Royal
Botanic Garden
Edinburgh

IMPACT

Exploring, conserving and explaining the world of plants for a better future

The last five years have been a period of challenge and transition for all of us, characterised by growing awareness of the threats posed by climate change and biodiversity loss, and of the fundamental connections between the natural world and human health and wellbeing. Plants are a fundamental component of our functioning planet, and plant-related research, conservation and education are therefore essential to humanity's future.

With a 350-year history of biodiversity science and training, and internationally-renowned living and preserved collections, the Royal Botanic Garden Edinburgh is a world-leading botanical institute taking positive action for plants and people; from local communities across Scotland, to more than 40 countries around the world.

This book illustrates our range of impacts over the past five years, from baseline biodiversity research to ground-breaking conservation action, from early years education to expert professional tuition, and from excellence in horticultural display to innovation in creative programming.

Looking forward, our plans are ambitious and innovative. These include the Edinburgh Biomes regeneration programme; improvements in access, inclusion and equity; expanded learning and engagement programmes, and continued action to restore biodiversity, mitigate climate change and support sustainable livelihoods.

The Royal Botanic Garden Edinburgh is in a strong position to continue to excel.

Dominic Fry, Chair, Board of Trustees
Simon Milne, Regius Keeper November 2021

Left: The biodiverse mountains of northern Vietnam

‘Diversity is essential for health, wellbeing and vibrancy. As we gently start to reengage with our fellows, we must also bear witness to the causes of our recent incarceration – a break in our relationship with the natural world. It is vitally important that we readdress our place in things, our use of land and natural resources, and finally set ourselves up as the guardians, rather than the ravagers, of this delicate planet. We must protect and explore the balance between ourselves and all other life in this world – support botanical research and conservation, take more positive actions to protect our natural world and the communities dependent on the wellbeing of their surroundings. As we have been so starkly reminded, we are all intertwined, and none of us is healthy until everyone and everything is healthy, protected and nurtured.’

Dame Emma Thompson and Greg Wise

Five-year impact snapshots

9 conservation hedges
planted to conserve threatened conifers

>40 countries
partnered in research, conservation, training and capacity building

83% of Scottish threatened plant species
secured in cultivation

95% of the endemic
and regionally important plant species of Arabia conservation-assessed

>100 short courses
dedicated to developing learners' skills, qualifications and interests

239kWh generated each day
by Dawyck's hydroelectric power scheme – enough to power 25 homes

>250 species new to science
described, enabling their monitoring, protection and sustainable use

>350 MSc students
from 49 countries graduated

>400 heritage sites on Soqotra
documented to facilitate their protection

c.750 tonnes of compost
produced and used annually at our Edinburgh Garden

>900 primary children
engaged with plants through free regional learning programmes

c.950 conifer species
monitored for the IUCN Conifer Red List

>1,000 wildlife species
recorded in our Edinburgh Garden 'Bioblitz'

>1,000 alpine blue sowthistle plants
propagated for research and reintroduction

c.1,200 Ha of primary *Araucaria* forest
secured in Chile's Reserva Nasampulli, with Rainforest Concern

>2,000 people
around the world enrolled on online learning courses

c. 2,500 people
around the world gained skills through Certificate courses

>3,750 people from 750 households
empowered to identify and eradicate invasive species in Nepal

>5,000 people
supported annually in our Botanic Cottage community hub

>7,000 people
annually gained practical experience and support through our Edible Gardening Project

>10,000 children
inspired and enlightened annually through our schools' programmes

c. 13,600 species
cultivated across our Gardens

>14,000 species
recorded in the first verified seed plant checklist of the lowland Amazon rainforest

c. 15,000 people
annually explored our Edinburgh International Science Festival Events

c. 19,000 people
visited Scotland's first titan arum flowering, and learned about the threats facing the species in the wild

c. 32,000 digitised specimens
transcribed by citizen scientists

c. 41,000 Himalayan cypress seedlings planted,
securing the future of Bhutan's national tree

c. 521,000 herbarium specimens
imaged, and over 1 million databased, making information about species' characteristics and distributions instantly available online, worldwide

>1 million visitors
welcomed to our four Gardens each year

Left: Fieldwork in Gunung Ambang, Sulawesi, Indonesia

A 350-year heritage – timeline

(Available as HTML)

PLANTS

In the

Physical Garden

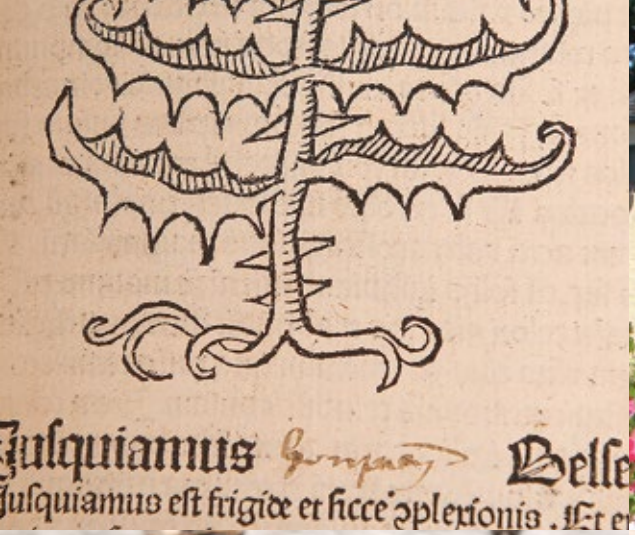
AT

EDINBURGH;

CONTAINING

Their most proper Latin and English Names; With an English Alphabetical INDEX.

