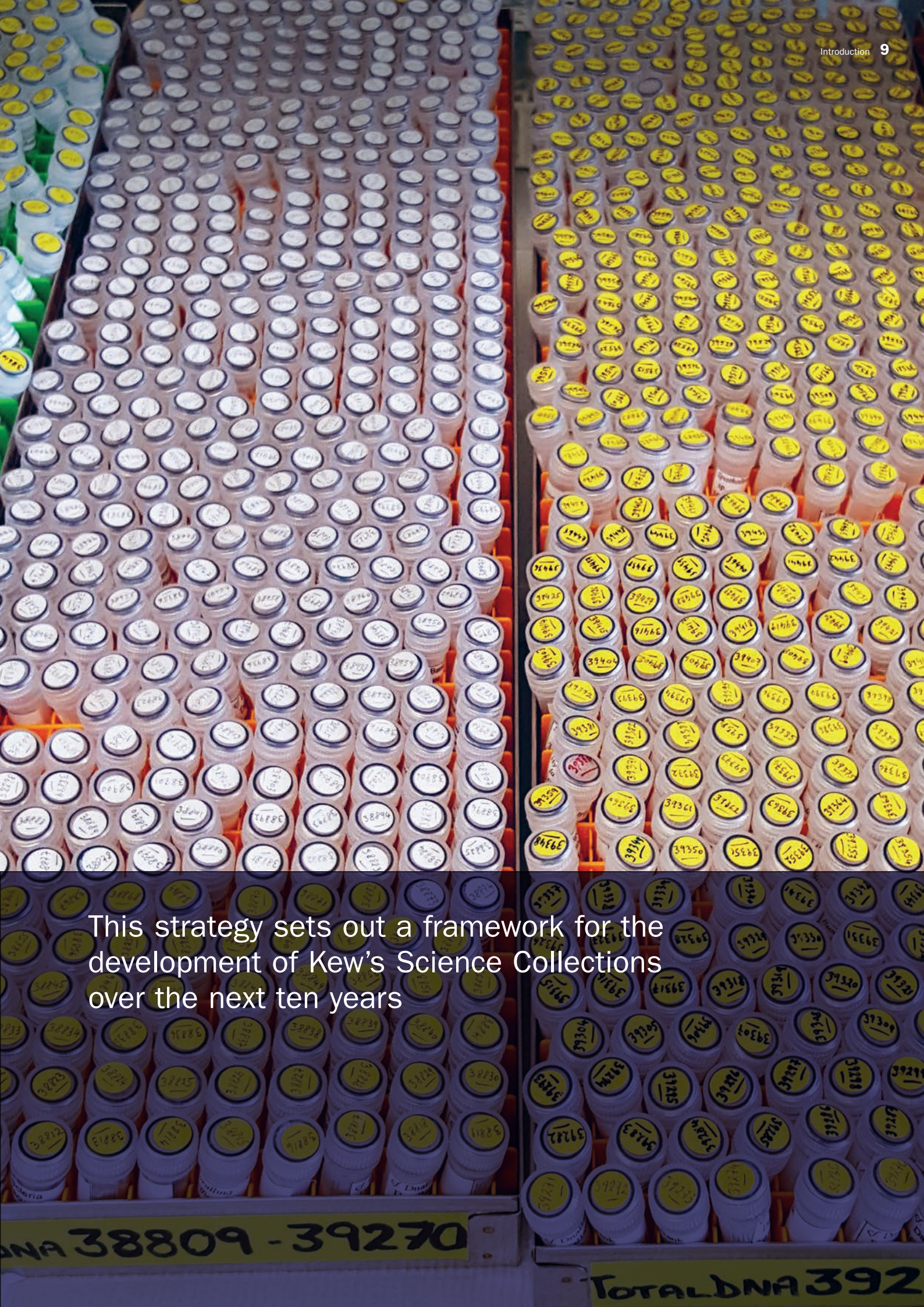
They have been built up over the past 170 years and their composition often reflects the priorities being addressed at the time of their collection, for example capitalising on the economic potential of plants such as *Hevea brasiliensis* – the source of rubber – or exploring the horticultural potential of exotic floras.

Although many of these collections remain relevant and important to current research (e.g. providing data to model species distribution in response to climate change), looking to the future it is essential to ensure that Kew's collections fill critical data and knowledge gaps and enable current and emerging global research questions to be addressed. A collection that is static loses its scientific value and we are therefore committed to making and curating new and relevant collections, ensuring they are widely used for active scientific purposes that benefit humanity. Implementation of this strategy will require decisions concerning resource allocation. Such decisions will be guided chiefly by our scientific priorities so that they contribute directly to our research objectives, helping to find solutions to global challenges.

This document sets out a framework for the development of Kew's Science Collections over the next ten years. We will work collaboratively to quantify and qualify what we already have in the context of the collections of scientific institutes globally – to minimise unnecessary duplication of effort and to identify important gaps both in geographical regions and in taxonomic groups. In addition, we will embrace new and innovative technologies to enhance our collecting activities; we will implement new processes and storage technologies to ensure that all our specimens are curated to the highest international standards; and we will develop mechanisms to ensure that the knowledge contained in Kew's collections is disseminated to a global audience.

4 strategic questions will be addressed to ensure our vision is achieved:

1. What collections do we currently have?
2. What current and future collections are critical to our research priorities?
3. How do we manage and develop our collections?
4. How do we increase access to our collections?



This strategy sets out a framework for the development of Kew's Science Collections over the next ten years

What collections do we currently have?

Kew's Science Collections date back to 1847, although the oldest individual specimens include ancient Egyptian plant wreaths and a small number of Indian herbarium specimens from 1696.

They originated principally through the amalgamation of several private collections, including the herbaria of Sir William Hooker and George Bentham and M. J. Berkeley's mycological collection. Today, Kew houses some of the largest and most diverse botanical and mycological collections in the world, and they continue to grow by approximately 38,000 new specimens a year – from herbarium sheets to microscope slides, artefacts, seeds, leaf tissue and DNA. Around 30% of these are collected in the field by Kew scientists, through active projects with our partners around the world. The remainder are sent to Kew by other institutions in areas relevant to our research programmes.

Kew's collections focus on vascular plants (ferns, lycopods, gymnosperms and flowering plants) and fungi (including lichens and fungal analogues such as oomycetes). Bryophytes and algae, held at Kew until the 1960s, are now housed at the Natural History Museum London, other than a small number of bryophytes that were collected to support specific science projects.

The geographical scope of the collections is global, and they contain specimens from all continents. In some focal regions, the collections are extensive in both taxonomic breadth and depth (see Figure 2), and these collection 'hotspots' reflect Kew's historical scientific interests. From the 1960s, for example, Kew concentrated its research and conservation programmes in the tropical areas of Africa, Asia and South America, where much of the world's plant diversity is concentrated. A UK and UK Overseas Territory focus was also maintained for plant and fungal specimens related to conservation work. Prior to this, collections tended to be focused in areas once part of the British Empire – for example, eastern and southern Africa, Australia, southern Asia, and areas important to British trade in the New World, such as Brazil. The collections were also enhanced with duplicates from prolific collectors.

More recent collections at Kew have continued to focus on key areas of the world and model taxonomic groups in which we have historical collections and particular expertise, including Arecaceae (palms), Asteraceae (daisies), Fabaceae (legumes), Orchidaceae (orchids) and Poaceae (grasses). However, there has also been a complementary focus on collections of species that share particular traits of interest and those that represent themed groups of taxa, such as ectomycorrhizal fungi and crop wild relatives; these collections lie across geographic regions and lineages.

Historical collecting strategies have similarly influenced other collections the world over. Given limited resources for collections, it is imperative that in the future the global coverage of different institutes is properly recognised, and that collections and collection hotspots complement rather than compete. It is envisaged that the trend towards digitisation of collection data and increased accessibility will greatly improve knowledge of the global coverage of collections and flag up critical collection gaps.

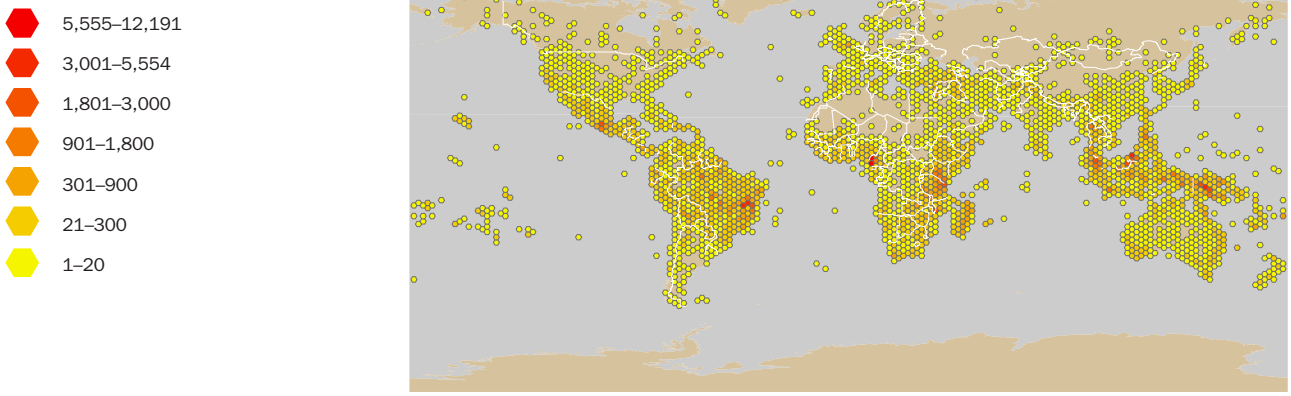
The contents of Kew's major scientific collections are summarised in the following section. Extended information on these important collections can be found on the Kew Science website (www.kew.org/science).

Today, Kew houses some of the largest and most diverse botanical and mycological collections in the world, and they continue to grow by approximately 38,000 new specimens a year

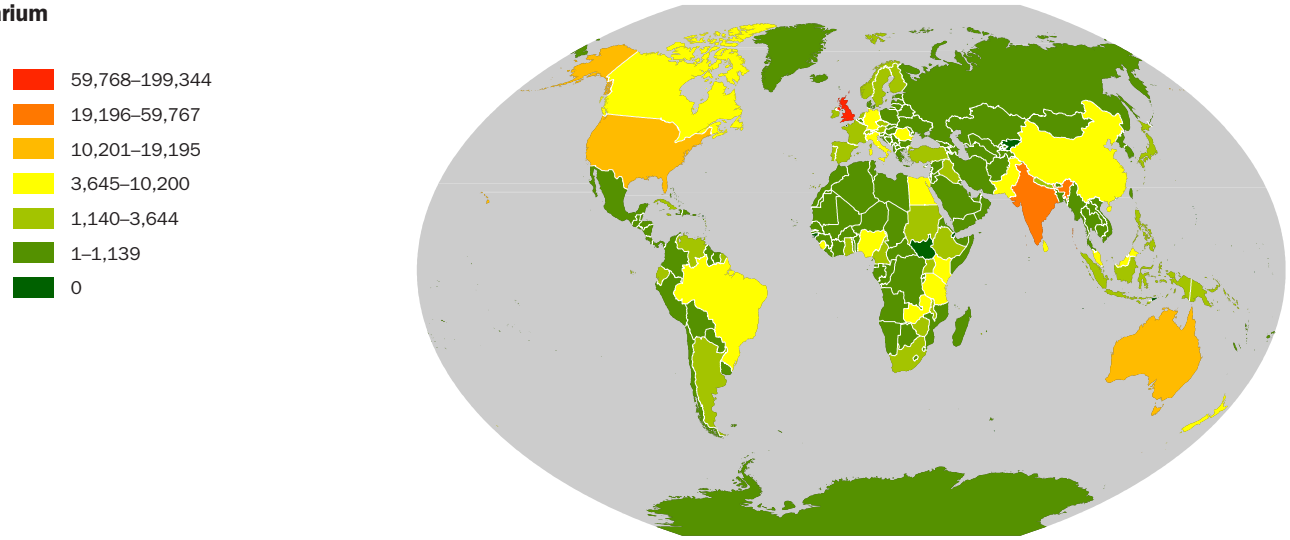
Figure 2: Maps showing geographical distributions of the major collections

The full geographical distribution of specimens in the Herbarium and Fungarium is unknown, as only a proportion of the specimens have been databased (12% and 40% respectively). The Herbarium map is based on around 209,000 georeferenced records in the Global Biodiversity Information Facility, and the Fungarium map is based on 500,000 records in the Fungarium catalogue. All other maps reflect the actual distribution of the collections.

Herbarium



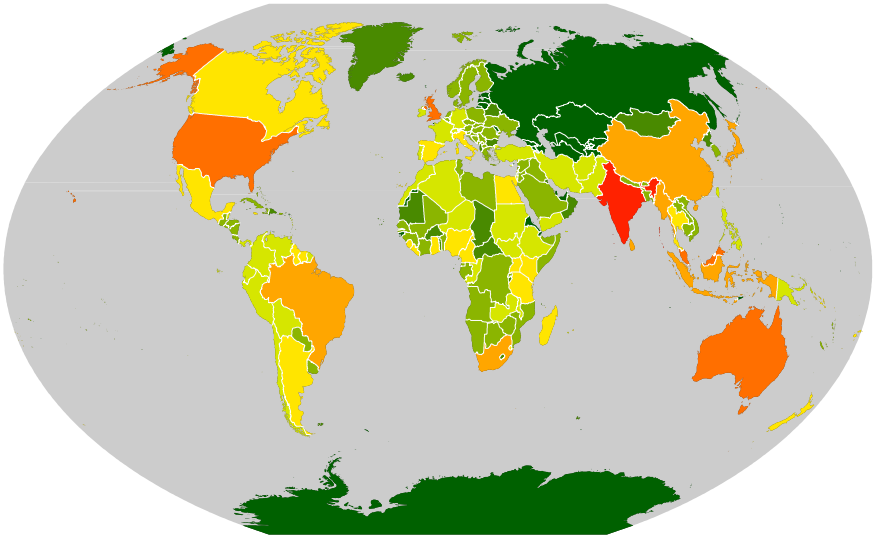
Fungarium



Digitisation of specimen data will greatly improve our knowledge of the global distribution of our Herbarium and Fungarium collections

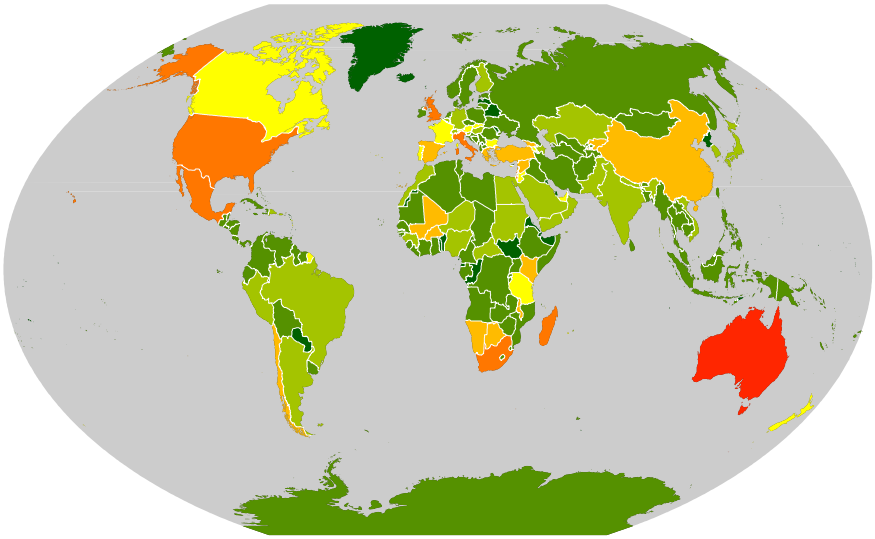
Economic Botany Collection

- 4,260–8,804
- 2,624–4,259
- 1,114–2,632
- 416–1,113
- 124–415
- 11–123
- 1–10
- 0



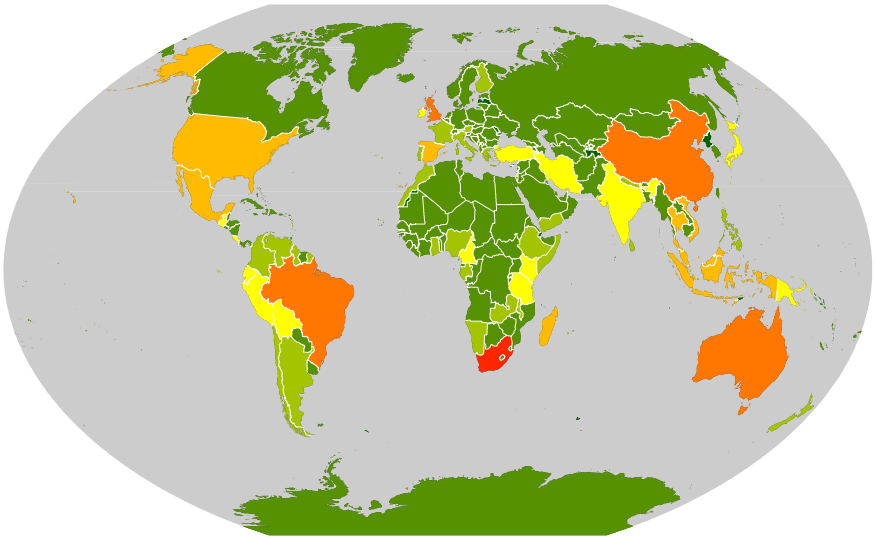
Living Seed Collection

- 6,963–11,814
- 2,358–6,962
- 901–2,357
- 417–900
- 110–416
- 1–109
- 0



DNA and Tissue Bank

- 2,288–4,069
- 1,261–2,287
- 624–1,260
- 301–623
- 96–300
- 1–95
- 0



Kew's Science Collections

Herbarium

Kew's Herbarium is one of the largest in the world, with around seven million pressed plant specimens and additional carpological collections of structures such as fruits that are difficult to press. It is representative of global plant diversity, containing approximately 95% of vascular plant genera and around 330,000 type specimens (the definitive specimens that act as standards for identifying the correct name for a plant).

