
Royal Botanic Gardens
Kew
Science for a
Changing World

Foreword

Life on Earth is in peril. The devastating and intertwined impacts of biodiversity loss and climate change are affecting each one of us on this planet, some more than others.

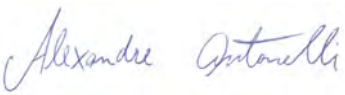
And yet we continue to destroy natural resources and deplete biodiversity – our life-support system – on a massive scale. The 'Great Acceleration' that has characterised human development since the 1950s has also been a time of 'Great Decline' for nature – a decline I have witnessed first-hand in the tropical ecosystems of my home country, Brazil.

But there is hope. Achieving sustainable human development requires a fundamental understanding of the world and practical solutions to redress the harm we have caused it, and science can underpin this effort. In this quest for solutions, the useful properties of plants and fungi are largely untapped, and hold the potential to bring equitable benefits to people and nature.

We at the Royal Botanic Gardens, Kew have an ambitious plan to help stop biodiversity loss and develop sustainable nature-based solutions to some of our biggest global challenges – as set out in our *Science Strategy 2021–2025* and summarised in this document. The next few years provide a closing window of opportunity for societies to protect and sustainably use Earth's remaining biodiversity and to restore what we have degraded.

My colleagues and I hope you will join forces with us in achieving this vision.

Sincerely,



Professor Alexandre Antonelli
Director of Science, Royal Botanic Gardens, Kew

Kew Gardens, our UNESCO World Heritage Site in south-west London.

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Science for a changing world

The world we live in is changing rapidly. The plants and fungi we depend on for food, medicines, building materials and our mental well-being are disappearing faster than ever before, as the full impacts of climate change and biodiversity loss take hold. We would have to go back 66 million years to find a similar wave of extinctions – then caused by a meteorite, but today undeniably the result of human activities.

These activities – such as clearing forests and peat bogs for agriculture and cities, polluting waterbodies and spewing greenhouse gases into the atmosphere – mean we have exceeded Earth's 'planetary boundaries' of sustainability. The RBG Kew-led *State of the World's Plants and Fungi 2020* report estimated that 40 per cent of all plant species are now threatened with extinction. And the *Global Risks Report 2021*, produced by the World Economic Forum, named biodiversity loss as among the top three global existential threats.

Renewing our focus

For more than two centuries, our scientific work at RBG Kew has focused on exploring nature, finding and describing species of plants and fungi, investigating their uses, and sharing their wonders. But in today's world, we need to do more. In response, we have developed our *Science Strategy 2021–2025*, an ambitious plan based around five Scientific Priorities, to help stop biodiversity loss and to develop sustainable, nature-based solutions to address our biggest global challenges.

Supported by collaborative partnerships across disciplines and sectors in the UK and abroad, we are uniquely placed to push the frontiers of fungal and plant science to this end. The dedicated work of our scientists across our three sites – Kew Gardens in south-west London, Wakehurst in West Sussex, and the Kew Madagascar Conservation Centre in Antananarivo, Madagascar – has already had a significant impact. In the last decade alone, our taxonomists have scientifically described and named more than 1,000 taxa of plants and fungi; in the last five years, we have completed conservation assessments to determine the extinction risk of 5,466 plant species; the 2.4 billion seeds we have stored in our Millennium Seed Bank are safeguarding more than 40,000 of the world's plant species; and over 880,000 of our herbarium specimens (dried pressed plants with a wealth of associated information) are now available online for taxonomists and researchers across the world to explore.

In delivering our strategy, we will build on our historic achievements and use our collections and expertise to halt the decline and loss of biodiversity. We will harness the powers of plants and fungi to find innovative ways to secure the future of humanity and all life on Earth.

Our mission

To understand and protect plants and fungi for the well-being of people and the future of all life on Earth

Together with our global network of partners, we aim to understand, protect, restore and promote the sustainable use of biodiversity, from genes through to ecosystems.

We will contribute our resources and expert knowledge in plant and fungal science to support programmes of wider work aimed at safeguarding all biodiversity. This might involve our scientists working with local collaborators to describe the biodiversity of a region and advising decision-makers on its importance for conservation, or sharing seeds with diverse organisations so they can grow plants to restore damaged habitats.

We will also bring significant benefits to society by exploring the useful properties of plants and fungi. For example, we might investigate how under-used but nutritious drought-tolerant food plants could help communities cope with climate change; conduct research into fungi containing active compounds that might help us to fight existing and emerging diseases; or support countries to develop new renewable fuels using local species.