BY


Zulquiamus
Zulquiamus eſt frigidæ et ſiccæ ꝑplexionis







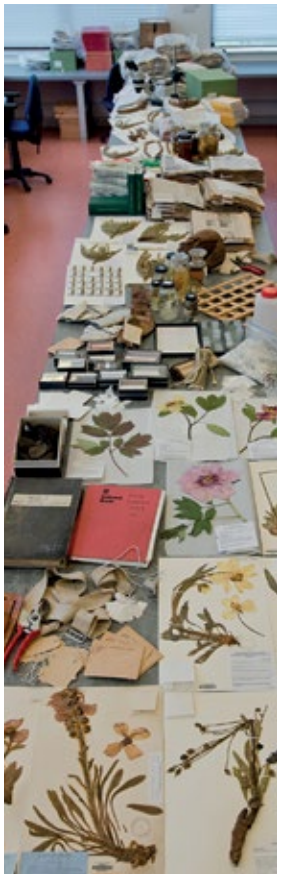
The Royal Botanic Garden Edinburgh

Providing evidence, action and engagement to combat the biodiversity crisis and climate emergency

Plants are the foundation of life on earth, yet many are threatened with extinction. Founded in 1670 on a plot little larger than a tennis court, today the Royal Botanic Garden Edinburgh encompasses sites across Scotland and has an impact around the planet. Our work sustains species, habitats and livelihoods, our four Gardens are centres of engagement with plants and the environment, and our learning and outreach programmes build knowledge and skills across Scotland and the wider world.

Previous right: Reintroduction site for alpine blue sowthistle, Cairngorms National Park

Left: Temperate Palm House, Edinburgh



Our Mission **is to explore, conserve and explain the world of plants for a better future.**

We grow understanding of the Earth's plant and fungal diversity, evaluate the threats facing species and habitats, guide interventions to protect and restore plant communities, and engage people of all backgrounds with the wonder of plants.

We work with scientists across the globe to understand the diversity and distributions of plants and fungi, and to monitor changes at scales ranging from genes to ecosystems.

We empower individuals and institutions to take crucial actions mitigating the threats facing the natural world – from invasive non-native species, pests and pathogens, to pollution, deforestation,

habitat degradation and land use change, exacerbated by the climate emergency.

We engage, inspire, train and upskill the next generation of botanists and conservationists in Scotland and internationally, with opportunities for all, from early years to lifelong learning.

Our work is underpinned by the extensive living, herbarium, library and archive collections in our care. We demonstrate excellence in horticultural display and in the cultivation of rare and threatened species. An ambitious new development, Edinburgh Biomes, will build upon this success to secure the valuable National Collections and enhance our impact in Scotland and across the world.

RBGE is a registered charity, a non-departmental public body sponsored and supported by the Scottish Government's Environment and Forestry Directorate, an academic institution and part of the SEFARI collective working to deliver the Scottish Government's Strategic Research Programme. Our remit is set out in the National

Heritage (Scotland) Act 1985 and guided by national and international treaties including the Environment Strategy for Scotland "*One Earth. One home. One shared future*", Scotland's updated Climate Change Plan "*Securing a green recovery on a path to net zero*", the United Nations' (UN) Convention on Biological Diversity and the UN Sustainable Development Goals.

Our Vision **is a world that increasingly values, protects and benefits from plants.**


Scotland


Nepal


China


Indonesia


Vietnam

International partnerships

We work in partnership with organisations and communities in more than 40 countries to conserve and restore biodiversity, support sustainable livelihoods, and co-create learning opportunities.


Saudi Arabia


Peru


Bhutan


Congo


Chile


EXPLORE

1 | Understanding diversity, distribution and threat

The evidence base to halt extinction

Our world faces a global biodiversity crisis in which 40 per cent of plants are threatened with extinction, including important wild relatives of crop plants, sources of new life-changing drugs, and providers of vital ecosystem services. Yet, an estimated 20 per cent of plant species await scientific discovery and description, remaining invisible to conservation efforts and leaving their potential useful properties unknown. Making extensive use of the living and preserved collections in our care, we work collaboratively to describe species new to science, determine their distributions, elucidate their properties and assess the threats to their existence. This underpins increasingly urgent biodiversity protection and restoration action for the benefit of all interconnected species, including humankind.

Previous right: Marañon Valley, Peru

Left: Moss forest, Papua New Guinea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■ We now describe more than one species new to science for every week of the year, making each one more likely be protected from extinction. Recently published species include *Begonia robii* (Begoniaceae) [**1**], *Cyrtandra kinhoi* (Gesneriaceae) [**2**], *Salvia subviolacea* (Lamiaceae) [**3**] and *Globba luteola* (Zingiberaceae) [**4**].

■ Our International Conifer Conservation Programme continually monitors the status of the world's more than 700 conifer taxa, 34 per cent of which are threatened with extinction. This enables focussed *in-situ* and *ex-situ* action to protect threatened species, such as these Endangered *Araucaria araucana* in Chile, [**5**] and improve sustainable use of plant resources.

■ Our taxonomic studies of *Solanum*, wild relatives of the potato and tomato, uncovered multiple species new to science, with potential to supply traits such as disease resistance and climate tolerance, enhancing food security.

■ Working with local institutes, our Centre for Middle Eastern Plants assessed the conservation status of over 95 per cent of the endemic and regionally important plants of Arabia, underpinning targeted conservation programmes in this biodiverse and environmentally-challenged region.

Case study | Forgotten forests

Often overlooked compared to neighbouring rainforests, South America's seasonally dry forests are the world's most threatened tropical forests. Fragmented and largely unprotected, dry forests' fertile soils make them prime targets for agriculture, and many have been reduced to 10 per cent of their original extent. Our science is strengthening the case for their conservation.

The DryFlor network, supported by the Leverhulme Trust, brings together baseline biodiversity data from over 50 partners across eight countries, to underpin conservation programmes. DryFlor's comprehensive analysis of the 4,660-species dry forest flora, in *Science*, uncovered huge variation in species composition and identified areas of exceptional diversity and endemism. In 2020 the network published a key protocol for long-term monitoring of dry forests, comparable to methods already used in tropical rainforests, a crucial weapon in the fight against climate change and biodiversity loss.

In Peru, our scientists are working with the University of San Marcos to document the highly diverse forests of the Upper Marañón Valley, supported by the British Council Newton Fund. In Brasil's understudied Caatinga forests, our computer models applied to several centuries' collection data are helping define dry forest boundaries and predict species' futures under climate change scenarios, supporting conservation planning and sustainable provision of ecosystem services.

Right: The cactus *Armatocereus rauhii* is found only in Peru's Marañón Valley

2 | Plants in space and time

Key investigations in plant evolution, development and ecology

Plants are the backbone of almost all known ecosystems. Understanding plant relationships, ecological interactions, developmental genetics and even genomic evolution, underpins a deeper understanding of the natural world, vital to its conservation and sustainable use.