Date established	1852
Number of specimens	c. 7,000,000
Number of species	Unknown; at least 187,000 in digital catalogue
New accessions per year	25,000
Scientific visits by researchers per year	3,000 visitor days
Supply to external users per year	5,000 specimen loans and samples; 5,000 specimens as gifts and exchanges to other institutions
Taxonomic and geographical strengths	Vascular plants; Global, particularly tropical regions

Spirit Collection

Kew's Spirit Collection is the largest collection of its kind in the world. Spirit-preserved material comprises plant parts, and some fungi, preserved in fluid and stored in glass jars in metal cabinets. The collection is particularly useful where standard herbarium specimen mounting is not appropriate, or to enhance other collections by allowing the three-dimensional structures of flowers and fruits to be observed.

Date established	1930
Number of specimens	76,000 (including 1,250 fungi)
Number of species	29,800
New accessions per year	400
Scientific visits by researchers per year	Counted under Herbarium visits; critical to researchers studying species where pressing specimens obscures important characters
Supply to external users per year	Science visitors working on these groups and occasional loans
Taxonomic and geographical strengths	Arecaceae, Orchidaceae, succulents; Global

330,000

Kew's Herbarium contains around 330,000 type specimens – these are the specimens on which the names and descriptions of species are based

Wing B of the Herbarium, added in 1902

The Fungarium, located in the Jodrell Laboratory

Fungarium

Kew's Fungarium collection is the largest in the world. It contains dried fungi, lichens, and fungal analogues such as oomycetes, in addition to a small collection of fungal cultures. There are samples from all seven continents, spanning the entire fungal tree of life. The specimens are representative of over 600 of the currently accepted 780 families of fungi, and approximately 60% of accepted genera.

Date established	1879
Number of specimens	Over 1,250,000 specimens, including 1,100 fungal cultures
Number of species	Unknown; at least 52,000 in digital catalogue
New accessions per year	5,000
Scientific visits by researchers per year	300 visitor days
Supply to external users per year	280 specimens and 150 samples for analysis
Taxonomic and geographical strengths	Basidiomycota, particularly Agaricomycetes, including plant pathogens and wood-rotting fungi, and selected Ascomycota formerly grouped under the name discomycetes; Global, particularly UK, India and Sri Lanka, east and west Tropical Africa, Malaysia, Australasia, Brazil, Venezuela and USA

Economic Botany Collection

Kew's Economic Botany Collection is the largest in the world. It documents the uses of plants by humans, represented by plant raw materials and objects made from plants. These include eating and drinking utensils, cloth and clothing, jewellery, musical instruments, weapons, medicines and timbers. A small proportion of specimens are not of useful plants, but are of plant parts (e.g. palm inflorescences) too large for the Herbarium, or fungi.

Date established	1847
Number of specimens	100,000, including 500 fungi
Number of species	20,000
New accessions per year	1,000
Scientific visits by researchers per year	500 visitor days
Supply to external users per year	130 specimen consultations, 80 samples for analysis and 25 loans for exhibition
Taxonomic and geographical strengths	Angiosperms and gymnosperms, particularly Arecaceae, Asteraceae, Euphorbiaceae, Fabaceae, Moraceae, Poaceae and Rubiaceae; Global, particularly India, UK, USA, Malaysia, Australia, Brazil and tropical Africa

100,000

Kew's Economic Botany Collection is the largest in the world, with 100,000 specimens documenting human use of plants and fungi

Seed Collection

Kew's Millennium Seed Bank (MSB) constitutes the largest and most diverse wild plant seed bank in the world. It is housed in Kew's Wellcome Trust Millennium Building at Wakehurst, West Sussex in -20°C vaults. Kew also manages a collaborative partnership with other seed banks globally, called the Millennium Seed Bank Partnership (MSBP), with 160 partners in 96 countries and territories. These partners hold additional seeds not stored in the MSB, and Kew has developed the MSBP Data Warehouse as our platform for sharing data, through which we can track collections and establish and maintain standards across the network.

Date established	1960s; moved to Wakehurst in 1973
Number of seed collections	85,800
Number of species	38,600
New accessions per year	5,000
Scientific visits by researchers per year	2,300 visitor days
Supply to external users per year	1,200 seed samples
Taxonomic and geographical strengths	Angiosperms, particularly Asteraceae, Cyperaceae, Fabaceae, Myrtaceae, Orchidaceae, Poaceae and Rosaceae; Global, particularly dry tropics, UK, Australia, USA

DNA and Tissue Bank

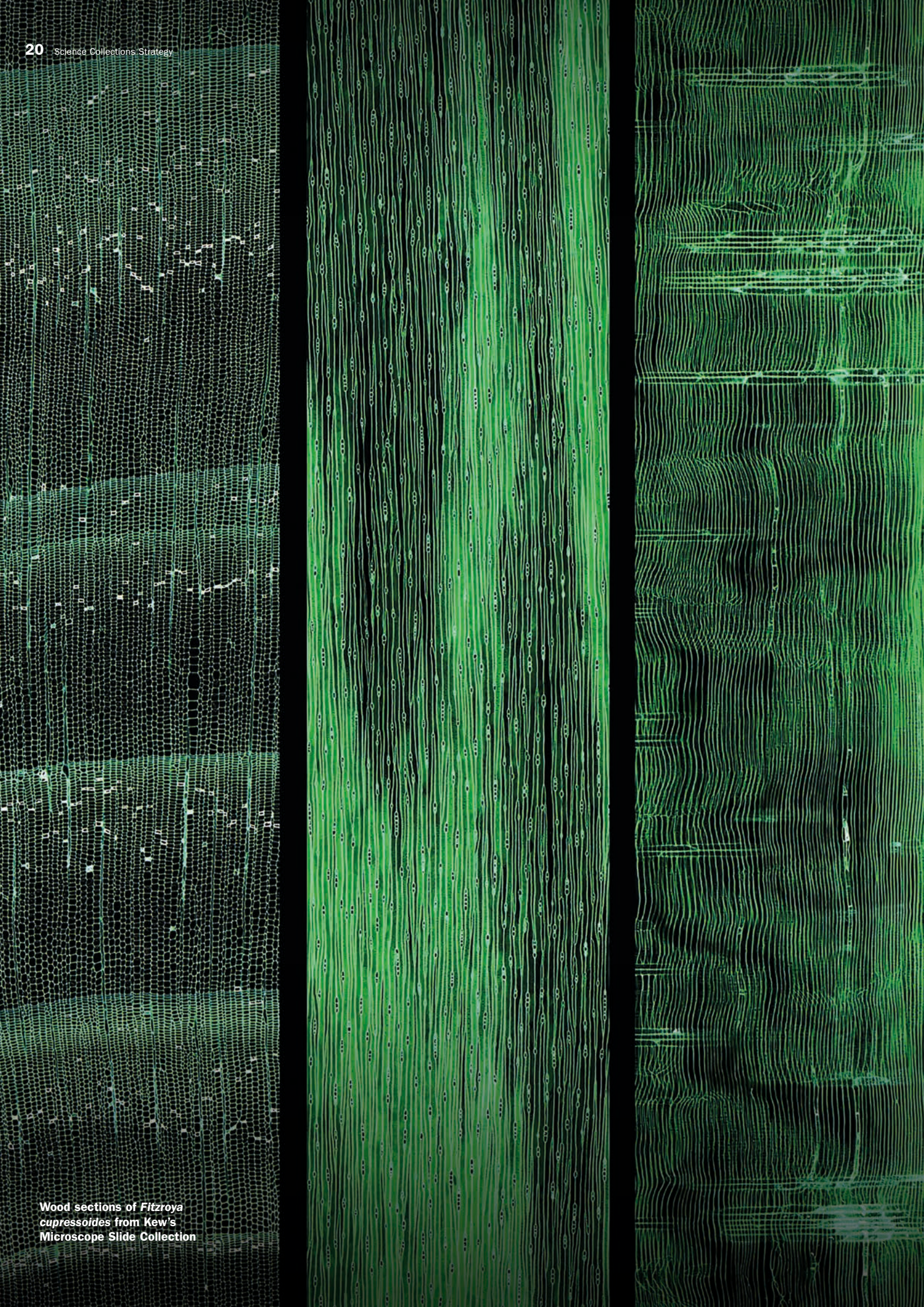
Kew's DNA and Tissue Bank is the most diverse of its kind in the world and contains samples from nearly all angiosperm families and over half the genera. In addition, all gymnosperm families are represented along with a selection of ferns and bryophytes. The DNA samples are stored in -80°C freezers to reduce degradation, and the tissue samples are preserved in silica gel at room temperature. Increasingly, material for genomic study is being stored as tissue as it can support a broad range of genomic and biochemical studies. Samples of fungal DNA are being formally accessioned from 2018 onward.

Date established	1992
Number of samples	58,000
Number of species	35,000
New accessions per year	2,000
Scientific visits by researchers per year	n/a
Supply to external users per year	1,500 samples
Taxonomic and geographical strengths	Angiosperms, particularly Cyperaceae, Fabaceae, Myrtaceae and Orchidaceae; Global

35,000

Kew's DNA and Tissue Bank contains samples from 35,000 species, covering almost all the world's flowering plant families

The Millennium Seed Bank at Wakehurst



Wood sections of *Fitzroya cupressoides* from Kew's Microscope Slide Collection

Microscope Slide Collection

Kew's Microscope Slide Collection is an important resource for determining plant micro-traits, such as wood density and leaf thickness, and for plant authentication, such as identification of timbers covered by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). The slides include leaf and stem surfaces and sections, wood, roots and flowers, with separate specialist pollen and chromosome collections.

Date established	1930s
Number of slides	150,000 (incl. 40,000 palynology slides; 10,500 fungi)
Number of species	Unknown; 30,600 in collection database (14,000 for palynology slides)
New accessions per year	1,700
Scientific visits by researchers per year	Not recorded
Supply to external users per year	Not recorded
Taxonomic and geographical strengths	Fabaceae, Orchidaceae; Global

In Vitro Collection

Kew's *In Vitro* Collection consists of plant and fungal specimens that have been cultured in an artificial environment in tissue culture media in glass jars or on petri dishes. The current composition of the collection represents their primary use to support Kew's conservation and restoration programmes in the UK and Madagascar.

Date established	Late 1970s
Number of specimens	6,000: 1,000 *in vitro* plants of orchids, and 5,000 isolates of mycorrhizal and non-mycorrhizal fungi, many of which are wood-rotting fungi
Number of species	20 species of orchids, plus 600 genetically distinct isolates of fungi covering 200 identified species
New accessions per year	500
Scientific visits by researchers per year	Not recorded
Supply to external users per year	Restricted supply; less than ten per year
Taxonomic and geographical strengths	Orchidaceae; UK, UK Overseas Territories, Europe, Madagascar and Indochina

150,000

There are 150,000 slides of plant and fungal sections, pollen and chromosomes in Kew's Microscope Slide Collection

Digital resources

Alongside the physical collections, Kew holds a vast and growing collection of plant and fungal data and databases that store information on specimens, names, taxonomy, traits, distributions, phylogenies, phenology and conservation. These include digital taxonomic and trait-based resources (see Table 3) and collection databases and images (see Table 4). These resources link to all our collections and provide the basis for their integration. The collection databases are curated alongside the physical collection. A key challenge to our collections is the integration of currently disparate systems, facilitating more efficient curation and management.

Table 3: Summary of Kew's digital science resources

Database	Description	Type of data	Number of records
Plants of the World Online (POWO; in development)	A portal for accessing all Kew's plant scientific data, using IPNI and WCSP data for the name spine. The current focus is on African floras. A fungal portal (Fungi of the World Online; FOWO) will be developed for fungi, using Index Fungorum and Species Fungorum for the name spine.	Taxon-based information, images and distribution maps	843,400 records; 321,600 species
International Plant Names Index (IPNI)	A database of names and associated bibliographical details of seed plants, ferns and lycopods – a collaboration between Kew, the Harvard University Herbaria and the Australian National Herbarium.	Names	1,664,900 plant names
World Checklist of Selected Plant Families (WCSP)	A database of the latest peer-reviewed and published opinions on the accepted scientific names, synonyms and distribution of selected plant families. Further data under review is held offline.	Taxa	515,900 names at all ranks; 137,100 species (offline: an additional 629,500 names; 142,500 species)
The Plant List (TPL)	A working list of all known species of vascular plants and bryophytes published in 2013. We intend to publish a dynamic version in 2018.	Taxa	1,064,000 species-level scientific plant names; 350,699 species
Seed Information Database (SID)	A compilation of seed biological trait data from the Millennium Seed Bank Partnership's own collections and from other published and unpublished sources.	Taxon-based Information	84,500 records; 51,900 taxa
Plant DNA C-values Database	A database of plant and algal DNA C-values (the DNA amount in the un-replicated gametic nucleus) from Kew's own research and from other published and unpublished sources.	Taxon-based Information	18,300 records; 12,300 taxa
Medicinal Plant Names Service (MPNS)	A database covering the alternative scientific, pharmaceutical, trade and common names used for plants and herbal substances reported to have a medicinal use.	Names	283,900 scientific names and 100,900 non-scientific names; 24,900 species
Survey of Economic Plants for Arid and Semi-Arid Lands (SEPASAL)	A database of useful wild and semi-domesticated tropical and subtropical dryland plants.	Taxon-based Information	28,200 records; 7,000 species
Index Fungorum	A database of names of fungi (including yeasts, lichens, chromistan fungal analogues, protozoan fungal analogues and fossil forms) at all ranks. Produced in partnership with Landcare Research, New Zealand and Institute of Microbiology, Chinese Academy of Sciences.	Names	545,300 names
Species Fungorum	A database of fungal taxonomic concepts forming the Kew-coordinated content included in the Catalogue of Life.	Taxa	142,500 species

Table 4: Summary of digital information in Kew's collection catalogues

Digitised collection information is available from Kew's website and online international initiatives such as the Global Biodiversity Information Facility (GBIF), the Global Genome Biodiversity Network (GGBN) and Genesys, a gateway to information on plant genetic resources for food and agriculture.