Our efforts to protect biodiversity and explore the useful properties of plants will ensure we contribute substantially to one of the critical United Nations (UN) Sustainable Development Goals (SDGs) – Life on Land (SDG 15). This seeks to 'protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land declaration and halt biodiversity loss'.

Our work will also directly support several other Goals, with aims to build sustainable livelihoods (SDGs 1, 8, 11), increase resilience under climate change (SDG 13), underpin food security (SDG 2), source new medicinal plants (SDG 3), protect watersheds (SDG 6), explore alternative energy sources (SDG 7), build the research capacity of countries (SDG 9) and develop international partnerships (SDG 17).

We have partners and collaborators in over 100 countries worldwide to help us to make a real difference. And, closer to home, our work will help the UK government to achieve its 25-Year Environment Plan, as well as supporting the environmental commitments of the devolved nations and the UK Overseas Territories.

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Five Scientific Priorities

To fulfil our mission, we are aligning our work to five Scientific Priorities, reflecting how we can best deploy our scientific expertise and assets to make a distinctive and substantial contribution to solving today's global challenges.

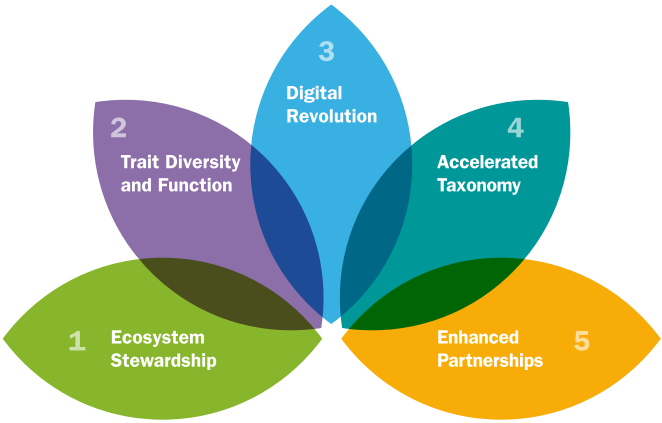
1) **Ecosystem Stewardship**
   We will provide the evidence needed to protect biodiversity and ecosystem services while supporting the sustainable use of species and natural capital.

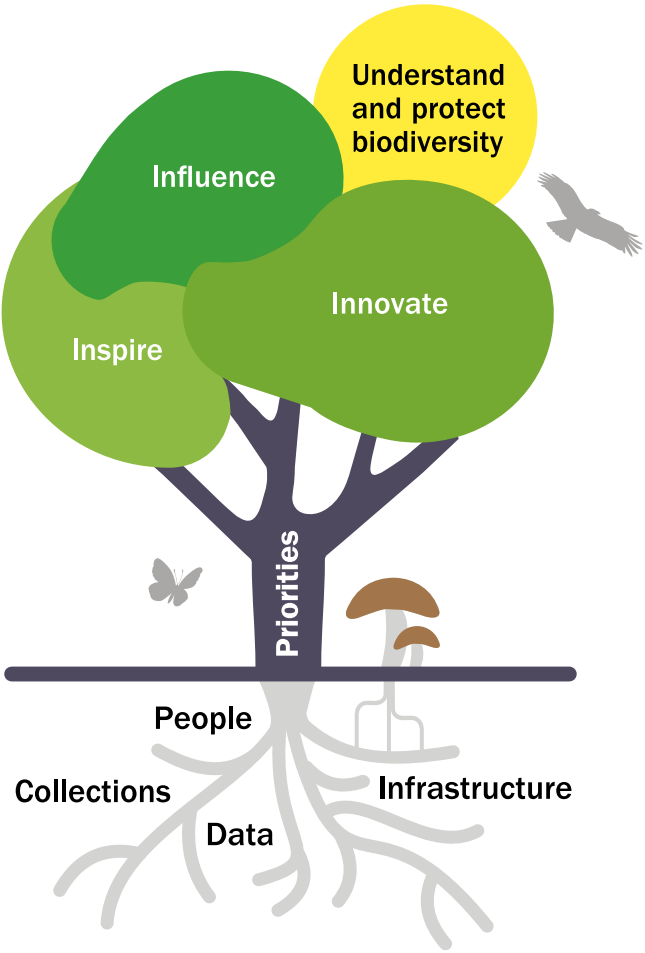
2) **Trait Diversity and Function**
   We will research the characteristics and properties of plants and fungi, to inform conservation and to enable us to identify species and molecules that could benefit humankind.

3) **Digital Revolution**
   We will digitise our Science Collections to make them globally accessible, and we will mine and analyse our data, unlocking this vast resource for scientific discovery and innovation.