Left: Puerto Princesa Subterranean River National Park, Palawan, Philippines

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■ Our studies of cocoa (*Theobroma cacao*), a subsistence crop crucial to the livelihoods of around six million people, suggest the species dates back an exceptional ten million years, and identified significant genetic scope to improve traits such as disease resistance and climatic tolerance, which could enhance its long-term sustainability [**1**].

■ Our new, DNA-based classification of the pantropical ginger tribe Alpinieae (cardamoms) supports future research and conservation planning for this group [**2**].

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■ Genotype analysis revealed high levels of hybridisation between wild and cultivated apples in the UK and identified the 'last bastions' of pure wild apples in England's Lake District and Scotland's southern highlands [**3**]. This will facilitate protection of the wild genotype through conservation horticulture in remote sites, to bolster populations of the native species.

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■ We conducted the first DNA-based study of relationships in the little-studied black nightshades (*Solanum spp.*), wild relatives of potato and tomato, providing a vital framework for future research contributing to crop health and food security.

■ The living collections in our care are integral to our research, with scientists and horticulturalists working together to discover species' identities, relationships, ecology, and cultivation requirements. These Gesneriaceae collections were used to generate a specific gene capture kit: a new molecular resource for study of Gesneriaceae and related groups [**4**].

Case study | Begonia: a megadiverse model

Begonia is an economically-significant ornamental and also a group with incredibly high levels of diversity, endemism, and sensitivity to environmental change. This makes it an ideal model to explore evolutionary and biogeographical questions from gene to biome level, and an indicator of ecosystem health.

New *Begonia* species are described every year at RBGE and, with over 2,000 species, it is now the fourth largest known plant genus. In 2018, with international colleagues, we published a DNA-based phylogeny and classification of this huge group, providing a sound framework for future research.

Fieldwork in Papua New Guinea uncovered a huge variety of species, perhaps signifying one of the fastest ever diversifications in flowering plants. Work is ongoing to confirm this and uncover the genomic changes underlying such a massive burst of speciation.

Our rich *Begonia* herbarium and living collections are ideal for ground-breaking research into novel methods of extracting DNA from dried material, techniques which are helping unlock knowledge from historical specimens and design future collecting protocols.

We also use *Begonia* to explore fundamental questions of plant evolution and development, including traits ranging from leaf pores, inflorescence architecture and sex ratios, to woodiness and the nature of the genome itself, with implications for understanding development across the plant kingdom.

Right: *Begonia joshii*, a newly described species from Amazonas, Peru

3 | Science, technology and conservation

Pioneering approaches to tackle contemporary challenges

Unprecedented challenges demand extraordinary solutions. We work collaboratively to develop rapid, radical, large-scale methods to combat the biodiversity crisis and mitigate the climate emergency, from curiosity-driven science to practical conservation horticulture.

Left: Our Edinburgh laboratory is a Genome Acquisition Lab for the Darwin Tree of Life genome-sequencing programme


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■ Our International Conifer Conservation Programme's unique programme of 'safe sites', like this one at Drumlanrig Castle, Dumfries and Galloway [**1**], uses living collections to protect threatened conifers against disease and natural disasters. Fourteen thousand genotypes of 285 species are planted across more than 200 sites, dramatically extending the variety of these economically and ecologically important plants protected in *ex-situ* collections. Nine additional 'conservation hedges' conserve large numbers of trees in a small space, including native heritage yews, Chile's Vulnerable endemic *Prumnopitys andina* (plum yew), Near-Threatened *Saxegothaea conspicua* (Prince Albert's yew), and over half of all known genotypes of Critically Endangered *Xanthocyparis vietnamensis*.

■ Our 'citizen science' projects harness the power of the population to digitise and transcribe herbarium sheets, such as this historic Proteaceae specimen [**2**], making them accessible to scientists across the world.

■ Our DART (Direct Analysis in Real Time) mass spectrometer, installed in collaboration with Edinburgh's Roslin Institute and supported by the players of the People's Postcode Lottery, enables us to determine the provenance of wild-collected threatened cycads, and track timber products to their source, combating illegal logging and forest degradation [**3**].

We use ‘Hyb-Seq’ technology to achieve cost-effective, high-throughput retrieval of DNA from degraded genomes. We demonstrated Hyb-Seq’s potential across a range of plants and fungi to unlock the huge stores of genetic data held in herbaria, elucidate evolutionary relationships, and uncover the genetic bases of key traits such as disease tolerance or pharmaceutical properties.

Case study | Barcoding biodiversity

‘DNA barcoding’ – a genetic approach to distinguishing species – is crucial to accelerating species discovery in the face of unprecedented extinction rates. We led a global effort to identify the best parts of the plant genome for barcoding, and to build a library of reference sequences against which unidentified specimens can be compared. Working with the National Botanic Garden of Wales, we generated DNA barcodes for all UK flowering plants, a key step towards barcoding the world’s flora.

Barcodes are particularly useful for differentiating morphologically-indistinguishable (‘cryptic’) species such as many liverworts, for which we are building a comprehensive barcode library. Our liverwort work uncovered many species new to science and clarified the conservation status of others. We also generated the first barcode library for species of cyanobacteria in the genus *Nostoc*, symbionts of lichens in Scotland’s Atlantic rainforests. This allows us to investigate the impact of ecological factors such as climate and habitat connectivity on *Nostoc*-containing lichens, supporting conservation of these complex organisms.

As part of the Edinburgh Consortium for Giant Panda Conservation and Forest Landscape Restoration, we barcoded panda faecal samples to identify bamboo species in their diet, to guide habitat restoration programmes. We used the same method much closer to home to investigate the impact of grazing feral reindeer on mountain plant communities, working with the Cairngorms National Park and University of the Highlands and Islands.

Top left: Barcoding identified multiple species of *Aneura* in the UK, where previously only one was thought to exist **Top right:** reindeer herd, Cairngorms National Park, Scotland

4 | Our changing world

Measuring and mitigating human impact on plants and planet

Climate change and biodiversity loss are the greatest challenges in a generation. As the global impetus for action grows, there is a pressing need for quantitative data on global rates of change and local and regional impacts on species and habitats. Our research provides evidence to substantiate the reality of the environmental crisis at multiple levels, stimulate legal and political measures, and promote practical actions to protect biodiversity and livelihoods.