Collection	Number of specimens databased[1] (% of total)	Number of specimens imaged (% of total)	Species represented in collection catalogue	Estimated number of species in whole collection
Herbarium	850,000 (12%)	575,000 (8%)	187,500	Unknown
Spirit	76,000 (100%)	0	29,800	29,800
Fungarium	500,000 (40%)	20,000 (1.6%); not online	52,000	Unknown
Economic Botany	95,000 (95%)	2,500 (2.5%)	12,000 non-wood; 13,000 wood	20,000
Seed (Those available for distribution are accessible via the Seed List)	85,800 (100%)	c. 85,000 X-ray images to check viability (99%); 1,200 of seed morphology (1.4%); not online	38,600	38,600
DNA and Tissue Bank	58,000 (100%)	0	35,000	35,000
Microscope Slide (not online)	55,600 (37%)	1,000 (<0.1%); not online	30,600	Unknown
In Vitro (not online)	6,000 (100%)	0	600 operational taxonomic units of fungi, and 20 species of plants	At least 200

[1] Databased refers to data entered into an institutional database and with data available externally (unless stated), where permitted by agreement with partner country

Auditing our collections

This section has provided a brief overview of the major assets in Kew's Science Collections. What becomes apparent from this review is that although Kew has extraordinary and unique specimens, with often global representation of vascular plant and fungal families, the finer details of the collections and their specimens are often poorly known, as only around 21% have their details entered in a database and only 8% have digital images available. There is also poor understanding of which species have good representation across the different collections (e.g. Herbarium, Seed, DNA), and a unified system for accessing information on the different material in our collections is lacking. In the next decade we therefore propose to:

- Complete an audit of our Science Collections – to include an understanding of their age, quality of specimens and geographical scope; generic level audit across collections by 2020, species level by 2028 following digitisation of the Herbarium and Fungarium.
- Provide a unified system for accessing collection information digitally by 2020.
- Share data with our global partners and collaborators to identify critical gaps in collections and reduce duplication of efforts between institutes.

What current and future collections are critical to our research priorities?

Collecting herbarium specimens in New Guinea

Supporting Kew's scientific vision

Kew is primarily a collections-based research institute, and our collections provide an exceptional evidence base that can be used to support Kew's scientific vision: *"to document and understand global plant and fungal diversity and its uses, bringing authoritative expertise to bear on the critical challenges facing humanity today"*

This vision, which was articulated in Kew's *Science Strategy 2015–2020* (available on www.kew.org/science), is being delivered by six research departments in our Science Directorate and by a number of cross-departmental strategic research outputs.

The scientific vision and research priorities outlined in the strategy address fundamental questions relating to plant and fungal diversity, its evolution, conservation and uses, and capitalise on Kew's fundamental strengths. They are therefore likely to remain in place for the lifetime of this strategy, but, if new research priorities and opportunities arise, our collection priorities will need to retain the flexibility to adapt accordingly. For future collections we aim to follow the decision process outlined in Figure 3, enabling us to embark upon a focused and directed collecting strategy to 2028 and beyond. Decisions regarding collection resource allocation will be determined by our science priorities. The following section sets out our collection priorities for 2018–2028 in more detail.

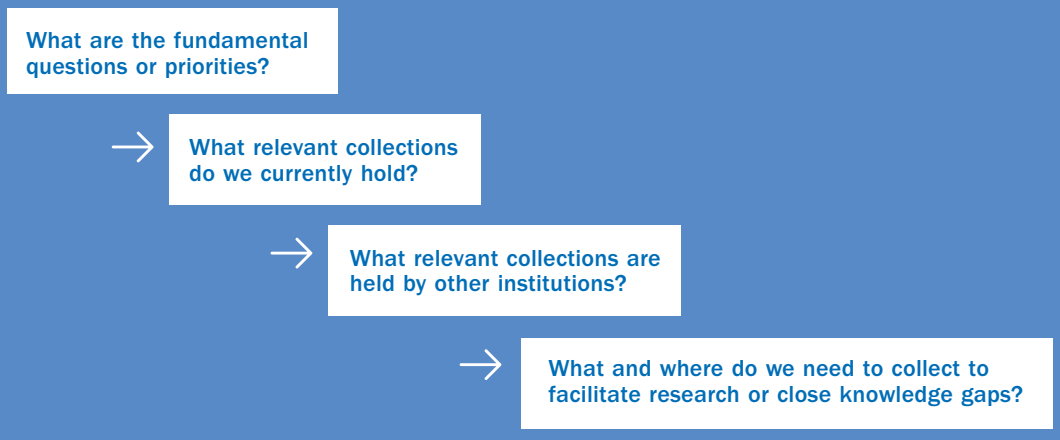
Addressing global challenges

In our *Science Strategy*, we articulated four key research questions that we would use our collections to address. Our ambition is to conduct evidence-based, collections-based research to address some of the greatest global challenges currently being experienced by humankind. These challenges include climate change, habitat destruction, disease and the urgent need to ensure food and fuel security across the globe. The four research questions articulated in our *Science Strategy* are as follows:

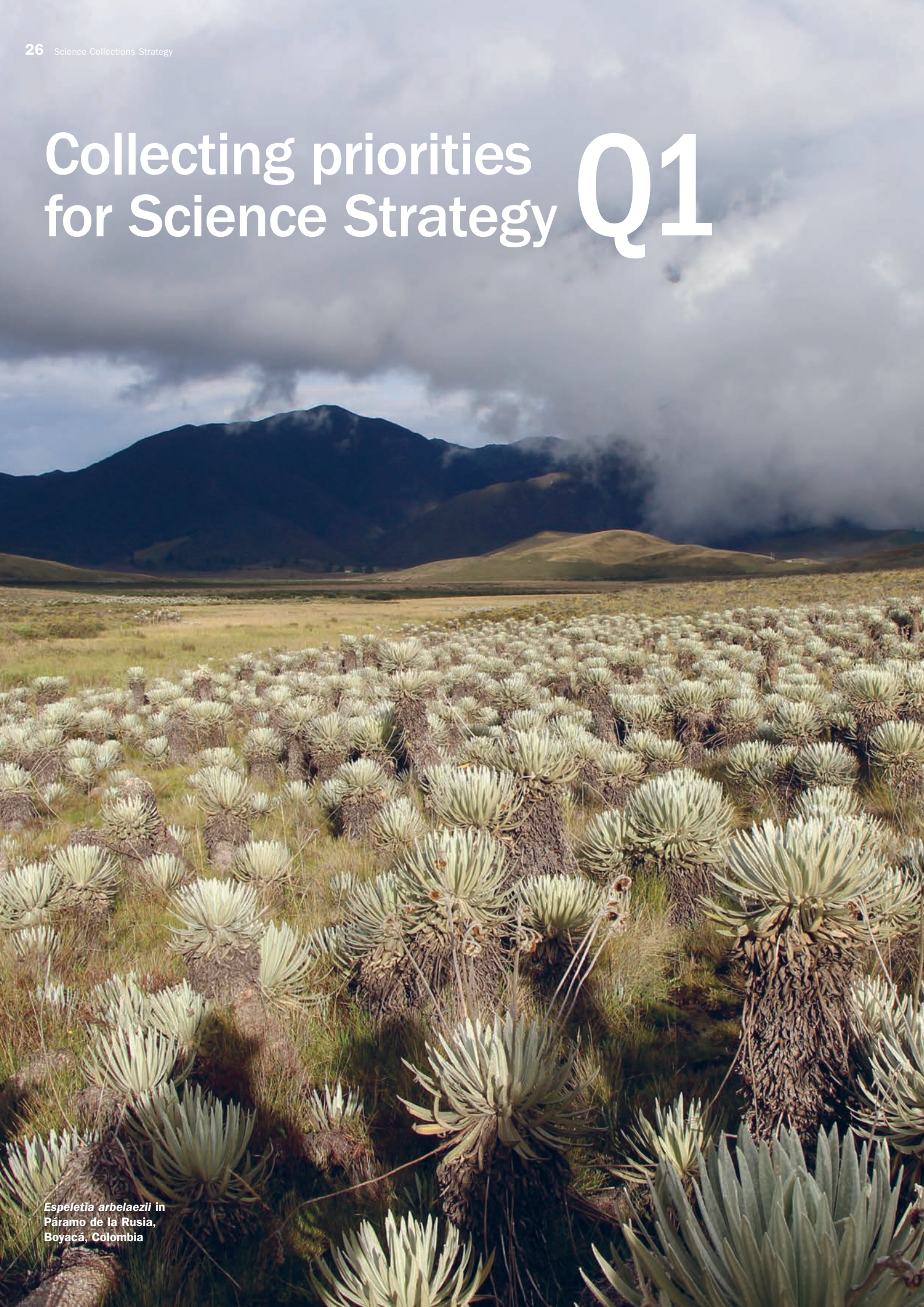
1. **What plants and fungi occur on Earth and how is this diversity distributed?**
2. **What drivers and processes underpin global plant and fungal diversity?**
3. **What plant and fungal diversity is under threat, and what needs to be conserved to provide resilience to global change?**
4. **Which plants and fungi contribute to important ecosystem services, sustainable livelihoods and natural capital, and how do we manage them?**

We believe these four questions will remain as relevant, if not more so, in the coming decades, and we will align our collecting priorities to these questions to ensure we have the right material to facilitate Kew's research contribution to finding solutions to global challenges. In the following section, we take each of these questions in turn and set out our priorities for collections that will support fundamental research in these areas.

Figure 3: Process for prioritising collecting efforts



Collecting priorities for Science Strategy Q1



***Espeletia arbelaezii* in Páramo de la Rusia, Boyacá, Colombia**

What plants and fungi occur on Earth and how is this diversity distributed?

Describing plant and fungal diversity, determining how each species is defined, mapping their distributions and discovering novelties are all critical research activities. This work can only be achieved with extensive, well-documented collections to act as a reference and to provide comparative material for research and conservation.

Over the next ten years we will therefore focus our collecting activities in targeted regions, taxonomic groups and thematic groups – filling critical gaps in our collections and addressing historical sample bias in key areas.

Collecting priorities for plant and fungal diversity

Kew's current plant collections are a sample of global vascular plant diversity, with particular focus on parts of Africa, South-East Asia, and Central and South America. The taxonomic coverage in these countries reflects historical priorities and contemporary activities and expertise. Nonetheless, a glance at global specimen data for Kew's collections (similarly for all collections recorded in the Global Biodiversity Information Facility) reveals gaps in some of the most diverse countries of the world, even in reasonably well-sampled countries (see Figure 4). Sharing data and specimens with other institutions and using international infrastructures will help provide greater resolution of where the critical gaps are and how to fill them. We therefore aim in the next decade to undertake detailed gap analyses so that, with partners, we can undertake targeted collecting activities and specimen exchanges, enhancing collection data for research questions and allowing identification of particularly biodiverse and threatened plant communities.

For fungi, the gaps are orders of magnitude larger, and relatively little is known about their global diversity and distribution. Our aim in the next ten years is therefore, with partners, to begin to determine the diversity and distribution of fungi in South-East Asia and north-western South America – two hotspots of fungal diversity.

In addition to geographical targeting, as part of our regional identification and naming work there are priority families and genera where a greater understanding of their taxonomy will help us answer key questions or to complete regional floras. We will continue to build on our specialist knowledge in priority groups – in particular, the plant families Arecaceae (palms), Asteraceae (daisies), Fabaceae (legumes), Myrtaceae (myrtles), Orchidaceae (orchids), Poaceae (grasses), Rubiaceae (the coffee family), the fungal family Cortinariaceae and the lichen-forming fungal order Teloschistales – filling gaps, describing new species and producing monographs on key genera.

In the next decade, we will focus collecting activities on the regions, taxonomic groups and priorities detailed in Tables 5 and 6, which all fulfil one or more of the priorities for new collections specified below.

Priorities for new collections (Q1):

- Regions that have high or unique plant and fungal diversity, particularly those that are under threat and for which Kew has specialist taxonomic expertise.
- Countries for which there is limited botanical or mycological knowledge, infrastructure and capacity, and that are not the focus of major investment by other institutions.
- Taxa that help us address important research questions relating to global plant and fungal diversity and distribution.

Figure 4: Outputs of Kew's collections from the Global Biodiversity Information Facility (GBIF)
A: Africa, B: Madagascar, C: New Guinea, D: Central and South America. Each yellow dot represents a specimen in Kew's collections, allowing geographical gaps in our collections to be identified. Using this information and data from other institutions, we can provide greater resolution of where we need to collect to fill global gaps.

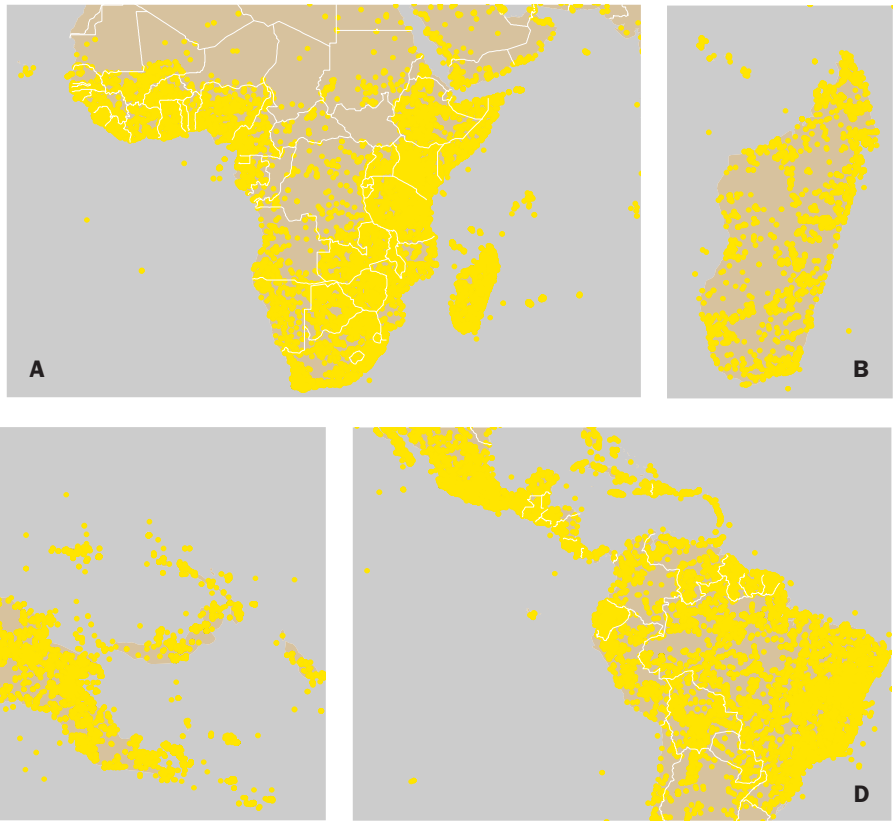


Table 5: Priorities for general collecting and taxonomically focused collecting in target regions

Target region	Countries/ habitats for general collecting	Priority taxonomic groups for more in-depth sampling
Africa (sub-Saharan)	Diverse and poorly sampled regions: Liberia, parts of the Democratic Republic of Congo, Congo-Brazzaville, Cameroon, Angola, Mozambique, Equatorial Guinea Countries with specific data gaps: Madagascar, Guinea-Conakry, Uganda, Zambia, Ethiopia, Namibia, Ghana, Sierra Leone	**Africa** Acanthaceae, Apocynaceae, Cyperaceae, detarioid legume trees, Malvales, rheophytes, Rubiaceae, saprophytes (Burmanniaceae, Triuridaceae) **Madagascar** Plants: Arecaceae, Asphodelaceae, Dioscoreaceae, Fabaceae, Malvaceae, Orchidaceae, Poaceae, Rubiaceae Fungi: Agaricomycetes, Teloschistales and endophytic Ascomycota
South-East Asia	Eastern Malesia: the region from, and encompassing, Sulawesi, the Lesser Sunda Islands, Moluccas and the island of New Guinea (Papua New Guinea and Indonesian New Guinea; see Box 2)	Plants: Actinidiaceae, Arecaceae, Ebenaceae (*Diospyros*), Euphorbiaceae, Gesneriaceae, Lamiaceae, Orchidaceae, Primulaceae, Ranunculaceae and Urticaceae; full species coverage for the island of New Guinea Fungi: Agaricomycetes, Teloschistales and endophytic Ascomycota
Central and South America	Brazil: Caatinga, Campo Rupestre, Mata Atlântica; Colombia (see Box 3): Chocó rainforest, Andean Páramo; Bolivia: Chiquítania dry forest; Peru; Paraguay; and the northern, western and southern borders of Amazonia	Plants: Achariaceae, Asteraceae, Euphorbiaceae, Fabaceae, fleshy-fruited Myrtaceae, Orchidaceae and Urticaceae Fungi: Agaricomycetes, Teloschistales and endophytic Ascomycota

Table 6: Priorities for widespread sampling – model groups and themed collections