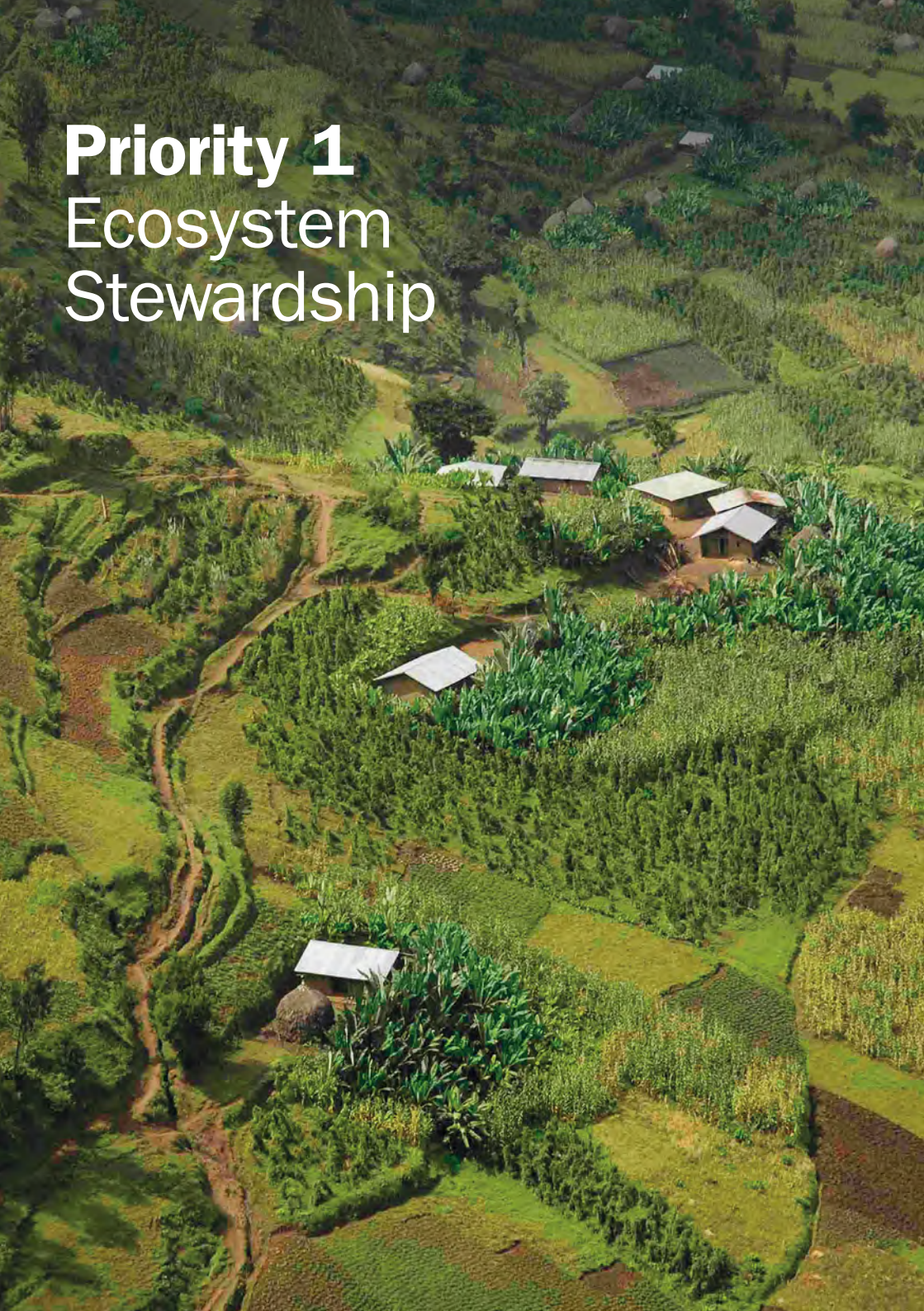
4) **Accelerated Taxonomy**
   We will employ state-of-the-art technology, including machine learning, to push the frontiers of taxonomic research, focusing on species groups and geographic regions where work is most needed.

5) **Enhanced Partnerships**
   We will strengthen existing partnerships and forge new collaborations in the UK and around the world – with communities, governments, companies, and practitioners – to catalyse positive change.





Underpinned by our collections, data, people and infrastructure, and guided by our Scientific Priorities, we will innovate, inspire and influence to achieve RBG Kew's mission.