Left: Degraded forest, Tanzania

■ In central Africa – where we have carried out continuous forest surveys for many decades in collaboration with local organisations – our data helped show that tropical forests may, by 2035, become sources, rather than sinks, of carbon [**1**]. Identifying this crucial tipping point adds impetus to global efforts to slow climate change.


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■ In China and Southeast Asia, our work provides a deterrent to a major driver of forest destruction – clearance for rubber plantations – by identifying areas where rubber cultivation is neither biologically nor economically sustainable. Our projections indicate that more than half of existing plantations may ultimately fail: a lose-lose scenario for both people and biodiversity. Working with in-country partners ensures this message reaches local policymakers, land managers and small-scale farmers [**2**].

■ Working with Heriot Watt University, we showed that marine maerl beds – one of Scotland's most important and understudied ecosystems – are severely threatened by climate change, with up to 84 per cent losses predicted by the end of the century [**3**].


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Our dedicated phenology volunteers monitor annual changes in development of over 500 plants of 156 species across our Gardens, providing an early warning of plant responses to changing climate [**4**].

Case study | World leading lichenology

Lichens, stable symbioses of fungi and algae or bacteria, are vital to water and nutrient cycling in many habitats and, with other cryptogams, account for a substantial proportion of global carbon capture and nitrogen fixation. Scotland is a world lichen hotspot with around 1,500 species including 179 of international importance. Lichens are highly susceptible to pollution, landscape management and climatic changes, and are important bioindicators of climate change and habitat degradation.

We are elucidating the ecology, taxonomy and conservation status of poorly known species, and have rediscovered several species previously thought to be locally extinct. We are developing novel translocation methods to help save species whose populations have plummeted below a point of no natural return, and have already established a new protected population of globally rare *Pseudocyphellaria 'intricata'.*

Our comparative studies of lichen growth under varied combinations of temperature, rainfall and light pave the way for improved understanding of these species' responses to climate change. Our evidence-based model of habitat connectivity, incorporating not only climatic trends but also potential changes in tree populations due to emerging diseases, helps mitigate climate change impacts on lichens at sites across Scotland. We work closely with habitat managers and organisations such as Forestry and Land Scotland and NatureScot to determine present and future site suitability for hundreds of lichen species vital to forest biodiversity.

Top: In the Arctic tundra of the Cairngorms, lichens and bryophytes may outnumber vascular plants


CONSERVE

5 | Safeguarding Scottish biodiversity

Scientific foundations to protect and restore Scotland's unique natural heritage

Scotland hosts a rich array of internationally important ecosystems, from the world's best-preserved examples of Atlantic woodland to Europe's largest expanse of climate-balancing blanket bog; from highly biodiverse North Sea maerl beds to the Cairngorms' rapidly retreating alpine snowbeds. These habitats support beautiful, scarce and threatened species from rare ferns and epiphytes to woolly willows and Scots pine.

This complex mosaic, central to Scotland's agriculture, tourism, health and wellbeing, is threatened by changing land use, habitat fragmentation, pollution, climate change and invasive non-native species. We provide essential baseline data to monitor and protect species and ecosystems for all to enjoy, while our rigorous ecological and genetic studies combined with horticultural expertise translate into conservation practice through effective recovery and reintroduction programmes.

Previous left: Snowbed, Cairngorms National Park

Previous right: *Rhododendron* in riverine forest, China

Left: Atlantic woodland

- Across our four Gardens we cultivate and safeguard 156 (83 per cent) of Scotland's threatened species from extinction [**1**].

- Working with partner organisations, we reintroduced priority species such as woolly willow (*Salix lanata*) to Scottish sites where they are now protected and monitored.

- Our risk analyses of Scotland's unique forest epiphytes and botanical indicator species contribute to the evidence base for the UK's *National Adaptation Programme* on climate change and support ecosystem health in the Cairngorms National Park.

- With NatureScot, we carried out the world's first genetic risk assessment for wild species, identifying UK species (including wildcat, ash, great yellow bumblebee and freshwater pearl mussel) at high risk, and contributing to global biodiversity conservation targets.

- Our *DNA-based Metabarcoding Approach for Water Framework Directive Classification for Rivers* (with the Environment Agency) provides a now widely-used technique based on diatom DNA to assess the ecological status of UK rivers.

- We are the Sector Lead for Horticulture and the Natural Environment in Scotland's Centre of Expertise in Plant Health, providing evidence and advice to minimise threats from emerging plant disease.

Case study | A sowthistle story

Cicerbita alpina (alpine blue sowthistle) is one of Britain's rarest and most striking plant species. Threatened by grazing and climate change, its 1.5m, bright blue flowering spikes persist at only four small sites in the UK – all in the Cairngorms National Park. Natural regeneration is at a standstill: neither young plants nor seedlings have been found.

RBGE scientists and horticulturists discovered that Scotland's sowthistle populations lack critical diversity – with fewer than 50 genetically distinct individuals in the country. Pollination experiments showed that, although the sowthistle sets seed, germination rates are low, unless there is crossing between populations, which is unlikely to occur in the wild.

Using controlled cross-pollination, over 1,000 individuals with maximised genetic diversity were cultivated and reintroduced to carefully selected sites in the Cairngorms. Thanks to strict quarantine measures, healthy populations were established with potential to be self-sustaining and naturally-regenerating, and to adapt to future climate change. This tripled the number of wild populations in the UK, providing insurance against geological instability, grazing and extreme weather events. The populations are carefully managed and monitored – using drone technology for the most inaccessible sites – in partnership with NatureScot and local landowners.

Graeme Dey MSP, Species Champion for the alpine blue sowthistle and woolly willow describes the project as a "flagship for species recovery", which helps raise awareness of other threatened Scottish species.

6 | Combating climate crisis

Nature-based solutions promote carbon sequestration, ecosystem resilience and human survival

Climate change is a defining issue of our time and is intrinsically linked to biodiversity loss. Rapid climatic change can impact negatively upon species and ecosystems, accelerate the spread of invasive species, pests and diseases, and damage human health, wellbeing and security. However, protecting and restoring plant biodiversity can have positive impacts on both climate change mitigation and adaptation: the IUCN calculates that nature-based solutions could provide over one third of the mitigation needed to limit global temperature rises to 2°C by 2030.