Region	Priority groups
UK, continental Europe and the UK Overseas Territories (UKOTs)	Plants: endemic species, targeted threatened plant species, invasive species in the UKOTs, crop wild relatives Fungi: selected fungal pathogens and their hosts; mycorrhizal partners of dominant forest trees and woody alpine plants; rarely-recorded UK fungi, species of conservation concern and those requiring taxonomic resolution, including waxcaps and earthtongues; widespread collection for a DNA-verified, updated *Checklist of the British and Irish Basidiomycota*
Global	Plants: Arecaceae, Asteraceae, Fabaceae, Myrtaceae, Orchidaceae, Poaceae, Rubiaceae, crop wild relatives, succulents, families with extensive genomic diversity Fungi: Basidiomycota, including rusts, mycorrhizas and Cortinariaceae, and lichen-forming Ascomycota, particularly Teloschistales

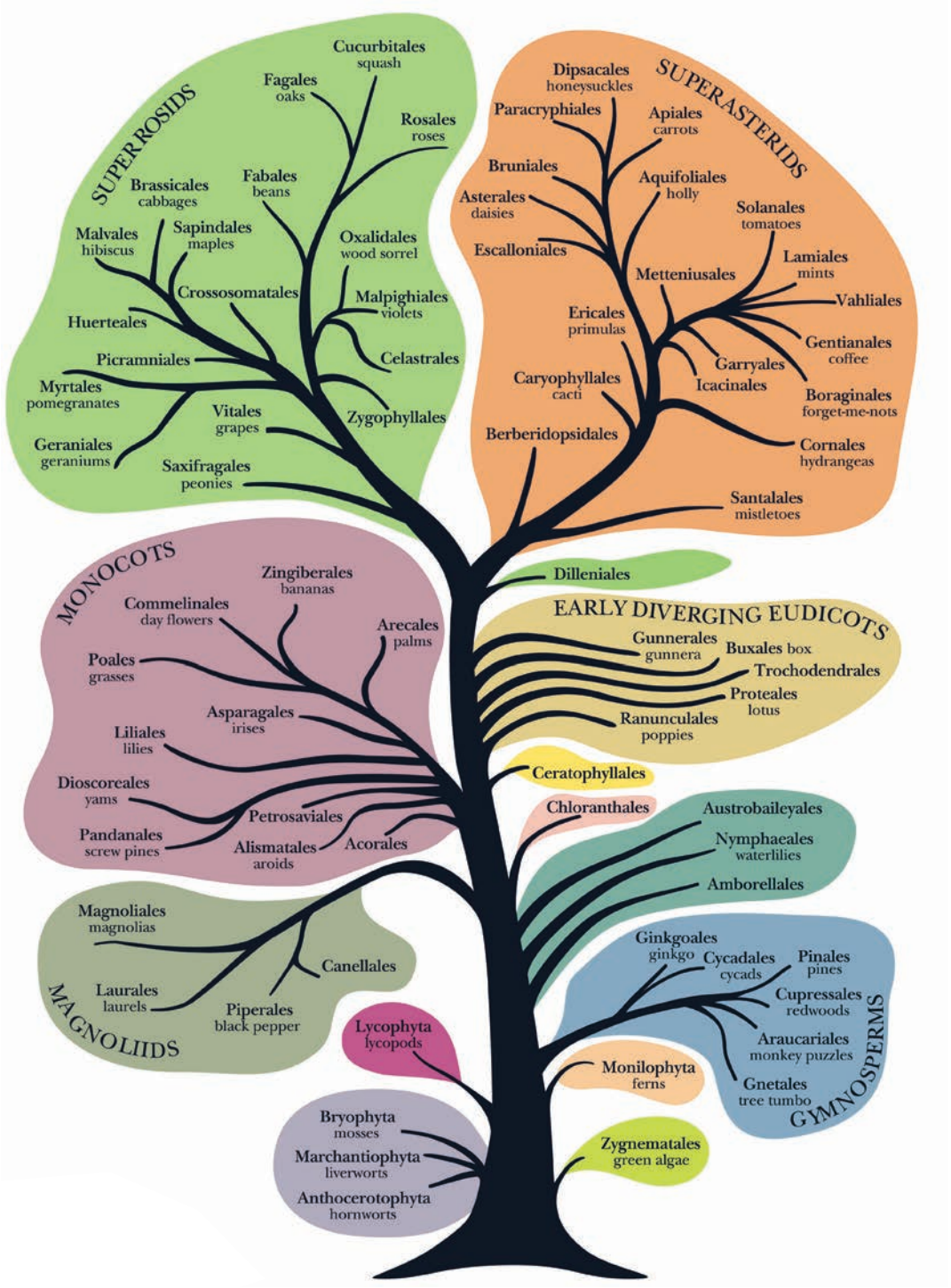
Box 2: Flora of New Guinea

The island of New Guinea has vast unsampled areas, and its diverse habitats – ranging from mangroves through large tracts of unbroken rainforest to alpine grasslands – could harbour as many as 40,000 species. By prioritising collections in New Guinea, Kew and partners are working towards the first *Flora of New Guinea*, filling an important gap in the knowledge of this diverse region. The image shows tree fern (*Alsophila* sp.) grassland in the Cromwell Mountains, Papua New Guinea.

Box 3: Species discovery and inventory in Colombia

Over the next five years, our collecting activities will contribute to exploring the rich biodiversity of Colombia as part of the Colombia Bio programme, delivered with in-country partners. The aim of the programme is to discover and describe plant and fungal diversity to aid the conservation and sustainable use of Colombia's natural capital. The image shows collections of fungi made on a recent expedition to Boyacá.

Collecting priorities for Science Strategy Q2



Kew's Plant and Fungal Trees of Life strategic output aims to fill gaps in our understanding of evolutionary relationships in plants and fungi to genus level, and within genera for our model groups.

What drivers and processes underpin global plant and fungal diversity?

The diversity of life we see on Earth today is a result of billions of years of evolution and has been shaped by many different biological and environmental drivers.

Comparative biology research at Kew aims to understand these drivers and processes and therefore the underlying principles that determine patterns of plant and fungal diversity. Our collections underpin this research, and we aim to focus our collecting activity to ensure that the necessary evolutionary and ecological data are available to provide the evidence base for addressing key biological questions. Given the rapid advances being made in genomic sequencing technologies, we also aim to ensure that our specimens and collections are suitably stored so that the wealth of genomic information they contain can be extracted. Such data will open up possibilities to address both pure and applied research questions that seek to understand the role of genomic factors in shaping the evolutionary trajectories of species and their ecological interactions.

Evolutionary context informs all studies of plant and fungal diversity and in the next decade we will collect representatives of plant and fungal genera for which there is currently a phylogenetic knowledge gap, including material from germination tests conducted at the Millennium Seed Bank and living plants at Kew and Wakehurst. In addition, tissue for genomic study will be sampled at every field collection. Together, these collections will contribute to our understanding of the Plant and Fungal Trees of Life (see opposite), providing a robust phylogenomic framework for research.

Building on this, we will focus in on target families to use as model systems for studying patterns of diversity and the drivers and processes that lead to this diversity. In-depth sampling within these families will provide specimens for detailed taxonomic and phylogenomic analyses, forming the basis for studies on speciation, biogeography and the evolutionary and environmental drivers of diversity. Specifically, we will increase collections in the following model families: Arecaceae, Asteraceae, Fabaceae, Myrtaceae, Orchidaceae, Poaceae, Rubiaceae, Cortinariaceae and Teloschistaceae. (See Box 4.)

Finally, we will increase collections that look across species, genera and families at specific genomic, anatomical, chemical and ecological characteristics of plants and fungi. This will underpin research seeking to illuminate similarities and differences between species, allowing a greater understanding of the evolutionary and ecological drivers at work. We will enhance our collections with specimens that enable research on traits including seed germination and dormancy characteristics, genomic diversity, floral structure, succulence, biochemical characteristics and the mycorrhizal trait in fungi. (See Box 5.)

Priorities for new collections (Q2):

- Taxa that help to fill key gaps in our knowledge of the Plant and Fungal Trees of Life.
- Taxa from our target plant and fungal families, to allow the study of the patterns and drivers of diversification.
- Taxa that underpin trait-based research, to enable greater understanding of the drivers of plant and fungal characteristics and their evolutionary and ecological relevance.

Box 4: Target families for global research

Arecaceae

Arecaceae (the palm family) contains species that are notoriously difficult and time-consuming to collect due to their size and complexity, and they are therefore often under-represented in herbaria. A specialist programme on palms has existed at Kew since the 1970s, which has resulted in the adoption of specialist curation methods and a unique resource for research. In the next decade, we aspire to obtain at least one specimen (plus ancillary collections e.g. DNA) of every known species of palm. These will be essential for providing comparative data of key traits for evolutionary and ecological studies.

Satranala decussilvae

Asteraceae

Asteraceae (=Compositae; the daisy family) is one of the two largest families of flowering plants (along with Orchidaceae), with more than 32,000 species. We aim to ensure that all 1,600+ genera are represented in the Herbarium collection, with DNA samples obtained from as many of these as is feasible. This will help to fill gaps in the collection and resolve relationships between the genera, tribes and subfamilies. Additionally, obtaining targeted collections from outside the more intensely studied regions (e.g. from the Andean countries, Mesoamerica and northern South America, Paraguay and the West Indies), will help complete the evolutionary picture of the Neotropical Asteraceae.

Paranephelius ovatus

Cortinariaceae

Cortinariaceae is one of the most diverse families of ectomycorrhizal fungi, containing several thousand species found all over the world. The species are associated with many different trees and shrubs, including members of Pinaceae, Fagaceae, Salicaceae and Nothofagaceae, and play an important role in supplying the mineral requirements of many forest trees. Due to its species richness and global distribution, Cortinariaceae is an ideal model family to address diverse evolutionary questions. We will focus our collecting efforts in areas south of the Tropic of Cancer, although several new species to science are also discovered annually from more northern latitudes.

Cortinarius brunneoalbus

Fabaceae

Fabaceae (=Leguminosae; legumes) can be found in all habitats and account for around 10% of total plant diversity. The geographical distribution of legume diversity is highly correlated with total flowering plant diversity, and thus the family provides a good model for the study of global plant distribution. To ensure our collections are useful for future studies aiming to resolve evolutionary relationships across the whole family, we will increase representation of genera and species from Brazil, Colombia, Ecuador, Peru, Bolivia, Mexico, Central America, Madagascar, Cameroon, Sierra Leone, Gabon, Mozambique, Angola, New Guinea, Thailand, and the UK Overseas Territories.

Chamaecrista rotundata var. *grandistipula*

Myrtaceae

Species diversity in Myrtaceae (the myrtle family) is high, and they provide valuable bio-indicators of the diversity and health of tropical forests. Over the next decade, major collection effort will be focused on the Neotropics (Brazil and Colombia), South-East Asia (Borneo and New Guinea) and the Indo-Pacific region (New Caledonia and Pacific islands). Targeted collection will also continue in groups of economic importance, building comprehensive datasets to facilitate rapid responses to changing global conditions. Kew's world-class collection will continue to be developed in response to threats from the outbreak of myrtle rust, currently spreading through the Pacific.

Accara elegans

Orchidaceae

Orchidaceae (the orchid family) is one of the two largest families of flowering plants (along with Asteraceae) and is particularly diverse in the wet tropics and some temperate regions (southern Africa and Australia). The orchids of South-East Asia are in particular need of further study, and we will continue efforts to revise selected taxa and to expand collections in this region. In addition to Indochina, areas of special interest are Wallacea and New Guinea. Evolutionary studies designed to understand patterns of species richness and the drivers of diversification will continue in the Neotropics, where orchid taxonomy is better resolved than elsewhere. Further collections will aim to fill gaps in the representation of species in our current collections and in published phylogenetic and genomic studies.

Dendrobium spiculatum

Box 4 continued: Target families for global research

Poaceae

Poaceae (the grass family) is the modern world's most successful angiosperm family. Ecosystems dominated by grasses cover over a third of the world's land surface, and grass-dominated landscapes are responsible for 33% of global primary productivity. Over the next decade, we will focus on building collections of ecologically dominant and widespread grasses as well as local endemics, to understand spatial patterns of diversity in grass-dominated ecosystems in the context of evolutionary history. The highest priority will be given to obtaining new collections of grasses from Madagascar and continental Africa, which will drive internationally collaborative research in savanna ecosystems.

Tristachya betsileensis

Rubiaceae

Rubiaceae (the coffee family) is the largest and most poorly known woody plant family in the wet tropics. Kew houses the world's most comprehensive herbarium collection of Rubiaceae, including carpological and spirit specimens. With an estimated two thousand species still lacking scientific names, collections of Rubiaceae from key areas in Africa and Asia remain a high priority. Countries of specific focus for Africa include Angola, Cameroon, Guinea-Conakry, Mozambique and Madagascar; for Asia, target areas are Indochina (Myanmar to Vietnam, and southern China), Indonesia (Sulawesi and Indonesian New Guinea) and Papua New Guinea. We will also aim to increase the general representation of collections from Central and South America, particularly Bolivia and Colombia.

Hyperacanthus sp. nov.

Teloschistaceae

Teloschistaceae is the largest family included in the order Teloschistales, which accounts for >10% of all known lichen-forming fungi. With a cosmopolitan distribution, this hyperdiverse family – dominated by bright orange-pigmented species – has adapted to extreme arid conditions and biological soil crusts. Over the next decade, the current collection of Teloschistaceae will be expanded to include at least one specimen and DNA sample from all species occurring in Teloschistaceae-dominated habitats in the world. This will support a global taxonomic revision of Teloschistaceae and provide insights into the traits that have enabled these lichens to survive in extreme habitats.

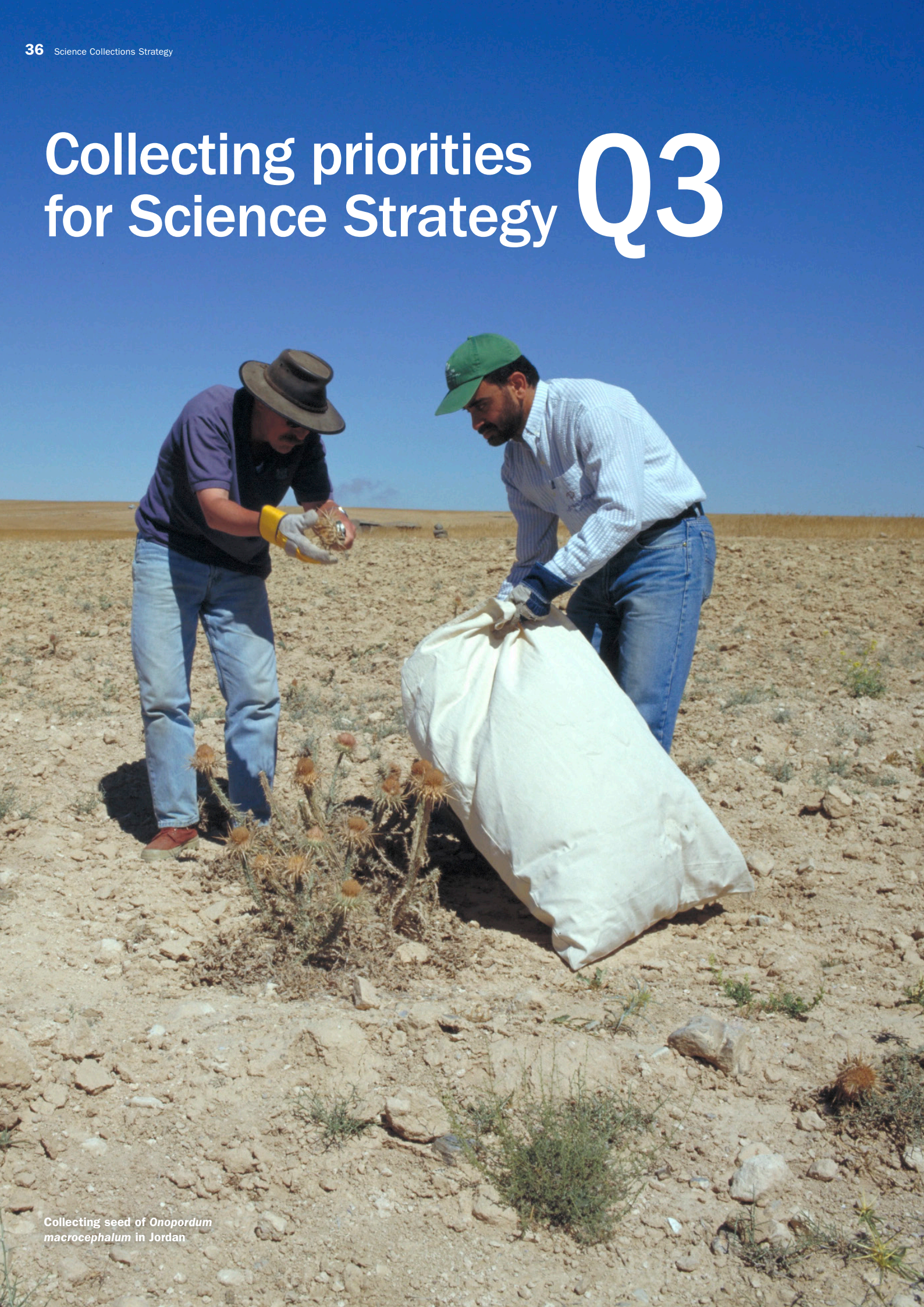
Xanthoria elegans

Box 5: Studying the evolution of traits across lineages

To understand the role that genomic processes (e.g. polyploidy, epigenetics, genome size) play in influencing how plants evolve and respond to environmental change, we aim to increase the representation in Kew's Living Collections of key plant families that fully encapsulate particular genomic traits. These will include at least 50% of genera in all families that exhibit extensive genomic diversity, including Liliaceae, Melanthiaceae, Santalaceae and Asparagaceae. The image shows fluorescence *in situ* hybridisation of rDNA loci in *Artemisia umbelliformis* subsp. *eriantha*.