Priority 1
Ecosystem Stewardship

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Ecosystem Stewardship

Ecosystem stewardship involves protecting biodiversity *in situ* (on-site, in-country) while supporting the sustainable use of natural capital – the Earth's biological assets and the services they provide. Good ecosystem stewardship generates knowledge and practices that restore and sustain healthy habitats, communities and livelihoods.

RBG Kew's unique contribution to this field is made through our expertise in collecting and identifying plant and fungal materials, and analysing data on their diversity (from genes and species through to whole ecosystems). This helps us to understand how species evolved and how they interact (for example, through pollination, or by forming symbiotic relationships, such as between plants and fungi). This knowledge then informs work to restore ecosystems and to develop diverse and sustainable agriculture and agroforestry systems that promote ongoing ecosystem health and productivity.

Using all our resources and tools, from our unrivalled collections to our fieldwork and interactions on the ground, we will conduct innovative research into how we can best protect biodiversity and ecosystem services, while also seeking new and beneficial ways to use plants and fungi without depleting wild resources. Taking a holistic approach will help us to maximise the impact of our work and ensure the benefits are shared by wider society.

Our collections and taxonomic experts are essential to accelerating the description and conservation of biodiversity.

Ectomycorrhizas of *Xerocomellus pruinatus* on the roots of sessile oak, *Quercus petraea*.

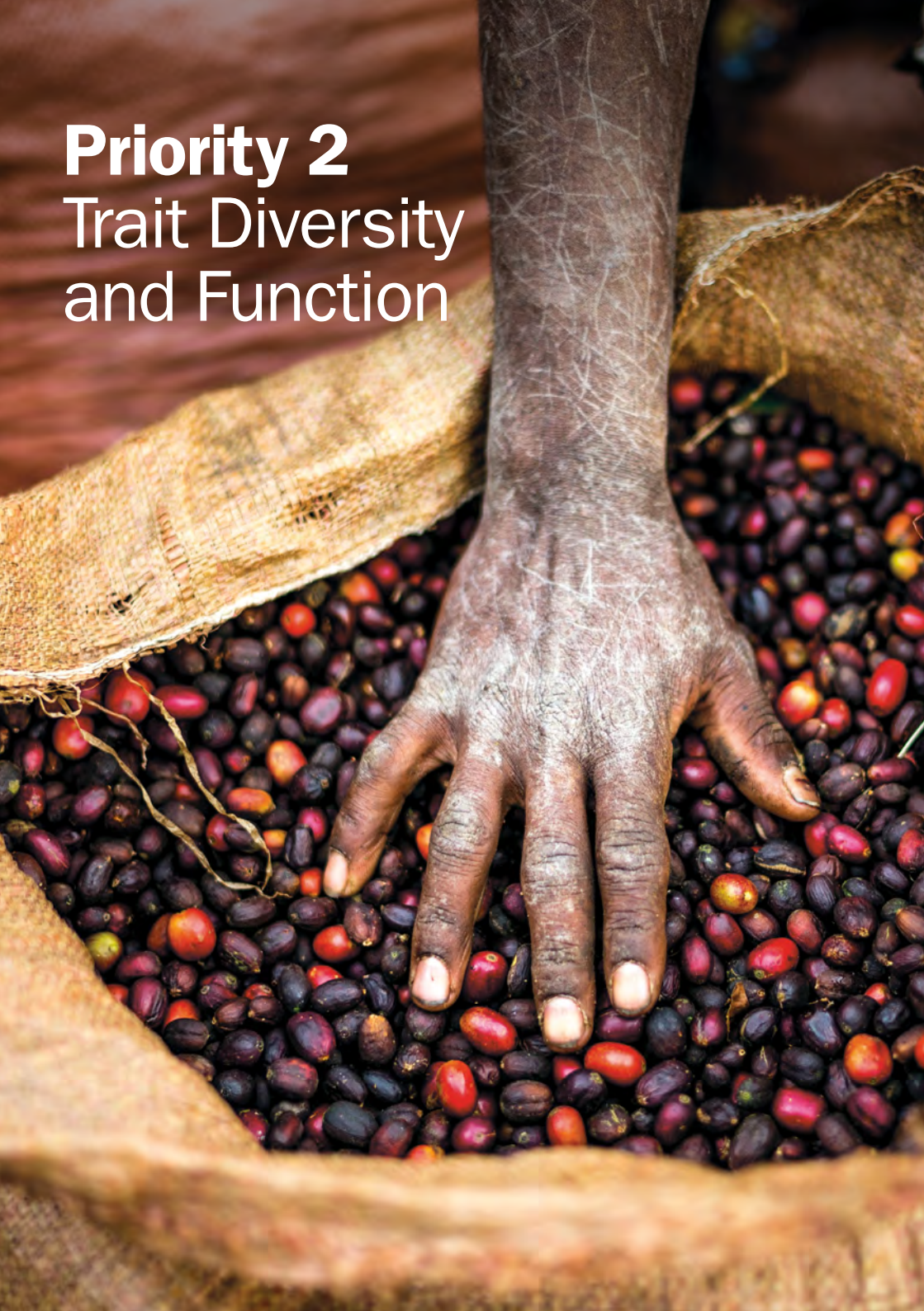
Case study
The effect of nitrogen pollution on fungi and forest function