We are helping Scotland to play its full part in responding to these crises, and the climate emergency influences every part of our work: from documenting impacts on species and ecosystems, through building resilience at home and some of the worst-hit regions of the world, to engaging public and policymakers whilst minimising our own carbon footprint.

Left: Clearing land for rubber plantation, China


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■ The Edinburgh Shoreline project helps local communities adapt to and mitigate coastal impacts of climate change. For instance, with school children we created structures to encourage wildlife to colonise essential coastal defences [**1**], and with community groups we replaced dune-destabilising invasive species with native, stabilising ones, harnessing nature's resilience to sea level rise. Edinburgh Shoreline is part of the Edinburgh Living Landscape initiative, funded by the Heritage Lottery Fund, European Green Infrastructure Programme and NatureScot Biodiversity Challenge Fund.


2

■ The carbon footprint of RBGE Dawyck [**2**] has been dramatically reduced by a new sustainable biomass boiler and on-site hydroelectric scheme, diverting excess renewable energy to the National Grid. At Logan, we built the UK's first public glasshouse heated exclusively by green energy, including solar photovoltaic panels and air source heat pumps. Edinburgh Biomes, our ambitious redevelopment plan, will substantially reduce our glasshouses' carbon footprint whilst engaging new audiences with the wonder of plants and the urgent need to act on climate change and the biodiversity crisis.

■ Climate change intensifies the threat to Scotland's natural environment, horticultural and agricultural sectors from potentially devastating emerging plant pathogens. Our Plant Health programme provides early warning of new threats through the International Plant Sentinel Network; our Gardens employ some of the world's most rigorous plant quarantine procedures [**3**]; and, with the USDA Forest Service, we are researching disease resistance in conservation-priority trees.

■ Globally, our influential analyses help tease out the pros and cons of large-scale afforestation programmes and identify habitats such as African grasslands [**4**], where tree-planting would in many cases be counterproductive.

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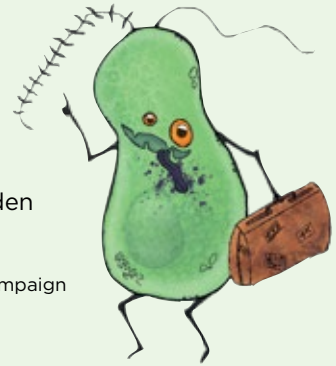
Case study | Bug wars

We are reducing the use of chemical fertilisers and pesticides, which have a significant carbon footprint, in all our Gardens. Artificial fertiliser use is minimised by composting all green waste: in Edinburgh alone, we return 750 tonnes of material to the soil each year, adding nutrients, preventing desiccation, and improving soil health. Our productive Market Garden, supplying our own restaurants as well as local food banks, has been certified organic by the Soil Association.

Glasshouses present a particular dilemma, with many rare and threatened species grown in warm, enclosed surroundings with few natural predators: ideal conditions for pests to thrive. A suite of strategies helps prevent infestations without chemical pesticides, starting with strict quarantine measures and plant movement restrictions. Foot-baths, supported by a strong awareness campaign, reduce 'hitchhikers' on visitor and staff boots alike.

When pests do strike, larger culprits may be removed by hand. Then, we enlist biological controls ranging from predatory mites and beetles to parasitic wasps, bacteria, and microscopic nematodes. Our display glasshouses are now pesticide-free havens for natural, native predators which were previously unwanted victims of broad-spectrum pesticides: biological control benefits our collections, garden wildlife, and the planet.



Right: Hatch, an oomycete pathogen, is the face of our 'No Hitchhikers' campaign

7 | Supporting sustainability

Collaborative stewardship of our shared planet

Most of the Earth's plant biodiversity is centred in regions which are facing the greatest losses due to human activity. We work with governments, institutions, and non-governmental organisations around the world to find science-based solutions that protect biodiversity and support local livelihoods.

Left: Propogation training, Nepal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■ Botanical surveys in Oman by teams working with our Centre for Middle Eastern Plants (CMEP), working with local partners, identified 43 Important Plant Areas, which are now recognised and protected in Oman's National Spatial Strategy [**1**]. With funding from the UK Darwin Initiative, CMEP worked with Afghanistan's Ecology and Conservation Organization and UNEP to supply 1,000 people in Bamyan Province, Afghanistan, with more efficient and healthier stove technologies. This triggered a 30–40 per cent decrease in timber extraction and substantially reduced levels of indoor pollution.

■ Working with the Royal Botanic Garden Serbithang, Botanic Gardens Conservation International and local people, we developed an intensive programme to protect Bhutan's sacred national tree, the Himalayan cypress (tsenden), *Cupressus torulosa*, from unsustainable logging for construction [**2**]. A new community tree nursery now provides a sustainable supply of tsenden timber, relieving pressure on natural forests. In one year, an astounding 41,000 seedlings were planted out at protected sites.

■ In Tanzania, we work with local communities and organisations on a Darwin Initiative project to develop rigorously-evidenced community-based approaches to forest management, enhancing sustainability, equity and gender balance [**3**].

- In Laos we launched a restoration programme for the Critically Endangered conifer mai hing sam (*Glyptostrobus pensilis*) [**4**], in collaboration with the University of San Francisco, Nakai Nam Theun Watershed Management Protection Authority and Nam Theun Power Company.

- In Nepal, DNA-based identification tools are helping protect threatened species including Critically Endangered jatamansi (*Nardostachys grandiflora*). More than 15,000 people rely on income from harvesting jatamansi for medicinal uses, but are increasingly undercut by illegal exporters. Our Darwin Initiative project with TRAFFIC International and others developed monitoring and certification mechanisms promoting a regulated, sustainable jatamansi trade.

Case study | Integrating cultural heritage and conservation

A UNESCO World Heritage Site, Soqotra is an area of outstanding biodiversity, natural beauty and cultural heritage. CMEP has been at the forefront of ecological research and conservation on Soqotra since 1989.

Soqotra's natural history is intertwined with local culture and livelihoods. However, rapid population growth fuelled by conflict in mainland Yemen threatens both the islands' cultural and botanical heritage. CMEP's British Council Cultural Protection Fund project aimed to integrate natural and cultural heritage into conservation and development planning by documenting tangible heritage sites and intangible endemic practices alike.