To understand the vital role that ectomycorrhizal fungi play in carbon sequestration and ecosystem functioning and resilience, requires deep understanding of the full diversity of ectomycorrhizal fungi. Over the next ten years, we plan to increase collections of the dominant and ecologically relevant fungi associated with key plants in different ecosystems: mycorrhizal species associated with the dominant forest trees in Britain and other parts of Europe; species associated with woody plants in alpine ecosystems; and species associated with endemic trees in Madagascar. The image shows ectomycorrhizas of *Boletus pruinatus* on oak roots.

Collecting priorities for Science Strategy Q3



Collecting seed of *Onopordum macrocephalum* in Jordan

What plant and fungal diversity is under threat, and what needs to be conserved to provide resilience to global change?

To address this question, in the next decade we will focus our global collecting on specimens that increase our understanding of threat and those that contribute to *in situ* and *ex situ* conservation.

Collections of endemic, threatened, ecologically important and useful species will be prioritised. We will collect in areas undergoing rapid environmental change, including loss of habitat, to contribute to our global overview of threats to plants and fungi.

This will include collections that contribute to extinction risk assessment (including extending coverage of plants in the IUCN Red List of Threatened Species) and to the prioritisation of key areas for conservation. In the UK Overseas Territories, it also includes collecting and documenting the distribution of invasive species – a major threat to the biodiversity of these islands. In the UK, we will prioritise the accession of threatened plants and fungi and those most able to meet the challenges associated with global change.

Our *in situ* and *ex situ* conservation priorities are primarily to support our two global conservation programmes: Tropical Important Plants Areas and Banking the World's Seeds.

Tropical Important Plant Areas

Our Tropical Important Plant Areas (TIPAs) programme aims to identify the most diverse and threatened tropical areas in seven countries/regions – Bolivia, selected Caribbean UK Overseas Territories, Guinea, Cameroon, Uganda, Mozambique (see Box 6) and Indonesian New Guinea – followed by a second phase including at least five more countries/regions. Specimen data from this programme will contribute to the conservation of these highly diverse areas. Priorities for our collections will be to:

- Capture all existing Kew-based specimen data on target species, focusing on species and sites of high conservation importance.
- Analyse collection data to identify gaps and determine priority sites for field surveys and further collections, which can also be supplemented by sourcing pertinent material through exchanges, gifts or loans from other herbaria.
- Target in-country fieldwork to record, collect and map endemic, range-restricted and (potentially) threatened species and wild-harvested species of high socio-economic value, particularly non-timber forest products and crop wild relatives.

Priorities for new collections (Q3):

- Areas containing high plant and/or fungal diversity under threat.
- Endemic, threatened, ecologically important and useful species.
- Species that increase our understanding of resilience to global change and to plant pests and disease.

Banking the World's Seeds

Kew's Millennium Seed Bank (MSB) provides large-scale *ex situ* conservation of the world's flora. In close cooperation with members of our global seed conservation network, the Millennium Seed Bank Partnership (MSBP), we are on target to collect and conserve high quality seed of 25% of the world's bankable (orthodox) flora, a total of 75,000 plant species, by 2020. The seeds are stored in the country of origin, with duplicate storage in most cases at Kew. In addition, partner institutes within the MSBP deposit their collections data in the MSBP Data Warehouse, providing a unique global database of wild seed collections.

Beyond 2020, we will to continue to collect and conserve seed from threatened biodiversity and from useful plant species that are important for human well-being, prioritising under-collected regions, those with high or unique plant diversity and countries with limited seed-collecting infrastructure and capacity. In addition, we aim to make seed collections from plant species that demonstrate resilience to climate change and plant disease. We will focus on obtaining multiple seed collections across species' ranges.

In the UK, with our partners, we will maintain and enhance our seed collections in the context of current and future threats to the UK flora and Kew's research priorities, increasing the number of species conserved and the genetic diversity within species.

We will also begin large-scale use of cryopreservation to store those seeds that typically cannot be banked using the standard drying and freezing processes. This will be achieved through the development of a dedicated cryogenic storage facility at the Millennium Seed Bank (see page 46).

The quality of our seed collections, coupled with our expertise in storage and germination protocols, makes the Millennium Seed Bank an important resource for research, conservation, restoration, reforestation and crop breeding (see Box 7). The seeds, together with associated data and knowledge, are available for such uses, where permitted by partnership agreements, through the MSB Seed List.

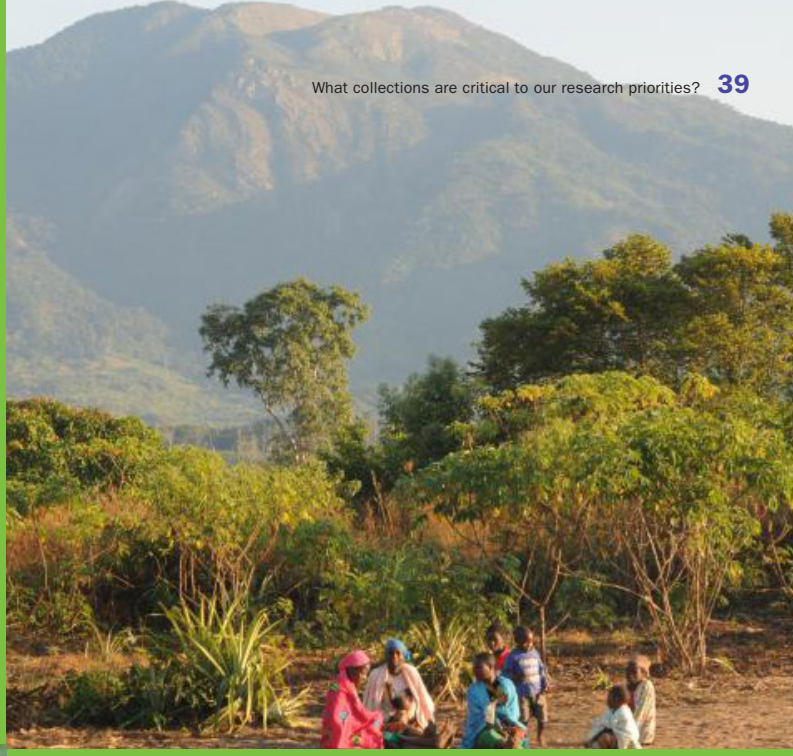
Over the next ten years we aim to:

- Increase the taxonomic scope of the collections: 100% of plant genera banked by 2028, with each genus represented at least once from each biogeographic region in which it occurs.
- Bank seed of endemic, threatened and ecologically important plant species not already in *ex situ* conservation, and increase the genetic diversity of collections.
- Bank seed of selected useful plant species: for example, 50% of all priority crop wild relatives banked by 2028.
- Increase collections of tree seed to bank 60% of all bankable (orthodox) tree species by 2028, building on the achievements of the Global Tree Seed Bank Project.

Resilience

To facilitate research into the resilience of plants and fungi to climate change and pests and pathogens, we will enhance the meta-data associated with all new collections and increase collections in selected taxonomic and ecological groups of relevance. We aim to:

- Record phenological data and anatomical traits useful for predicting responses to temperature and rainfall changes.
- Extend collections of succulent plants to study the evolution of succulence as a plant strategy to cope with limited water resources.
- Extend collections of extreme habitat-adapted fungal endophytes and lichens, and ex *situ* collections of halophytes, xerophytes and montane species, to study the ability of species to adapt to harsh environments.
- Increase seed and genomic collections of UK native trees, and isolates from the continental range of their fungal pathogens, to understand the threats faced by our native trees (see Box 8).
- Enhance collections of rust fungi to address global threats from the largest group of fungal pathogens.



Box 6: Identifying Tropical Important Plant Areas

There is an urgent need to identify the critical sites for plant conservation in diverse tropical areas, so that limited resources can be directed towards sustainable management and long term conservation. Kew scientists and partners are surveying the vegetation types and flora of areas such as the Chimanimani Mountains in Mozambique (right) to identify Tropical Important Plant Areas (TIPAs) – diverse tropical areas under threat. Collecting specimens in the field is critical to this work, which has already identified prospective threatened species across the tropics, including many new to science.

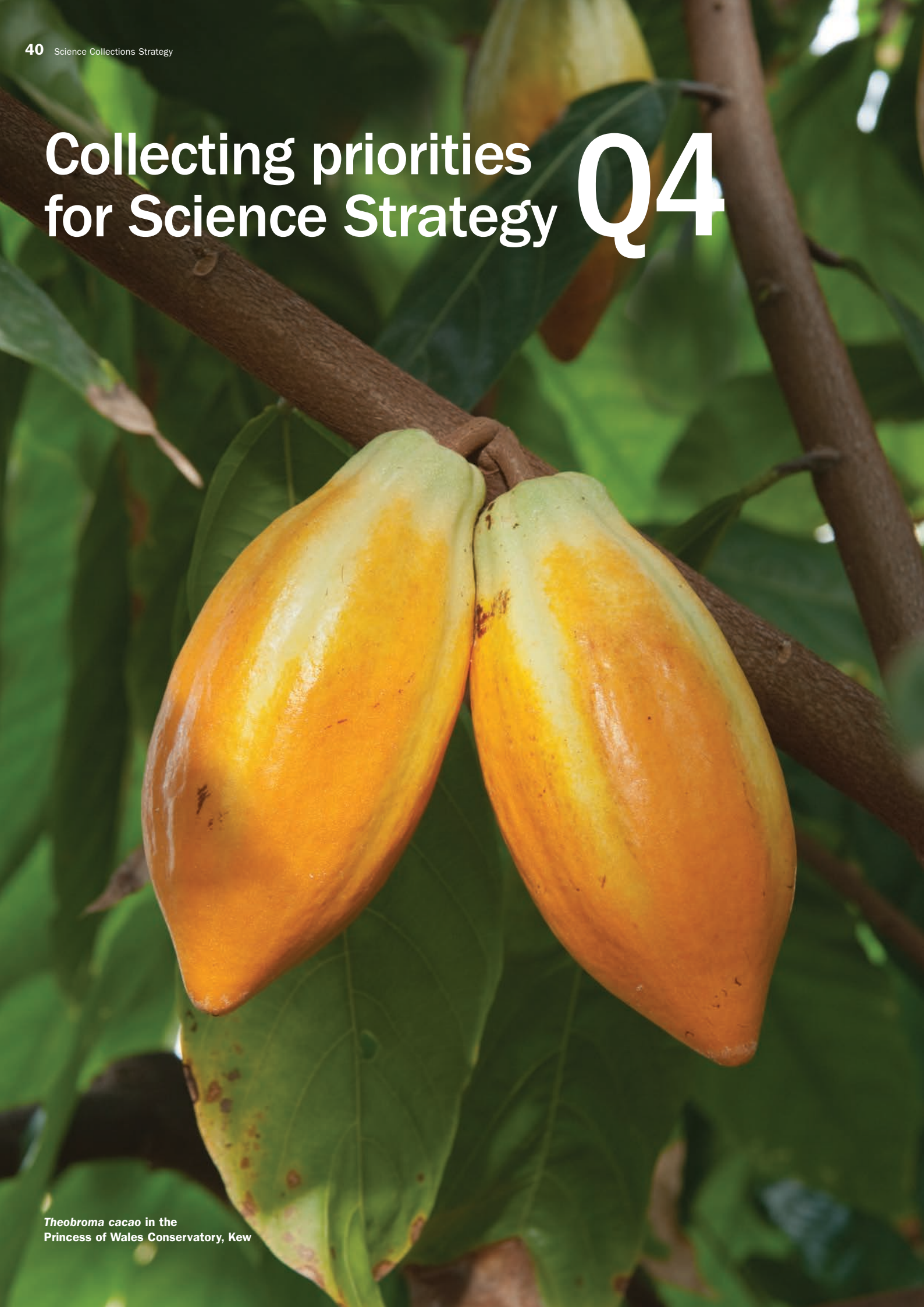
Box 7: Seed collecting in the UK Overseas Territories

Kew has been working in close partnership with the UK Overseas Territories (UKOT) for many years, to conserve their unique floras. Our collections provide an important back-up for restoration following natural disasters such as hurricanes (through germination of conserved seed), as well as important data for island research programmes. Priorities in the next decade are to collect and bank the remaining UKOT endemic and threatened species, with the biggest gaps occurring on Tristan da Cunha, Pitcairn, and the Cayman Islands. The image shows *Mellissia begoniifolia* (St Helena boxwood), which has declined to only a small handful of plants in the wild and is conserved in the Millennium Seed Bank.

Box 8: Fungal pathogens

Kew scientists and collaborators are studying fungal infections of UK trees. We are particularly interested in how tree genomes contain information governing the susceptibility of trees to pathogens. A major focus is *Fraxinus excelsior* (ash), for which we are sequencing 1,500 trees to search for genes for resistance to *Hymenoscyphus fraxineus*, the ash dieback fungus. At the same time, we are examining the genome of the fungus to find out what makes the species pathogenic. We hold major collections of native UK ash seeds in the Millennium Seed Bank. We are also working on *Quercus* (oak), which is affected by several fungi including *Armillaria* (honey fungus) species. We will sample and sequence whole genomes of up to 2,000 oak specimens, resulting in reference collections of DNA sequence data and herbarium vouchers. The image shows an ash tree infected with the ash dieback fungus.

Collecting priorities for Science Strategy Q4



***Theobroma cacao* in the Princess of Wales Conservatory, Kew**

Which plants and fungi contribute to important ecosystem services, sustainable livelihoods and natural capital, and how do we manage them?

In addition to its inherent value, the world's biodiversity is critical to our survival – it provides vital natural resources, such as food, clean water, fuel, shelter and medicine, supports life through carbon, oxygen and nutrient cycling, helps to regulate global climate and provides space for contemplation and recreation.

Collecting, conserving and understanding those plant and fungal species that are important natural assets, underpinning ecosystem services and associated societal benefits in the UK and worldwide, are all essential activities.

Identifying and collecting these natural assets for research will therefore be a priority in the next decade. As well as contemporary research, the time depth of Kew's collections offers exceptional opportunities to study processes of change in plant diversity and associated human use and knowledge. Targeted acquisition of plant raw materials and artefacts for the Economic Botany Collection will further strengthen its capacity to support this research.

Aside from our Economic Botany Collection, many of our collections contain only small numbers of specimens of useful plants, and we will therefore aim to increase the representation of useful plants across Kew's collections. Collections will also be made to strengthen Kew's expertise in particular areas, for example by enhancing our wood reference collection with specimens of timber species threatened by international trade, to support the Convention on International Trade in Endangered Species of Wild Fauna and Flora (see Box 9).

In relation to natural capital research, it is particularly important for collections, or parts of collections, to be preserved in a way that allows the extraction of secondary metabolites for chemical analysis or plant extracts for *in vitro* pharmacology/microbiology. We will also analyse the ploidy of selected species, since polyploids may show greater potential when breeding for resilience and yield.