Beneath the soil of Europe's forests, the trees and fungi are intricately linked through mutually beneficial mycorrhizas – an association between fungi and the roots of plants. In exchange for carbon, these mycorrhizal fungi supply their plant hosts with essential nutrients that help them to grow well and resist attacks from pests and diseases. However, nitrogen pollution negatively affects these important fungi, reducing the nutrients received by trees and making them less robust. The research of our scientists and collaborators has revealed that even low levels of pollution can have a negative impact. This has important implications for both biodiversity and timber production.

We analysed nearly 40,000 mycorrhizas (tree-fungi associations) alongside long-term data on soils, trees, pollution and climate from 137 forests across 20 European countries. This showed that nitrogen pollution negatively affects mycorrhizas at a lower threshold than previously estimated. The pollution decreases diversity, with fungi that are less useful to trees increasing at the expense of beneficial ones. We identified a tipping point beyond which the loss of fungi led to severe nutritional imbalances in trees. This discovery could have major ecological and economic consequences for forests.

Our findings call for the re-evaluation of acceptable nitrogen thresholds, and can be used as evidence to help shape effective environmental policy.

Sampling mycorrhizal roots from the forest floor.



Priority 2
Trait Diversity and Function

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Trait Diversity and Function

As humans, we have characteristics that vary from person to person, and others that define us as being different from other animals – the same is true for plants and fungi.

These characteristics, or traits, and the genes that underly them, can reveal how individual species have adapted to the world around them, and how resilient they might be to global change, including increasing temperatures and emerging pests and diseases.

We will identify species and populations that we can use sustainably and equitably to benefit humankind and build long-term resilience. For example, studying the traits that make plants nutritious, tasty and able to grow in dry conditions might enable us to develop new food crops that will thrive in areas made more arid by climate change.

Understanding traits, their functions and how they have evolved will also enable us to better conserve plants and fungi. For example, understanding the capacity of seeds and spores to tolerate extremes of temperature, moisture and oxygen will help us to store and use this material effectively. We will also continue to identify naturally occurring molecules in plants and fungi that could benefit the health of people and ecosystems.

RBG Kew's collections, particularly the Seed Collection at the Millennium Seedbank and the Living Collections at Kew Gardens and Wakehurst, provide a unique resource of plants and fungi to explore as part of this work, driving forward scientific discovery in collaboration with our global partners.

Understanding plant and fungal traits will enable us to identify species and molecules we can use sustainably and equitably to benefit humankind.

Heathlands are important
for supporting bee populations.

Case study
Revealing the hidden health benefits of heathlands for bumble bees

Ling heather (*Calluna vulgaris*) has long been known to be an important food source for bumble bees, but our research in this area suggests it may also keep them healthy. When we examined the chemistry of the heather's nectar, we found that it contained the compound callunene, which is bioactive against the widespread bumble bee parasite, *Crithidia bombi*. At naturally occurring concentrations, callunene can dramatically reduce infection, and its presence in the landscape could help bumble bees to resist parasites and optimise pollination.

Having healthy bumble bee populations is important, as these insects provide vital pollination services. As the bees visit flowers to gather pollen and nectar for food, they fertilise plants by moving pollen from male to female individuals. In doing so, they help to sustain natural habitats, and support the production of a wide range of crops, from apples and pumpkins to tomatoes and strawberries. However, populations of the UK's 24 bumble bee species are dwindling, with diseases and parasites contributing directly to this decline.

Although heather is a common heathland plant, this habitat is in serious decline in the UK. Its loss could reduce the potential for *C. vulgaris* to lessen the detrimental effects of parasites on the health of the UK's bumble bees. This suggests that if we restore heather-rich heathlands, we could help to keep our vital bumble bee pollinators healthy. By understanding the wider value of floral resources in the landscape, we can target conservation efforts to underpin the pollination services we rely on to sustain our countryside and agriculture.

Bombus terrestris feeding on ***Calluna vulgaris***.