A team of local experts working with the Freie Universität, Berlin, the Senckenberg Research Institute, Frankfurt, UNESCO, Friends of Soqotra and Soqotra Environmental Protection Agency, recorded more than 400 significant heritage sites and a wide range of cultural traditions and practices, many relying on the islands' endemic plants. Around 5,000 people engaged with the project through traditional poetry, music, dance and theatre events.


EXPLAIN

8 | A foundation for biodiversity and conservation science

Accessible information provides the keys to the plant kingdom

Science and conservation depend on accessible knowledge. We share our herbarium and living collections, data and discoveries with users from researchers to conservationists, policymakers and the public, in formats ranging from user-friendly local identification guides to an online checklist of the entire world flora.

Previous left: diversity of Begonia leaf shapes

Previous right: Schools' taxonomy day in the Herbarium

Left: Bukit Timah National Park, Singapore

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■ Floras – comprehensive accounts of the plants of a country or region – are fundamental to plant identification in research and conservation. Working with in-country institutes, we contribute to the *Flora of Nepal* [**1**], *Flora of Thailand, Flora of China, Flora of Cambodia, Laos and Vietnam*, and *Flora of Arabia*. Recent monographs – in-depth accounts of closely-related plants – cover the 61 species of *Aframomum* (grains of paradise and alligator peppers), and the southern hemisphere Podocarpaceae and Araucariaceae (monkey puzzles).

■ Innovative new resources include an online guide, *Endemic Plants of Chile*, which covers all known ferns, conifers and flowering plants unique to Chile and its islands, helping guide *in-situ* conservation actions. *Plants and You* is an extremely popular series of bespoke identification guides to the plants of Nepal, in English and Nepali, helping local communities make informed choices around sustainable use of native plants and invasive non-native species [**2**].

■ We are founding partners in the *World Flora Online* (WFO), a comprehensive, accessible baseline for monitoring plant species and an essential first step in meeting the targets of the Global Strategy for Plant Conservation. Currently around 20 per cent of plants are being incorporated, with RBGE responsible for around 17,600 species in 17 families, including all the world's conifers.

■ We published the first verified plant checklist of the lowland Amazon rainforest, with more than 14,000 species, a sound basis for research and conservation in this key biodiversity hotspot. We also supply a continuously-updated online checklist to the plants of Laos, and are working towards a checklist for Burma's Northern Forest Complex, the largest remaining primary forest in mainland Southeast Asia, with New York Botanic Garden, the Wildlife Conservation Society and Myanmar Forest Department.

■ Our in-house journals, *Edinburgh Journal of Botany* and *Sibbaldia: The International Journal of Botanic Garden Horticulture* are both now available on a Diamond Open Access model: free to read and free to publish.

Case study | ***Sapotaceae*** one-stop shop

The pantropical family Sapotaceae includes many economically-important timber trees, fruits, and the sources of shea butter, argan oil and gutta-percha latex. These trees contribute structure and function to tropical rainforests and provide food sources for birds and primates.

RBGE research into the 1,200 species of Sapotaceae has generated a wealth of useful data. To make this available and accessible for research and conservation around the world, we built the Sapotaceae Resource Centre*, a virtual information hub, in conjunction with Naturalis Biodiversity Center, Leiden, Conservatoire et Jardin Botaniques, Geneva, the Forest Research Institute Malaysia, Royal Botanic Gardens, Kew, Singapore Botanic Gardens and Sarawak Forestry.

The constantly updated, searchable database contains 54,000 specimen records and over 17,000 images, a mapping interface, links to active researchers and an index of relevant literature.

The Sapotaceae Resource Centre is one of a family of expertly curated biodiversity data resources generated using our database software, PADME: from our website you can explore collections ranging from images of microscopic algae, to more than 50,000 worldwide specimen records of the mega-diverse genus *Begonia*, to a gazetteer of Himalayan collecting localities.

Right: Plantation of *Palaquium gutta* (Sapotaceae), grown for its latex

* https://padme.rbge.org.uk/sapotaceae/

9 | Engaging diverse audiences

Making the nature connection

Our four Gardens, three of them five-star attractions, attract over a million visitors each year, more than at any time since the 1930s. Engagement activities, arts and cultural events create crucial links between our visitors, our science and conservation programmes, and the community. A visit to RBGE can spark the imagination, inspire interest in – and action to protect – the natural environment, enhance health and wellbeing, and build connections between individuals and groups.

Left: East Gate, Edinburgh Garden

1

■ We work with external partners to stage regular exhibitions, festivals and large-scale, innovative public engagement projects. These have tackled issues from food security, plant pathology and biodiversity conservation to connecting young people with nature. Our popular Edinburgh International Science Festival events draw thousands of children and adults alike. Expert volunteer Garden Guides lead almost 2,000 tours each year, while self-guided trails include our popular new Lichen Safaris, raising awareness of globally-rare bioindicator species.

■ Scotland's celebrated first flowering of a titan arum (*Amorphophallus titanum*) in 2015 was, remarkably, repeated in 2017 and 2019 [**1**]. Over 19,000 people experienced the spectacle, at the same time learning about the threats facing its natural habitat in Java and Sumatra.

■ Our inclusive, accessible and international arts programming centres around Inverleith House, which has recently been transformed into 'Climate House', an immersive space fostering connection and climate action among artists, scientists, horticulturists, activists, entrepreneurs, policymakers, visitors and local communities, thanks to a three-year Outset Award project with London's Serpentine Galleries. Hugely popular previous exhibitions included Jackie Morris and Robert Macfarlane's *Lost Words* [**2**]; *Natural Selection*, Peter and Andy Holden's exploration of the contentious history of egg collecting; *Microsculpture, the Insect Photography of Levon Biss,* which drew a record 46,000 visitors, and the UK premiere of ecological artist Lisa Roet's enormous inflatable *Golden Monkey*.

2

Case study | The BigPicnic

Food security is a global issue with local impacts: worldwide, over 800 million people are considered undernourished, and many staple crops are threatened by disease and climate change, while Britain is reported to have the worst levels of child food poverty in Europe. The BigPicnic – a £3.5 million project supported by EU Horizon 2020 and coordinated by Botanic Gardens Conservation International – brought together the public, scientists, policymakers and industry to seek solutions.