In regional terms, our focus will be where the most biodiverse areas of the planet intersect with those areas in greatest need of enhancement of human lives and livelihoods, as indicated by the UN Sustainable Development Goals. Former long-standing conflict zones are also under-collected and can be valuable sources of collections. Collections-based research can bring societal benefits in such countries.

Four priority areas for research are food security, pollination, human health-related ecosystem services and climate regulation.

Priorities for new collections (Q4):

- Taxa important to food security – primarily selected crops and their wild relatives but also including edible wild plants.
- Selected plant species associated with pollinators that play key roles in ecosystem function, crop pollination and bee health.
- Species that contribute to human health and well-being.
- Taxa that can help to ameliorate the effects of global climate change.

Food security

There are around 30,000 species of edible plants globally, but just three crops (wheat, rice and maize) account for almost 60% of global food consumption, and just 64 crops deliver 80%. Research to enhance diversity of food sources is vital. The genetic bottlenecks that have arisen from crop breeding have resulted in many being genetically depauperate and thus vulnerable to pests, diseases and changing environmental conditions. Genetic diversity is therefore the key to resilience against these threats and to solving the problems arising from nutritional depletion of crops. The sources of this genetic diversity are often orphan crops (those that are not traded internationally but are valuable sources of nutrition regionally), minor crops (those that are not widely grown), their land races (locally adapted strains), wild-harvested food plants and the wild relatives of crop species.

In the next decade, we therefore aim to make collections of key crops (including forage crops), crop wild relatives and edible plants exploited from wild sources, for which there are not already strong, diverse research collections. Our focus will be on taxa such as *Coffea* (coffee), *Theobroma* (cocoa), *Dioscorea* (yams), and other tuber or tuber-like crops such as *Ensete* (enset; see Box 10) and aroids. Cryopreservation (freezing material in liquid nitrogen to preserve it) will be an important resource allowing us to collect and store clonal crops (see pg 46). Other collection foci will include *Musa* (banana), minor cereals and other grasses involved in provisioning ecosystem services, neglected and underutilised legume and crucifer crops and their wild relatives (especially leafy crucifers and related species), and wild and domesticated accessions of grain and forage legumes for comparative domestication analysis (especially lupins).

Finally, we aim to enhance our collections of edible taxa and crop wild relatives that have undergone recent polyploidy (duplication of their genetic material). These typically have increased genetic variation, which can be exploited in breeding programmes to address food security challenges such as yield, disease resistance and nutritional quality.

Fungal benefits

Endophytes (fungi growing inside plants) are known to provide many benefits to plants, such as protection from herbivory and enhanced water retention during drought, so there is potential for applying them to agricultural systems, thereby relieving farmers' reliance on pesticides, fertilisers and irrigation. However, we are still grossly ignorant of the full extent of endophyte diversity and biology. To overcome this, we will explore options, with partners, to establish the first genetic resource collection in the world that is focused on endophytic fungi recovered from the seeds of plants – at Kew or based in a partner institution. This will particularly focus on those endophytes that are found in the seeds of crop wild relatives held at the Millennium Seed Bank, so that they can be compared with those from domesticated crops. Endophyte-mediated fitness benefits in crops can be combined with plant breeding approaches, exploiting, for example, genetic variation in polyploids, to explore the potential of combining these traits to aid crop growth in untended/marginal lands.

Pollination

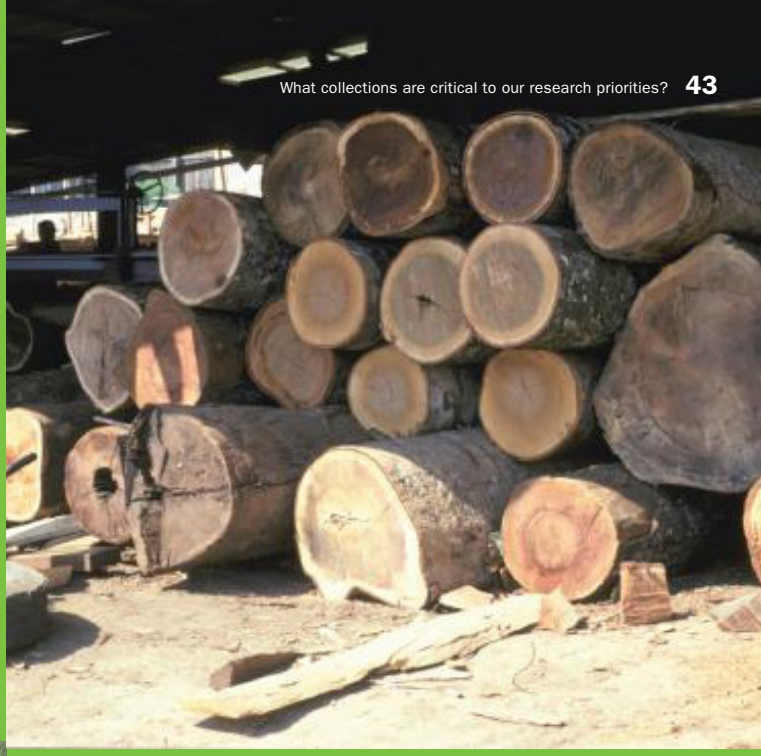
Pollination research through the lens of chemical ecology remains a research priority. This will require increased living collections of key UK and overseas plant species associated with pollinators that play roles in ecosystem function, crop pollination and bee health (e.g. members of Fabaceae, the legume family). Such species will be needed in experimental quantities for research on their natural product chemistry, especially of their nectar, but also at larger scale for field experiments. The landscape and vegetation at Wakehurst will play a key role in such research. The chemical reference collection, used for identification of compounds of the plant and fungal metabolome, is also an important resource and will be enhanced through this research.

Human health-related ecosystem services

We will maintain and enhance our collecting focus on plants that underpin human health and well-being. Thus, we will develop our collections of plant and fungal taxa associated with medicinal use in addressing conditions such as dementia, Alzheimer's disease, malaria and diabetes. We will increase research activity on plants and fungi associated with antimicrobials (see Box 11) and antifungals, and this will require collections of seeds and material from which metabolites can be extracted, especially plant and fungal tissue in silica gel and fungal tissue in the Fungarium. We will also seek to enhance the chemical reference data held at Kew, for identification of compounds of the plant and fungal metabolomes. The Economic Botany Collection contains 25,000 samples of crude drugs, dating from 1800 to the current day, and includes a major collection of Chinese medicines vouchered by herbarium specimens. The stability of many phytochemicals in these collections means that even the oldest specimens are of value for research into compounds of potential medicinal use.

Climate regulation

Plants and fungi have a crucial role to play in ameliorating the effects of climate change. To ensure that the plant and fungal species most important to tackling these effects are conserved, in the next decade we aim to develop our collections to facilitate research into the potential of different species to draw down atmospheric CO_2, and to mitigate the impacts of droughts, flooding and soil erosion. We will also develop our collections of plants with potential for energy production, focusing in particular on xeromorphic plants (those with adaptations to conserve water) to investigate their energy production when used in a biodigestor. This has the potential to open up the use of marginal lands for energy production, especially in lower latitudes. We will also target oilseeds and aquatic plants for comparative research on energy production to provide diverse potential solutions to energy needs.



Box 9: A global wood reference collection

The international trade of timber has significant impacts on many tree genera. Particularly vulnerable genera include *Dalbergia* (rosewood) and *Diospyros* (ebony). We aim to establish the global reference collection for threatened timber species, building on our existing wood collection and expertise at Kew. This will support both our research and our role as the UK Scientific Authority for Flora under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

Box 10: Food security – enset in Ethiopia

Ensete (enset) is a large, perennial, herbaceous plant similar in form to the related banana. It provides a food source for around 20 million people in Ethiopia through starch from its corms and leaf sheaths – 15 plants can feed a family of five for a year. With partners in Ethiopia we are currently studying the biology of this important plant, gathering information on variation in form, flowering, fruiting and chromosomes, genetic diversity and the occurrence of pests and disease. This will provide the knowledge to enable its use as a resilient, genetically diverse, climate-smart crop of the future. The image shows enset growing in the agri-landscape of south-west Ethiopia.

Box 11: Antiseptic plants for tropical ulcers

Ficus botryocarpa, a tree in the family Moraceae, is used in Papua New Guinea to treat bacterial skin infections such as the tropical ulcer. The sap is antibacterial and dries to form a flexible wound covering. For people living in remote, hard-to-access rainforest, local plant medicines are often the only practical treatment option. Kew is working with biomedical scientists to evaluate tropical ulcer plant medicines in Papua New Guinea. The aim is to carry out a clinical trial to assess the effectiveness of antiseptic plants as a convenient early treatment option.

Prescott et al. (2017). *Journal of Ethnopharmacology* 205: 240–245.

How do we manage and develop our collections?

Management and infrastructure

As a global resource and the foundation for our research, the collections need to be well-managed, curated to high standards, widely accessible and secure. For the preserved collections (Herbarium, Fungarium and Economic Botany), we will seek to adopt the UK Museum Accreditation Scheme standards by 2019.

In doing so, we aim to ensure best practice and provide a benchmark to help assess curation and management as mandated in Kew's Corporate Strategy. The benefits of adopting the accreditation scheme also include formalising procedures and policies, facilitating responses to users' needs and interests and developing skills of staff.

For our other collections, we will adopt and enhance similar protocols. For example, the standards developed through participation in the Global Genome Biodiversity Network (GGBN) will be used to enhance curation and dissemination of data from the DNA and Tissue Bank. In addition, we will continue to create and maintain high quality seed collections throughout the Millennium Seed Bank Partnership (MSBP) in accordance with the MSBP Seed Conservation Standards, through partner training and technical support. These Standards provide a framework to assess the quality of seed collections across the network. The Millennium Seed Bank Database, the Seed List and MSBP Data Warehouse will be further developed to strengthen curation and to promote research, use and supply of seed collections across the partnership.

Institutionally, we will aim to strengthen our international partnerships further and to participate in the development of the European Distributed System of Scientific Collections. Through such partnerships, we will play an active role in helping to develop common standards and protocols between institutions to improve collection access, digitisation and data mobilisation.

We will also continue to ensure that we comply with relevant international and national regulations governing access to genetic resources and benefit sharing, such as the Nagoya Protocol. As the reporting for these international protocols develops further, we need to adopt new methods to streamline the administrative requirements and to develop best practice with partners to ensure a fast, efficient and transparent process.

The global demand for increased digital access necessitates improvements to our technical infrastructure to enable better integration and dissemination. The collections management systems will therefore be updated to facilitate the flow and management of data across collections. We will continue our commitment to high quality curation to ensure that our physical and digital resources retain their value for global research through the next decade and beyond. We will adjust workflows and resources to ensure the collections most relevant to current research are kept up to date with new acquisitions and changes in taxonomy, and that all specimens and data are accessible, well-curated and secure, with an audit trail tracking historical determinations of the names of specimens.

The current infrastructure housing the Science Collections is variable between and across collections in terms of physical quality, access for research and public engagement and risks from hazards including fire, pests and flooding. In the next decade, as we consider modernising our science buildings and development of the sites at Kew and Wakehurst more generally, the initial priority will be to ensure the security of the collections and the access necessary to carry out our research. Increased space for liquid nitrogen storage of seed, biosecure handling of potential pathogens, and environmental soil samples to study fungal diversity will also make demands on the physical infrastructure. Options for increasing opportunities for visitor engagement with the collections on site will also be developed. These requirements will be fed into the planning process for Kew's built estate.

Innovation alongside excellent curation is the key to increasing the utility of the collections

Innovation

In the next decade, we aim to adopt new methodologies and technological innovations to enhance the collection, curation and storage of our Science Collections.

Establishing the 'Kew Cryosphere' for extended seed preservation

Around 10% of seed plants have desiccation-intolerant (recalcitrant) seeds, including a high proportion of tropical trees and many species of conservation concern. Further groups of plants have seeds that are relatively short-lived under conventional storage (e.g. many Ericaceae and Primulaceae), or behave unpredictably following drying (e.g. *Coffea* (Rubiaceae) and Orchidaceae). Such species are therefore not suitable for traditional seed storage through drying and freezing, which is currently the main method of preservation used in the Millennium Seed Bank. An alternative method is cryopreservation, which involves cooling samples quickly to very low temperatures; this avoids the formation of damaging ice crystals in the cells and prevents further chemical or enzymatic activity that would cause degradation.

Cryogenic storage using liquid nitrogen has been shown to offer solutions for long-term *ex situ* conservation of plant species as seed or embryo collections and has the potential to open up a new area of seed banking at the Millennium Seed Bank (see Box 12). Cryopreservation can also be used to preserve the tubers of important crops and crop wild relatives. In the next decade, we therefore aim to develop the 'Kew Cryosphere' – a storage facility to support research priorities and conservation targets by providing cryogenic storage facilities and training.

Enhancing storage methods for the genomic era

Genomic and transcriptomic techniques are rapidly evolving, and we need to ensure that the methods we use to collect and preserve material, and to store the data derived from that material for research, are robust. Currently, we collect and preserve tissue collections in silica gel, and this is an effective method for retaining samples for future DNA or secondary metabolite extraction. However, there may be more effective ways for storing this material, particularly for long term use. In the next decade, we will explore the use of alternative storage methods for tissue samples, including methods of RNA-preservation for studies of gene expression. With the increase in genomic studies, we will also establish methods for the storage of high-throughput sequencing libraries and develop the infrastructure needed to collect, curate and store genomic data.

Developing new field collection practices

The use of technology in field collecting has been increasing as devices such as GPS and laptops have become more portable and as the capacity to upload data through mobile internet signal has increased. We will ultimately work towards all collections being 'born' digital – utilising new technologies to directly upload specimen data, including name, description, habitat, traits, location, and associated images, into the core collections management system and relevant databases at the time of collection or soon after. From there, it can be curated and managed effectively before ultimately being disseminated via online portals. Until this becomes possible, we will implement a comprehensive accession process so that within three years of collection in the field, all parts will be catalogued in the appropriate collection, digitised and accessible online as well as in the physical collection.

We will also explore methods to increase the quality and usefulness of collections, for example how to ensure an appropriate level of sampling to capture genetic diversity of populations and species in seed collections (see Box 13). To support our research work on plant health, protocols for population sampling of plant material will also be developed.

In terms of fungal collecting activities, current collections of fruiting bodies and cultures in the Fungarium only capture a small part of fungal diversity. Over the next decade, we therefore aim to explore the expansion of fungal collecting activities to include environmental sampling. This will provide us with information about the fungal communities present at a certain time and place, yielding opportunities for species discovery and analysis of changes in communities through time and facilitating research on the associations between plants and fungi. This will require development of appropriate storage for environmental samples and clarification of the procedure for making specimens from fungi when no reproductive structures are present.

Finally, Kew scientists have demonstrated that genome sequencing in the field is now possible (see Box 14), and as this and other technologies develop and become more efficient, we will explore the potential for field DNA-sequencing to become standard practice during collection of herbarium and fungarium specimens.

Box 12: Cryogenic storage of desiccation-intolerant seeds

In tree-dominated vegetation in the tropics, recalcitrant (desiccation-intolerant) seed behaviour presents a serious barrier to successful *ex situ* conservation. At least 40% of tree species growing there are predicted or known to have recalcitrant seeds – they cannot survive the standard storage procedure of drying and freezing. Some economically and ecologically important temperate trees such as *Quercus* spp. (oaks) and *Aesculus hippocastanum* (horse chestnut) are also recalcitrant, and there is evidence that many others have relatively short-lived seed that would also benefit from cryopreservation. Expanded cryogenic storage will allow us to conserve such seeds effectively as we work towards our strategic output of Banking the World's Seeds.

Box 13: Increasing genetic diversity of seed collections

At Kew, we are exploring methods to increase the quality and usefulness of collections. The UK National Tree Seed Project (UKNTSP) has undertaken a population genetics study on *Taxus baccata* (yew), which has measured the amount and distribution of genetic diversity throughout UK populations of the species and compared these to the diversity present in Millennium Seed Bank collections. A similar study, undertaken through a modelling approach, has provided quantitative estimates of the capture of alleles in MSB collections of ash. The results from both suggest that a high proportion of alleles present in the UK have been captured using the UKNTSP sampling strategy. These innovative approaches provide models and tools for more effective and efficient genetic sampling throughout the Millennium Seed Bank Partnership in the future.