Priority 3
Digital Revolution

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Digital Revolution

RBG Kew holds a globally unique, substantial and growing collection of fungal and plant specimens, illustrations, data, databases, scientific literature, and archives of unpublished material.

The legacy of more than 260 years of scientific exploration, these items tell myriad stories about the distribution, diversity and uses of plants and fungi around the world and across the centuries – from the plants buried with Tutankhamun to sustain him in the afterlife, to the water mould that caused the Irish potato famine. Yet despite being continuously explored by botanists, environmentalists, artists and historians, our collections still hold vast quantities of data that have yet to be captured.

The large-scale digitisation of our major collections, which is already in progress, will release this information, helped by new, innovative online tools for retrieving, analysing and visualising data. Our world-class, authoritative resources on names and taxonomy (the International Plant Names Index, World Checklist of Vascular Plants, Index Fungorum, and Species Fungorum) provide the framework for this and underpin our digital portals, such as Plants of the World Online. Digitisation, together with digital innovation, will enable us to virtually repatriate images and data to the specimens' countries of origin, while unleashing new opportunities for large-scale data mining and analysis to support scientific discovery and innovation.

This digital revolution will help us to manage and curate our data and specimens more efficiently, while increasing the global value and use of the collections across society – from expert and citizen scientists, to teachers, policymakers and the wider public.

Through digitisation, our collections and expertise can underpin and enhance biodiversity research worldwide.

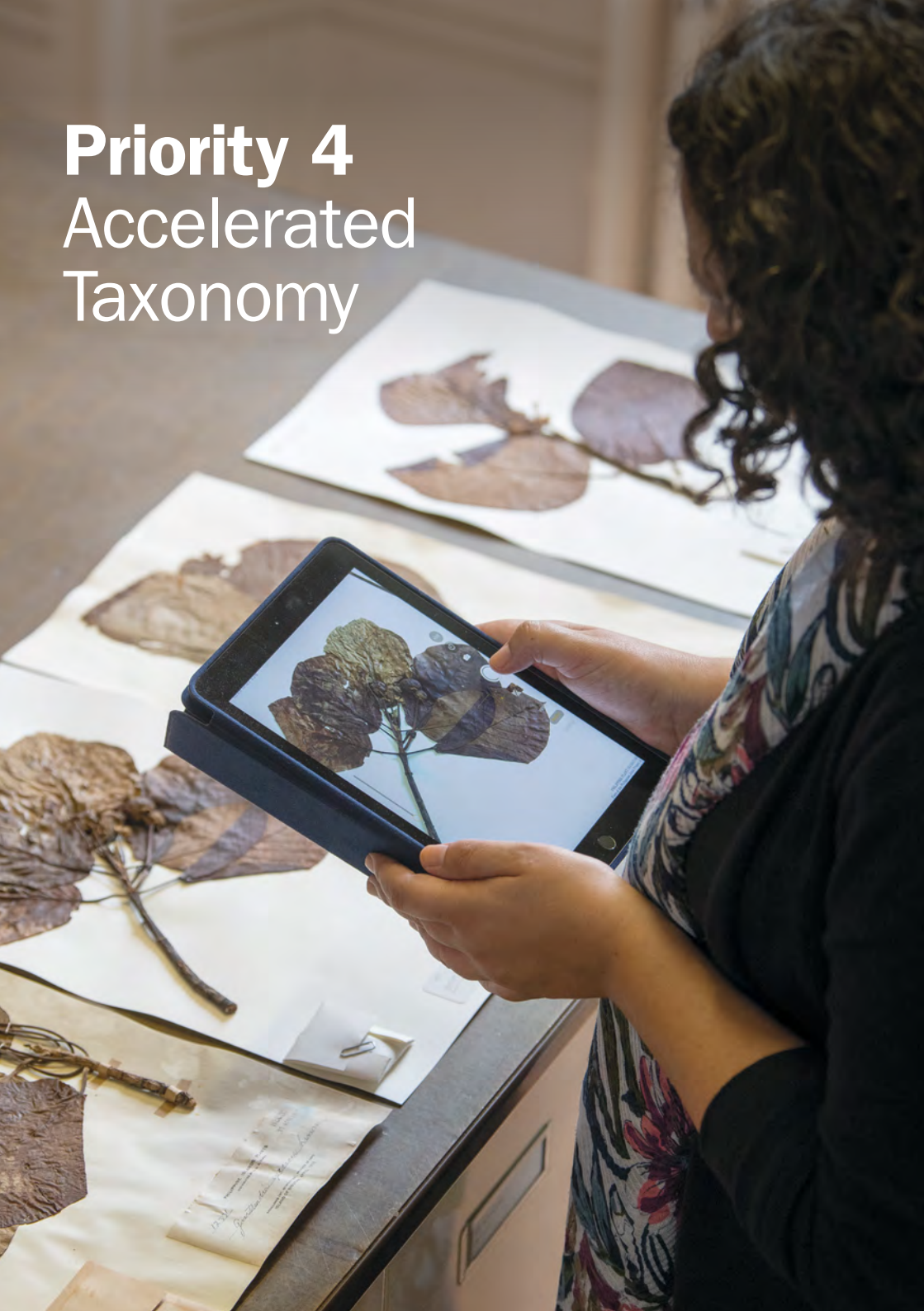
Ginkgo biloba, one of hundreds of plant species used as both medicine and food supplement.