The BigPicnic explored our food chain from supply to demand, addressing topics such as sustainability, climate change and healthy eating. With 18 partners across 13 countries, the co-creative programme generated new dialogues and built mutual understanding of the impacts of food security.

RBGE's main role was giving voice to local communities, bridging the gap between public and policymakers. We focused on communities facing food poverty, unravelling Scotland's notoriously poor diet, and engaging with challenges to accessing food including homelessness and disconnection. Through sharing food grown in our Edible Garden, participants came to discuss how food matters to them and generate 'bottom up' solutions to complement high-level policy initiatives.

One especially successful strategy was 'digital storytelling', whereby individuals recorded a short audio track accompanied by still images, retaining the emotional power of personal accounts without the pressure of public speaking. A diverse range of stories emerged, which were shared from community events to the Scottish Parliament and can still be viewed online*.

* https://www.rbge.org.uk/news/big-picnic/

10 | Inspiring, training, and lifelong learning

Incomparable educational opportunities and expert training, from early years to professional level

Reversing the biodiversity and climate crises depends on well-informed decision-makers, effectively trained practitioners, and wide public understanding. Our accessible, specialist programmes for all ages and abilities empower people across the world to understand, cultivate, work with and benefit from plants, and to embed sustainability into their lives and communities.

Left: Teachers on a continuing professional development course


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■ "*There was no bit I did not like. It was brilliant*" (P4 pupil). Twenty thousand hours of hands-on schools' programming, mapped to the Scottish Government's Curriculum for Excellence and supporting the Campaign for Outdoor Learning, are enjoyed by over 10,000 children each year [**1**]. Free Schools' Weeks also reach over 900 children at Benmore, Dawyck and Logan each year, thanks to the players of the People's Postcode Lottery. "*I love Benmore week – worthwhile and great learning experience for staff and pupils*" (teacher).

■ At graduate level, more than 350 students from around 50 countries have graduated our MSc in plant biodiversity and taxonomy over 25 years [**2**]. Eighty-five per cent of them are now employed in plant science or conservation, or undertaking further study. PhD students – currently hailing from 15 countries – are embedded within our research community, studying themes from taxonomy and genomics to conservation science and cultural history.

■ We grow global horticultural capability by over 500 students each year through our signature Certificates in Practical Horticulture and Field Botany [**3**]. Around 60 students gain practical horticultural experience and advanced botanical knowledge through our internationally recognised HND/BSc in Horticulture with Plantsmanship, with Scotland's Rural College. Graduates included both the 2017 and 2018 winners of the Young Horticulturist of the Year. Our reinvigorated apprenticeship scheme provides training and mentorship at Edinburgh and Benmore.


3


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■ More than 1,000 people participate in our popular short courses each year, as a first step into learning or work, to develop skills, or for fun [**4**]. Courses range from Beginning Botanical Illustration (*"The most satisfying time I've had in any class*") to contemplative walking (*"Very special experience"*).

■ Our online learning space, PropaGate*, delivers everything from free tasters to professional programmes to over 1,450 learners from over 50 countries, expanding our reach significantly beyond on-site capacity, and has proved invaluable during the Covid-19 pandemic and lockdown. Our newest course, *Plants and Climate Change*, is available free of charge.

* https://onlinecourses.rbge.ac.uk/

Case study | Ripple effect

Training even a single student can have huge positive impacts on people and biodiversity. In 2006, Sydney Thony Ndolo Ebika, from Wildlife Conservation Society Congo, joined a RBGE-Université Marien Ngouabi training course in the Republic of Congo supported by the Darwin Initiative. He was then granted post-project Darwin Initiative funding to study for an RBGE MSc, which he graduated with a prize for his dissertation.

Following a subsequent Darwin Fellowship, a three-year Russell E. Train Fellowship from the World Wildlife Fund enabled Sydney to study his real passion: fungi. In 2018 he was awarded a PhD by Marien Ngouabi, where he now teaches, mentors and supervises students, sharing his knowledge and skills acquired over the past 13 years. Collaborating with scientists from as far afield as Belgium and China, Sydney has founded an NGO, Initiative des Champignons et des Plantes du Congo, to document the plants and fungi of Congo, evaluate their use as non-timber forest products, and to train Congolese students and researchers, including leveraging grants for study abroad.

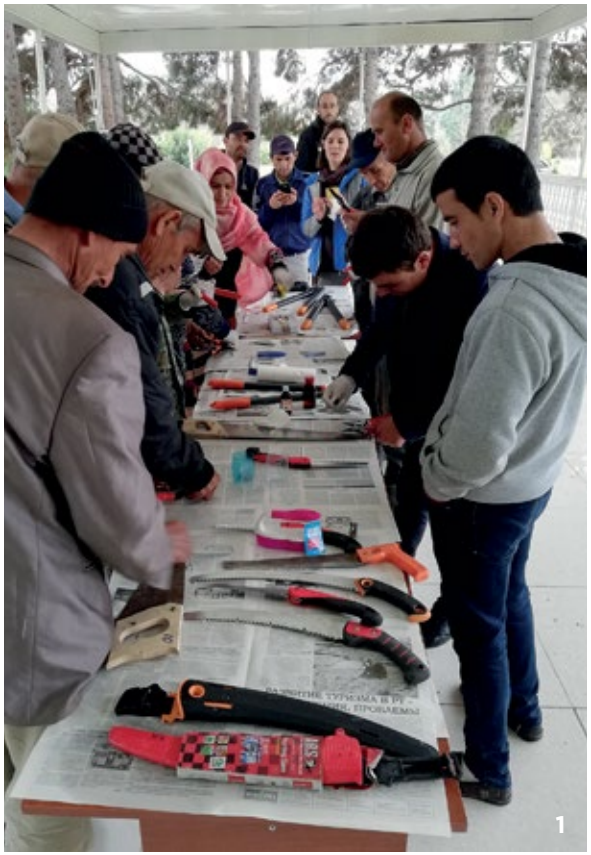
Top: Students in one of Sydney's classes

11 | Capacity and collaboration

Sharing essential skills and knowledge in the world's most biodiverse and threatened places

Protecting biodiversity whilst safeguarding sustainable livelihoods is an enormous challenge, particularly in countries with low incomes and high biodiversity. It is vital to share the complementary knowledge and skills of botanists between the global north and global south. Furthermore, organisations like RBGE, with a long history of overseas research, have a responsibility to repatriate resources to ensure equitable access and benefit-sharing. We co-create scientific, horticultural and conservation capability with partner institutions from South America to Africa, the Middle East and Southeast Asia.