Box 14: DNA sequencing in the field

In 2016, Kew scientists became the first in the world to conduct plant genomics in the field – using a hand-held device called a MinION to successfully sequence the DNA of two closely related species in Snowdonia, Wales. This method, revealing tens of thousands of letters of the genetic code in real-time, can be used for rapid identification of samples by comparing the data to DNA databases and is also useful for more in-depth genome-wide analyses. This experiment used mobile lab equipment to extract the DNA and prepare it for sequencing; as the technology becomes smaller and more efficient it may eventually lead to collection of genomic data as standard during fieldwork.

Parker et al. (2017). *Scientific Reports* 7: 8345.

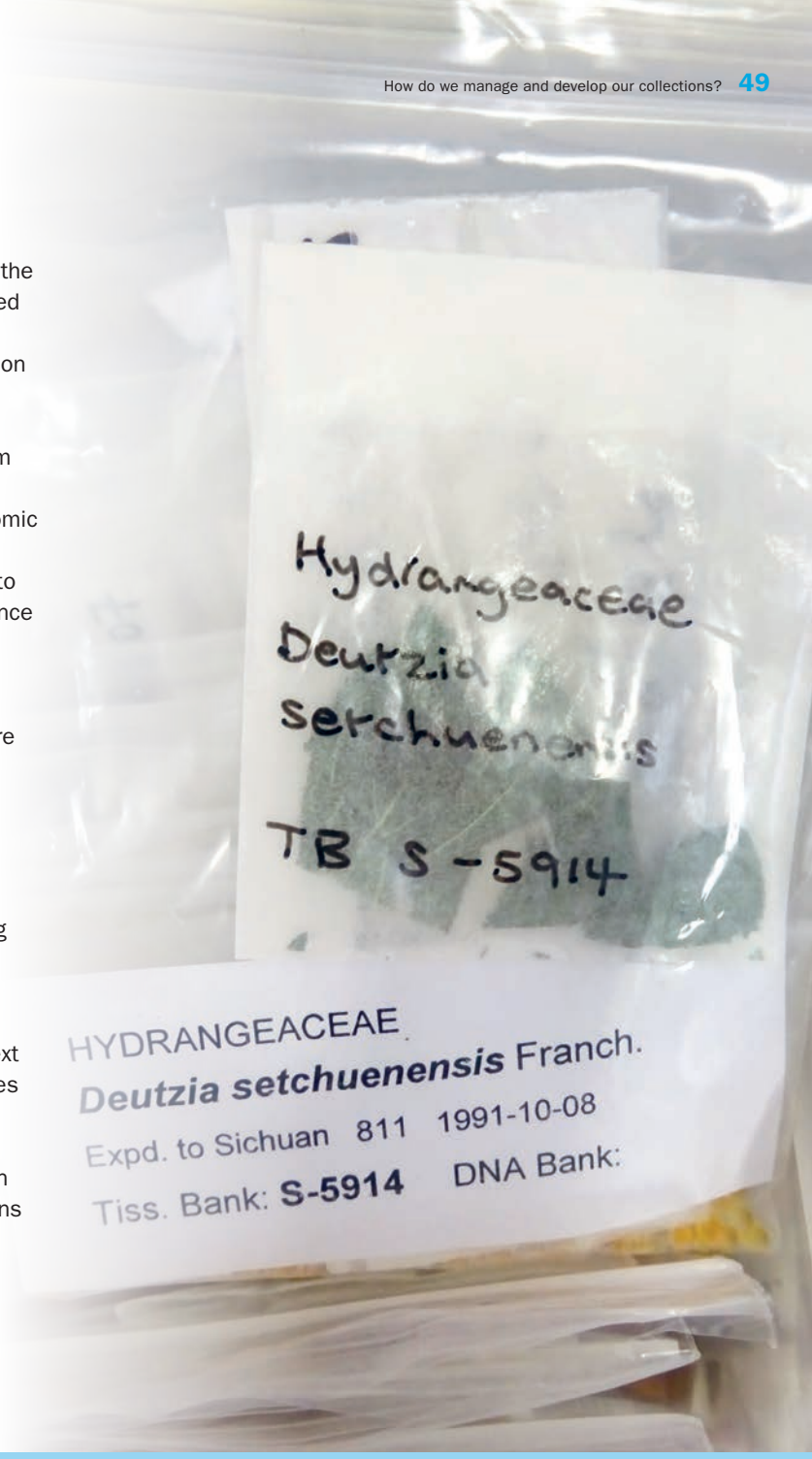
Collecting Rubiaceae specimens in *Baphia madagascariensis* forest, north-eastern Madagascar

Improving collecting efficiencies

To maximise the return on field expeditions and improve the value of our collections both for pure research and applied activities such as authentication of wood and medicinal compounds, our ambition is to implement a multi-collection aim – thus wherever feasible, any field visit will aim to collect samples relevant to multiple collections (i.e. two or more of the following: herbarium specimens, fungarium specimens, tissue samples in silica gel, seeds, wood samples where appropriate, plant products for the Economic Botany Collection and photographic images for online portals). We also aim to expand our collecting activities to capture traits relevant to ecological tolerance and resilience and associated data on phenology and ecology. Targeted collection will be prioritised for areas where plant and fungal material can be collected to support investigation into several research questions simultaneously and where partnerships allow effective delivery of research benefits and positive impacts on livelihoods.

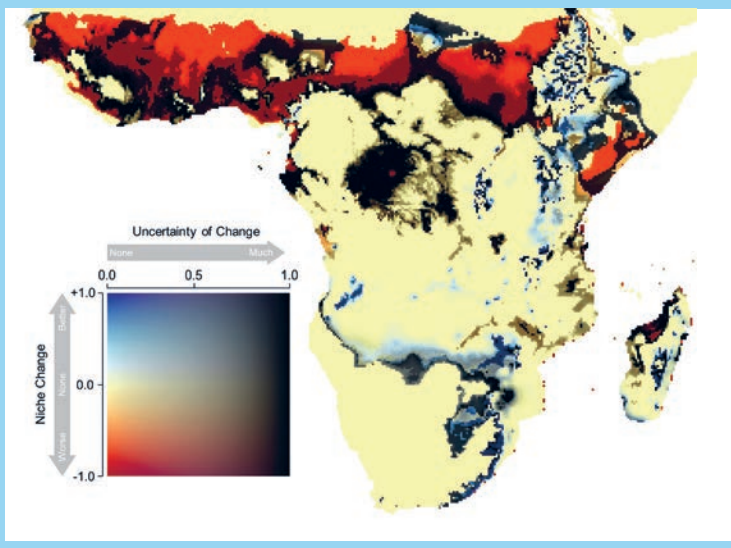
Enhancing the analysis of collection data

Kew is well placed to lead developments in the modelling and analysis of natural history collection data. The high standard of curation of the physical collections and their associated digital data provides a strong evidence base for the construction of models (see Box 15). Over the next decade, we will embrace new machine learning techniques to enhance the curation and analysis of the Science Collections. Possible applications of these techniques to Kew's collections include accelerating the interconnection of collection data, institutional-scale analysis of collections and comparison with other institutional collections, and identification of species most likely to be threatened.

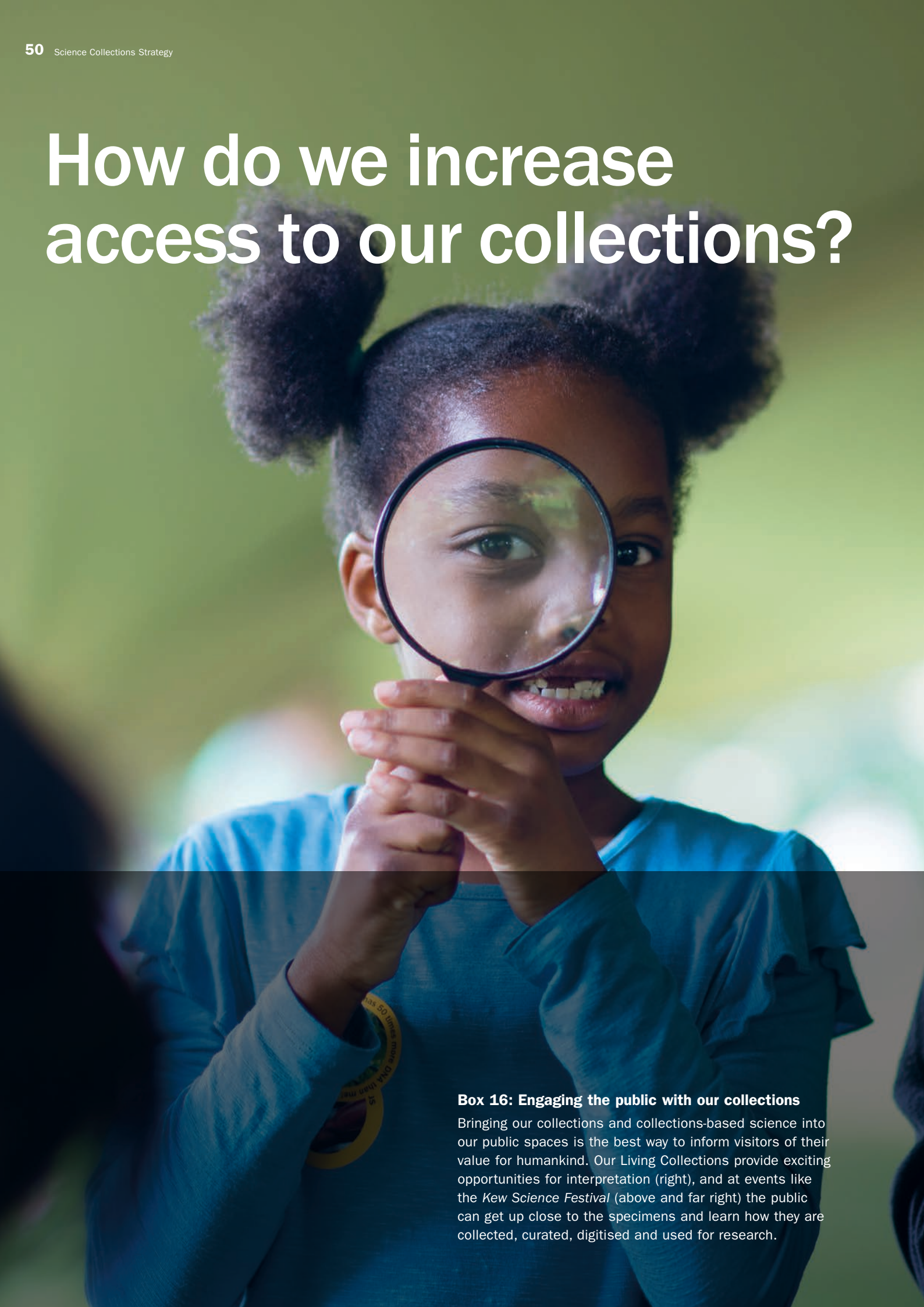


Box 15: Using specimen data for food security predictions in Sub-Saharan Africa

Kew is a partner in the FICESSA project (Food Security Impacts of Industrial Crop Expansion in Sub-Sahara Africa), and as part of this we are using location data from herbarium specimens and other sources to investigate how the climatic suitability for crops and crop wild relatives may change in the future across sub-Saharan Africa. This can be used to help identify locations that may contain priority species for collection, to ensure food security in the region. The map is an example of an output from one of these models, indicating where changes are likely to occur in a species' range, to what degree and how much confidence we can place in the prediction. This type of modelling can also be used to prioritise regions for collecting to support conservation and sustainable use.



How do we increase access to our collections?



Box 16: Engaging the public with our collections

Bringing our collections and collections-based science into our public spaces is the best way to inform visitors of their value for humankind. Our Living Collections provide exciting opportunities for interpretation (right), and at events like the *Kew Science Festival* (above and far right) the public can get up close to the specimens and learn how they are collected, curated, digitised and used for research.

Kew's collections provide a significant resource for the global research community and society as a whole, and we will continue to support and facilitate the research and information needs of others by increasing access to, and engagement with, our physical collections and their digital counterparts.

Improved physical access

Enhancing visits and use of the collections

Physical visits to Kew's Science Collections and related facilities add up to around 10,000 visitor days per year, and this daily use of the collections by researchers will continue to be encouraged. To optimise visits to the collections, we aim to improve the databasing tools available to our staff, volunteers and visitors. This will enable them to target relevant collections more quickly, thereby increasing the efficiency of their work. We will also continue to loan specimens from across the collections to other institutions for study, and (whenever possible and permitted under the terms of our agreements) samples will be given to facilitate research. We will improve the accessibility of our Seed List – which provides details of seed collections available for supply – through linking it to our other data resources and online portals, increasing the visibility and use (where permitted) of our collection.

Finally, we plan to carry out a user survey to more clearly identify the value of our Science Collections to external researchers and to gain feedback on aspects of collection management. This feedback will be used to review and revise our practices to provide more effective and efficient access to the collections.

Increasing public engagement

Over the next ten years, we aim to provide greater public visibility of the Science Collections in our galleries and public spaces and to continue to engage in events such as open days and festivals. We will also develop a new public science interpretation space, which will be created as part of the overall development of the Kew site. Our vibrant *Science in the Gardens* programme will be further enhanced to provide informative ways for the public to interact with our scientists and the collections. As part of this, we will build further on the success of the annual *Kew Science Festival* (which began in August 2016), bringing key specimens out into the gardens to demonstrate the full breadth of collections-based work at Kew and the relevance of this work to finding solutions to global challenges (see Box 16).

Complementary to this, our Living Collections define Kew and Wakehurst as botanic gardens and provide a direct interface with visitors, allowing us to communicate our science in exciting and engaging ways (see Box 16). Increased synergy between the scientific and horticultural collections at Kew and Wakehurst will be actively sought, and this will enable increased opportunities for science-based public engagement. We will aim to develop displays

of plant species that illustrate Kew's science programmes, such as the Plant and Fungal Trees of Life and Tropical Important Plant Areas, helping to explain the importance of Kew's research and its wider relevance.

Finally, digitisation of our collections presents further opportunities for public engagement. Kew's digital resources have an important role to play in connecting the public with our collections and the importance of plants and fungi to human lives. We will utilise Kew's extensive media and social media channels to promote access to, awareness of, and engagement with, the digital collections – for example, strengthening links between the digitisation of the collections and public engagement initiatives such as *Grow Wild*. In addition, we will also be looking to engage the public in helping us with our science programmes through the development of a citizen science platform. Possible activities include transcribing the label data from digitised images of the specimens into our collection databases (see Box 17).

Enhanced digital access

Digitising the collections

Expanding digital access to collections can be achieved in a number of ways and will greatly facilitate the research required to understand, conserve, manage and use the Earth's plant and fungal diversity. Currently, just over 21% of Kew's collections are databased (data entered into an institutional database and available externally where permitted by agreement with partner country). This includes all data for the Economic Botany Collection, the DNA and Tissue Bank and the Seed Collection in the Millennium Seed Bank. Collections with incomplete databasing include the Fungarium (40% databased), Microscope Slide Collection (37%), and the Herbarium (12%) – the last being Kew's largest collection and greatest digitisation challenge.

Alongside database records, digital photographs (images) of the specimens allow us to share our collections more widely, adding a visual dimension and providing additional information. Currently, around 8% of Kew's herbarium specimens have been imaged, including all type specimens (c. 330,000 specimens). Very few of the other collections have images available (see Table 4).

Until very recently, the time taken to make physical collections accessible to all through data capture, and imaging where appropriate, was prohibitive. However, recent advances in industrial-scale imaging and processing now make this task possible, facilitating more efficient data capture from images of the specimens and their labels rather than directly from the physical specimen. Capturing data and imaging the collections is important for the dissemination of information but also to safeguard some of the value of this unique asset against the risk of physical disaster.

By 2020, we therefore aim to initiate a mass digitisation programme to image all herbarium specimens and capture at least the essential data from 80% of our Science Collections. By 2028, we aim to complete the databasing of the Science Collections and to image all our fungarium type specimens, all fungarium specimen labels and selected microscope slide, seed and economic botany specimens (such as fabrics, dyes, and baskets), making them available through online portals (see next section). As a major step towards Herbarium digitisation, we are collaborating with the Natural History Museum, London, Royal Botanic Garden Edinburgh and other institutions on the creation of a UK Open Herbarium, giving digital access to images of all the herbarium specimens held in these major UK institutions – this will eventually extend to other UK partners. In-depth data will be captured from the images, prioritising those specimens and/or data types that support research priorities.