Case study
Plants for Health – supporting the regulation of plant products

The accepted Latin name for the ginkgo tree is *Ginkgo biloba*. Yet this tree and herbal products derived from it are known by 31 alternative scientific names and 82 pharmaceutical and common names, including ginan, maidenhair and yin xing.

RBG Kew's Medicinal Plant Names Services (MPNS) aims to remove confusion or ambiguity around plant names to allow their safe and effective use. To develop the MPNS, our scientists first catalogued known plant-based medicinal products (including regulated drugs, and traditional remedies and plants used by indigenous and rural communities) and the 33,000 or so plants from which they are derived. They then mapped the many names used to identify these plants to RBG Kew's authoritative plant names resources. This dedicated piece of botanical detective work means that regulators, scientists, health practitioners and patients can now find information on species of interest and navigate regulations and research reliably.

MPNS has become the global 'standard' for medicinal plant names, and it can help researchers to understand how species are related, or to find out the conservation status of key medicinal plants. Importantly, it also supports protection of traditional knowledge and the efficacy of plant patents. In the next five years, we will expand MPNS to become 'Plants for Health', which will serve as the go-to resource for names of plants related to well-being. This enhanced resource will encompass food supplements, allergens, cosmetics and medicines, supporting the correct application and regulation of plants used for these purposes.



Priority 4
Accelerated Taxonomy

Priority 4
Accelerated Taxonomy

Taxonomy, the foundation of the scientific study of life, involves naming, identifying and classifying living organisms. It has been the backbone of RBG Kew's scientific research throughout our history, and our collections and taxonomic experts continue to be essential to the processes of describing and conserving biodiversity.

In 2020 alone, our taxonomists named 156 plant and fungal species that were new to science, including a species of mushroom found at Heathrow Airport and a herb collected in Zimbabwe that is from a medicinally important plant family.

Using innovative tools and technologies – such as phylogenomics (showing how species evolved, mapped out through their genes) and machine learning – we will push the frontiers of taxonomic research to better understand and protect biodiversity. For example, we will use image recognition, machine learning and DNA sequencing to accelerate how we identify and characterise species to near real-time.

We will also develop methods for speeding up the discovery of hidden diversity in natural history collections. In delivering the aims of this Priority, we will focus on taxonomic groups and regions where progress is most needed, such as biodiverse areas of the tropics that are under threat. Likewise, we will tailor our outputs, including detailed taxonomic publications, online tools and training resources, to the specific needs of researchers, conservationists and industry.

Our collections and taxonomic experts are essential to speeding up the processes of describing, naming and conserving biodiversity.

Case study
Using grass taxonomy to enhance smallholder farming in Madagascar

Madagascar has more than 500 species of grass. Some of these provide nutritious livestock fodder, while others are weeds that can have a negative impact on agriculture. For example, *Digitaria* grasses can damage crops and reduce yields, potentially threatening food security. Telling the useful species from the harmful ones can be challenging.

RBG Kew scientists are working with partners at the University of Antananarivo, Madagascar's National Center for Applied Research on Rural Development, and communities in Ambihidray, Ibity and Itremo to understand the origins of *Digitaria* and how they have diversified. This will lead to a more accurate biological classification of the genus and increase the ease with which the different species can be identified in the field, helping smallholders to effectively manage *Digitaria* grasses in their farming systems.

In a first for Malagasy agriculture, DNA barcode identification will be used to help to accurately identify *Digitaria* grasses when plants are not in flower. This method enables scientists to identify a species by scanning the complete set of genetic information – or genome – present within sampled plant material. It will ensure the most appropriate weed control can be applied to remove unwanted plants, without compromising the growth of the nutritious species that are suitable for grazing.

Agrisystems in Ibity, central Madagascar, are centred around rice cultivation, with numerous other crops grown alongside rice in small plots.