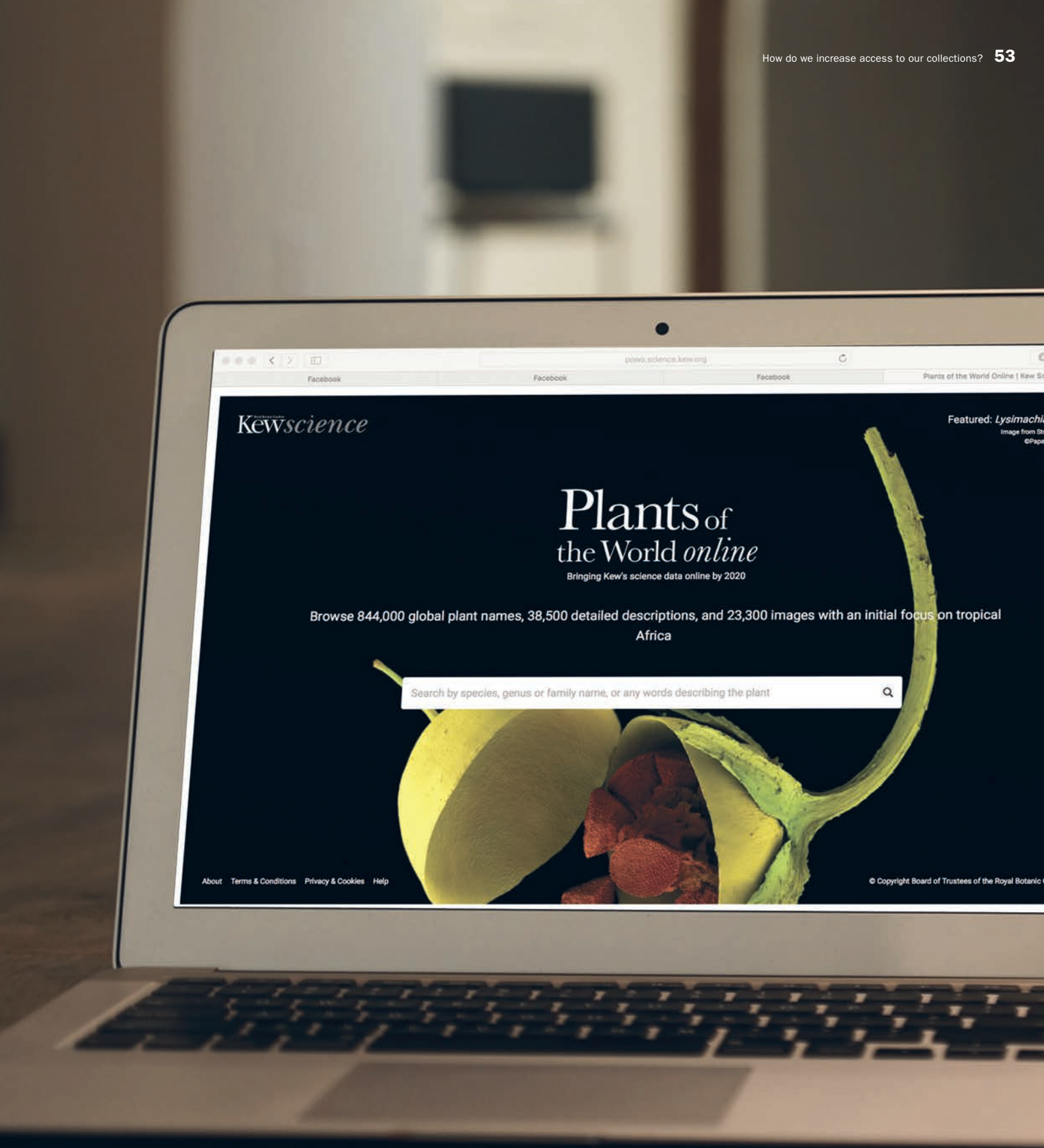
In addition to the collections and databases mentioned above, the Library Art and Archives department manages relevant archival material such as field notebooks. Mechanisms to provide greater digital access to the information held in field notes and photographs will be part of their collections strategy.

Mobilising Kew's collection data through online portals

Continuing our work to mobilise Kew's collection data through digital channels, the Plants of the World Online (POWO) portal aims to make our scientific data, including information on all seed-bearing plants, accessible online by 2020. The POWO portal will be a single point of access from anywhere in the world for authoritative information on Kew's plant collections and will be available through desktop, tablet or mobile interfaces. It will provide a multi-dimensional catalogue of plant life, including information on identification, distribution, traits, threat status, molecular analyses and uses. It will utilise our extensive data resources alongside images from the digitisation of the collections. This one-stop portal will enable dissemination of plant information at levels accessible to all and will enable us to share our scientific knowledge of plants more widely, maximising its impact in science, education, conservation policy and management.

The portal requires a comprehensive names backbone; this will be built on the globally renowned International Plant Names Index (IPNI) and World Checklist of Selected Plant Families (WCSP), both curated by Kew with support from many partners. A similar model for fungal content, Fungi of the World Online (FOWO), will be developed in the next decade, using POWO's architecture but with Index Fungorum and Species Fungorum as the name spine.

All collection data will be made available via POWO and FOWO and will be compatible with other data held at Kew, such as digitised Floras, art work, literature and photographs, and other data systems such as those for Tropical Important Plant Areas and the Plant and Fungal Trees of Life. The collections systems will benefit from the use of standardised taxonomic backbones developed for POWO and FOWO to ensure consistent standardised nomenclature and links between scientific and common names to increase the accessibility of collection data to a non-specialised audience.



Data on Kew's collections is widely available through internal collection catalogues and online portals

Integrating our systems

To improve digital access and management of our collections, we aim to improve the integration and data quality of our collection databases, plant and fungal name databases and other relevant data sources. This will provide efficiencies in cataloguing the collections, ensure easier tracking of movements between collections, and support increased digital access to collection data. We will evaluate collection management systems to identify an optimal solution for collection data, and will begin to plan for the implementation of an integrated system in 2018. The integrated system will also incorporate field-gathered data – specimen information captured by hand-held devices, including geographical location and photographs, or field-collected genomic data such as that described above (Box 14). This will enable more efficient data handling and analysis and faster dissemination of data through POWO, FOWO and other interfaces. By adopting the relevant data standards and protocols, innovative methods of data capture can be explored and integrated.

We will also continue to make our core science data openly available via appropriate data portals, such as Plants of the World Online, World Flora Online, JSTOR Global Plants, Genesys, Global Biodiversity Information Facility, TRY Plant Trait Database, Europeana, Global Genome Biodiversity Network and the Kew Science website. We will stimulate increased use by application of an open licence and by developing systems to support external annotation of collection data by researchers. In addition, we will aim to develop the use of unique persistent identifiers for all our collections data, to support integration with other systems, to aid citation of our data and to allow us to track its use.

Our online resources provide an authoritative source of accurately named material that can be used for a variety of research and applied activities (see Box 18). Currently, the collection digital catalogues are accessed via 825,000 unique page views annually by 65,000 unique users from Kew's website, and 75,000 datasets using Kew data were downloaded from the Global Biodiversity Information Facility in 2017. These statistics provide a baseline to monitor increased use. By improving access to these collections, we aim to increase their use and impact in scientific research and to build a stronger link between the public and the collections that underpin our understanding of the natural world.

Box 17: Using crowdsourcing to engage citizen scientists

WeDigBio is an annual global event that engages participants online and on site in digitising natural history collections. The image shows volunteers learning how to transcribe collection data from our herbarium specimen sheets during a WeDigBio event at Kew. In the next decade, we plan to greatly enhance crowdsourcing in order to tap into the vast and important resource provided by citizen scientists.




Box 18: Digital Amazon

A project is underway to digitise Richard Spruce's Amazon ethnobotanical specimens collected between 1849 and 1864. This will allow us to find out more about changes in landscape and environment, plant resources and cultural use of plants from the 19th century to today, and to make predictions for the future. A web platform connects a network of UK and Brazilian researchers and experts, enabling information on the biological, technological and cultural aspects of Richard Spruce's collection to be shared. The project also generates community-focused resources for the benefit of Brazilian researchers and indigenous communities and is a clear example of the benefits of digitising and sharing collection data. The image shows a shield made of timbó-titica *(Heteropsis flexuosa)* with a loop woven from tucum *(Astrocaryum vulgare)* thread, collected by Spruce on the Rio Vaupés, Brazil, in 1852.

What will success look like in 2028?

***Espeletia brachyaxiantha*,**
Páramo de la Rusia, Boyacá, Colombia

Success will be reflected in all new scientific collections explicitly supporting our research and strategic outputs, while increased accessibility of the collections will also support the research of others. Key successes, listed under the major headings of this strategy, are as follows:

What collections do we currently have?

By 2028:

- Kew's Science Collections will be audited to species level.
- Major gaps in our collections will have been identified and evaluated in the context of other international collections.

What current and future collections are critical to our research priorities?

By 2028:

- Critical gaps in the collections will be filled in line with Kew's scientific vision and research priorities.
- Our collections will contain increased representation of plant and fungal species from target areas in Sub-Saharan Africa, South-East Asia, Central and South America, and the UK Overseas Territories, particularly endemic, threatened, and ecologically or economically important species.
- Seed from all plant genera, 50% of all priority species of crop wild relatives and 60% of tree species that have bankable seeds, will be stored in the Millennium Seed Bank or banked by in-country partners.
- Our collections will contain increased numbers of those plant and fungal species important to addressing UK conservation and plant health issues.
- Our collections will contain targeted plant species associated with pollinators that play key roles in ecosystem function, crop pollination and bee health.
- Our collections will have greater utility for the study of climate regulation, the effects of climate change, and mitigation of the impacts of drought, flooding and soil erosion.
- Our collections will contain a global reference collection of wood specimens for tree genera threatened by international trade.
- Tissue samples will be routinely collected from every field specimen, from germination tests conducted at the Millennium Seed Bank, and from living plants at Kew and Wakehurst, to fill gaps for genomic and biochemical studies.
- Phenological data and trait data relevant to resilience to climate change and disease will be recorded as standard during field collections, where available.

How do we manage and develop our collections?

By 2028:

- We will achieve Museum Accreditation for the Herbarium, Fungarium and Economic Botany collections.
- We will adopt and contribute to Global Genome Biodiversity Network standards for the DNA and Tissue Bank.
- The Millennium Seed Bank Partnership's 'Seed Conservation Standards' will be applied to all seed collections across the partnership.
- Common standards and protocols will be developed and adopted for all collections as part of the 'European Distributed System of Scientific Collections' consortium.
- Streamlined workflows and agreements will be in place with partners and provider countries, ensuring fast, efficient, equitable and transparent processes for collecting and tracking material and monitoring its use.
- There will be a new 'Kew Cryosphere' storage facility at the Millennium Seed Bank at Wakehurst, providing greatly extended cryogenic storage and training facilities and the ability to bank key desiccation-intolerant tropical and temperate tree species.
- There will be improved infrastructure for the collection, curation and storage of genomic and transcriptomic data.
- Appropriate tissue preservation methods will be employed, allowing effective genomic, transcriptomic and biochemical analyses of plant and fungal material.
- Protocols will be established for environmental sampling, to support research into fungal diversity.
- We will have the ability to upload specimen data directly to our core collections databases at the time of collection or soon after.
- All field trips will employ a multi-collection sampling approach, where feasible, so that each plant, fungus or population contributes complementary material to two or more of our collections.
- Sophisticated modelling tools will be routinely employed to identify gaps and target collections.

How do we increase access to our collections?

By 2028:

- World-class physical and digital infrastructure will be in place for all collections.
- We will have achieved complete digitisation of Kew's Science Collections: data from all specimens will be in our institutional collections databases, with accompanying digital images for all herbarium specimens, fungarium type specimens, fungarium specimen data labels, and selected parts of other collections.
- All collections databases will be linked through an integrated data system.
- All data and images will be accessible through our online portals – Plants of the World Online and Fungi of the World Online – where permitted by law, international policy and partnership agreements.
- There will be a digitally accessible UK 'Open Herbarium' (established with UK partners) providing access to images of herbarium specimens held in major UK herbaria.
- The Millennium Seed Bank (MSB) 'Seed List' and seed collection data will be fully integrated with Kew's other data systems and with the MSB Partnership Data Warehouse, providing a global resource for wild seed collection data and supply.
- Visitors to the gardens at Kew and Wakeurst will enjoy enhanced interpretation linked to our Science Collections and associated research.
- Collections displays and opportunities to interact with specimens will be an integral part of the *Kew Science Festival* and other public engagement events in the gardens.
- Visits, tours and loans will continue to provide direct access to the physical collections.
- Crowdsourcing initiatives will be enhanced to increase data capture, analysis and citizen scientist engagement with all collections.

Spirit Collection specimen from the cactus *Melocactus macracanthos*

Acknowledgements and further information

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Front and back cover: Cross section of wood and bark from the stem of *Acacia dealbata*, also known as the silver wattle, blue wattle or mimosa (imaged using a 5X objective lens; A. Musson); slide originally prepared by Warwick, N. et al. (2017) for *Ann. Bot.* 119(8):1249–1266. **Inside front cover:** *Phallus* (stinkhorn) specimen and boxed specimen of *Clathrus archeri* (devil's fingers) from the Fungarium. (S. Lancefield). **Foreword:** Professor Katherine J. Willis (A. McRobb), Dr Alan J. Paton (M. Winwood). **Pg 3:** Fragment of barkcloth collected in the Solomon Islands by Lady Robinson in 1876 and conserved as a Master's project by Elizabeth Palacios, Centre for Textile Conservation, University of Glasgow (E. Palacios). **Pg 4:** DNA sample of *Nesiota elliptica* (A. McRobb). **Pg 5:** Overseas Territories Programme Officer completing the protocol for *Rondeletia buxifolia*, a critically endangered endemic forest shrub from Montserrat (C. 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Names and authorities of genera and species cited in the text

Acacia dealbata Link, *Accara elegans* (DC.) Landrum, *Aeonium* x *velutinum* (N.E.Br.) H.Y.Liu, *Aesculus hippocastanum* L., *Alsophila* R.Br., *Armillaria* (Fr.) Staude, *Artemisia umbelliformis* Lam. subsp. *eriantha* (Ten.) Vallès-Xirau & Oliva Brañas, *Astrocaryum vulgare* Mart., *Baphia madagascariensis* C.H.Stirt. & Du Puy, *Boletus pruinatus* Fr. & Hök, *Chamaecrista rotundata* (Vogel) Govaerts var. *grandistipula* (Vogel) Govaerts, *Clathrus archeri* (Berk.), *Coffea* L., *Cortinarius brunneoalbus* Ammirati, Liimat. & Niskanen, *Cyttaria darwinii* Berk., *Dactylorhiza majalis* (Rchb.) P.F.Hunt & Summerh., *Dalbergia* L.f., *Dendrobium spiculatum* Schuit., *Dioscorea* L., *Diospyros* L., *Ensete* Bruce ex Horan., *Espeletia arbelaezii* Cuatrec., *Espeletia brachyaxiantha* S.Díaz, *Ficus botryocarpa* Miq., *Fitzroya cupressoides* (Molina) I.M.Johnst., *Fraxinus excelsior* L., *Heteropsis flexuosa* (Kunth) G.S.Bunting, *Hevea brasiliensis* (Willd. ex A.Juss.) Müll.Arg., *Hymenoscyphus fraxineus* (T. Kowalski) Baral, Queloz & Hosoya, *Hyperacanthus* E.Mey. ex Bridson, *Lagenaria siceraria* (Molina) Standl., *Licuala grandis* (T.Moore) H.Wendl., *Mellissia begoniifolia* (Roxb.) Hook.f., *Melocactus macracanthos* (Salm-Dyck) Link & Otto, *Musa* L., *Nesiota elliptica* (Roxb.) Hook.f., *Onopordum macrocephalum* Eig, *Paranephelius ovatus* Wedd., *Phallus* Junius ex L., *Quercus* L., *Rondeletia buxifolia* Vahl, *Satranala decussilvae* Beentje & J.Dransf., *Taxus baccata* L., *Theobroma* L., *Theobroma cacao* L., *Tristachya betsileensis* A.Camus, *Weinmannia tomentosa* L.f., *Xanthoria elegans* (Link) Th. Fr.

Science Collections at Kew
Watercolour by Anita Barley (2016)

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