Digitaria ciliaris (right) is an annual weedy plant, while *Digitaria longiflora* (left) is a resilient perennial that persists in burned fields.

Priority 5
Enhanced Partnerships

Priority 5
Enhanced Partnerships

The aims of our Science Strategy are ambitious, and we cannot achieve them alone. Effective, structured partnerships, focused on delivering positive impacts, are essential to the continued success of our collecting, research and conservation activities.

Our partnerships in over 100 countries worldwide help us to gain a deeper understanding of the complex issues causing the loss of biodiversity. And they enable us to extend our reach to the indigenous peoples and local communities who are the key custodians of biodiversity. This is critical, as the livelihoods of these people are often the worst hit when species are lost and ecosystem services begin to fail.

We aim to develop multidisciplinary and cross-disciplinary partnerships in the UK and across the world, enhance our education, research and commercial activities, and build on the success of the Millennium Seed Bank Partnership (MSBP).

To achieve this, we will strengthen our relationships with our UK biodiversity partners, including the Natural History Museum, the Zoological Society of London and the Royal Botanic Garden, Edinburgh, along with our large network of international partners. And we will reach out to businesses, and demonstrate to them the economic importance of biodiversity. Expanding our network of partners will be key to successfully achieving our other four Scientific Priorities.

Diverse partnerships maximise scientific excellence, understanding and real-world impact.

The Millennium Seed Bank at our Wakehurst site is the hub for a global conservation partnership.

Case study
Working in partnership to secure the future of threatened species

The Millennium Seed Bank Partnership (MSBP) has provided an insurance policy against extinction in the wild for over 20 years. During this time, we have trained more than 2,000 practitioners and provided technical support to over 97 countries and territories, and more than 250 organisations. Described by Sir David Attenborough as 'perhaps the most significant conservation initiative ever', the MSBP today stores seeds from over 48,000 plant species, collected in 190 countries and territories with our partner organisations.

A conservation emergency in Australia in 2020 exemplified the value of such partnerships in saving biodiversity. After months of severe drought, wildfires burned 24 million hectares of bush, forest and parks, including an area known as Cudlee Creek that was home to the rare clover glycine pea (*Glycine latrobeana*). Fortunately, more than 1,000 seeds of the species had been collected from Australia's Mount Lofty Ranges in 2007 and stored at the MSB. In 2020, we sent 250 of those seeds back to Australia to grow new plants for restoring the Cudlee Creek fire scar.

By protecting national floras, including threatened, useful and endemic species, we are providing a solution to the biodiversity crisis now, and options to develop solutions to other global challenges for generations to come.

A Seed Conservation Techniques training course at the Millennium Seed Bank, enabling partners from around the world to share their experiences.

Putting our Science Collections to use

Every specimen in RBG Kew's plant and fungal Science Collections has a unique story to tell. For example, a 100-year-old specimen of the wild service tree, *Torminalis glaberrima*, from a site now growing crops, can tell us there was once ancient woodland there. Collectively, these form an unrivalled evidence base that can be used to tackle contemporary challenges, from mitigating the effects of climate change to safeguarding food security and human health.

Research does not take place in a vacuum, and knowing what happened in the past is crucial to understanding the present and predicting what might happen in the future. Our specimen collections include: dried plant and fungal material; seeds; DNA and tissue samples; wood cross-sections; flowers and fruits preserved in spirit; plants and fungi growing *in vitro*; microscope slides; and economic botany artefacts documenting the uses of plants by people.

Alongside the scientific specimens, our Library and Archives Collections provide the context for how such items came to be collected and why. They document hundreds of years of human knowledge about plants and fungi, and their distribution, appearance, properties and uses. The Archives also bring alive the history of the organisation and how it evolved from Princess Augusta's dream for a garden that would 'contain all the known plants on Earth' to becoming a world-class scientific organisation at the centre of a global network of botanic gardens. Our Living Collections of around 17,000 species of plants complement these resources, providing contemporary material for use in research, conservation and education.

Collections of the size and scope of those at RBG Kew have national and global significance and relevance. We will ensure they retain this relevance into the future, facilitating the delivery of our mission while continuing to serve the diverse needs of the wider research community and other stakeholders.

How you can help

The next few years provide a closing window of opportunity for societies to protect and sustainably use Earth's remaining biodiversity and to restore what we have degraded.

There is no time to lose, and we have already embarked upon our journey to fulfil this strategy and achieve our aims to understand and protect biodiversity. We invite you to join us on this path and help to make a real difference.

To find out more about Kew Science, visit **kew.org/science.**

To donate to Kew and support our critical work, visit **kew.org/donate.**

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