Left: Seed propagation training, Kulob Botanic Garden, Tajikistan



■ **Tajikistan:** we worked with staff of Kulob Botanic Garden to build expertise in all aspects of propagation and cultivation [**1**]. This supported conservation of Tajikistan's valuable heritage fruit trees, threatened by unsustainable planting of European cultivars. A new, three-year Darwin Initiative project is extending this capacity, increasing income for local farmers and improving access to local produce.

■ **Iraq:** working with Nature-Iraq, we developed local skills and equipment to survey and manage biodiverse areas, and improved in-country availability of botanical data, supporting protected area management and community-level conservation [**2**].

■ **Mexico:** supported by INECOL, we delivered the Certificate in Practical Horticulture (CPH) to staff and students at Jardín Botánico Francisco Javier Clavijero, most of whom also trained as CPH trainers. This equips the garden with a strong skills base in collections management, horticulture and arboriculture and a large pool of in-house trainers, improving job security and staff morale and securing an income-stream for the Jardín from training.

■ **China:** a trial horticulture course run with the Chinese Union of Botanic Gardens reached staff from 20 sites and initiated a long-term partnership to deliver our CPH, train trainers and build conservation horticulture capacity [**3**]. New agreements with Kunming Institute of Botany and Xishuangbanna Tropical Botanical Garden pave the way for joint research, skills transfer and repatriation of plant material.


3

Case study
An enduring relationship

One of RBGE's strongest international connections is with Nepal. Over two centuries, scientists and horticulturists from our two countries have collected and curated specimens, shared knowledge and capabilities, and developed strong institutional and personal relationships supporting multiple collaborative projects.

Following delivery of the CPH to staff at Nepal National Botanic Garden, we jointly worked with local craftspeople and constructors to create a 1.3 Ha Biodiversity Education Garden. Featuring more than 70 native species, the garden engages visitors with plant biodiversity, climate change and conservation, and has generated a notable increase in visitors.

With support from Botanic Gardens Conservation International, we worked with Nepal's Department of Plant Resources to conserve threatened native yews (*Taxus spp.*), building capacity for *in-situ* and *ex-situ* conservation, raising awareness amongst forest managers and the public, and working with local staff to identify threatened species. We delivered specimen digitisation equipment and training to Kathmandu National Herbarium, facilitating local staff to document the *Flora of Nepal* and produce user-friendly field guides, and enabling improved calculation of species' distributions to identify those at greatest risk.

Over 200 non-native plants are found in Nepal, with many problematically invasive. Our Darwin Initiative project helped raise awareness of, and build capacity to remove, invasive species, reclaiming land for sustainable, native, economic plantings. Eradicated plants are converted to soil-improving biochar or charcoal which, with improved stove technologies, has led to reduced firewood cutting and improved health and wellbeing.

Top: Clearing invasive non-native species in Makwanpur District


FISH 'n CHIPS
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FOR A BETTER FUTURE

12 | Prioritising health and wellbeing

Harnessing the healing power of plants

Access to nature has never been more important for physical and mental wellbeing. All four RBGE Gardens provide essential green space, with our Edinburgh Garden providing a free-to-enter, fully-accessible space in the heart of the city. Over the past five years we built strongly on this foundation with both structural and practical projects, and during the Covid-19 pandemic we intensified our actions to support people and communities.

Previous left: Schools' Gardening Project

Previous right: Trialling a poster detailing the 26 most problematic invasive plant species in Nepal

Left: Edible Garden Project, Edinburgh


1

First constructed in 1764, the Botanic Cottage was painstakingly transported to and rebuilt in the Edinburgh Garden, opened in 2016, and now provides a welcoming community hub for around 5,000 people each year [**1**]. A wide range of groups – many of whom might otherwise not visit the Garden – including underprivileged families and refugees, thrive in the accessible space of the Cottage. It also provides a supportive and restorative environment for those with learning disabilities, dementia, Parkinson's disease and mental health problems. Four annual community festivals bring people from a wide range of backgrounds together to share food, music and connection through outdoor activities.


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The Edible Gardening Project, supported by the players of the People's Postcode Lottery, benefits over 7,000 people each year [**2**]: groups including Garvald Edinburgh (for people with learning disabilities), Edinburgh and Lothians Regional Equality Council, NKS (empowering south Asian women and their families), Move More (for those affected by cancer), and TEENS+ (for young adults with complex communication needs) gain hands-on horticultural experience, a sense of value and belonging, and enhanced social cohesion through weekly sessions with our community gardeners. Popular 'Meet the Gardener' sessions empower people to 'grow their own', and our volunteer-run Market Garden trains local community gardeners in year-round production of fresh, nutritious vegetables – as well as supplying fresh, certified-organic produce to our refreshment outlets and local food banks.

■ We enhanced our offer to local communities during the COVID19 pandemic, supplying hundreds of kilos of fresh organic produce as food parcels and through a fortnightly on-site Open Pantry. Botanic Cottage programmes such as the Community Cook Club moved online, and a new online programme – Marley's School of Garden Magic – was developed to support home-schooling [**3**]. Over 1,000 'Expedition Dandelion' activity packs were provided to local children who may not have internet access, via local foodbanks.

■ Our new Garden of Tranquillity provides a safe, sensory greenspace for people with dementia, their friends, families and carers to experience the therapeutic benefits of nature [**4**]. It provides inspiration for visitors' own gardens, dementia resources, and news of Edinburgh's world-leading dementia research.


4

Case study | Out and about

Our impact extends far beyond the Garden, with a range of inclusive projects providing health and wellbeing benefits through connection with nature.

A founding partner of 'Edinburgh Living Landscape', we initiated an integrated, city-wide network for nature, enhancing biodiversity alongside the health and wellbeing of Edinburgh citizens. Programmes included a 'Square metre for butterflies', in which we worked with schools, businesses, and the Prison Service to deliver green roofs planted with pollinator-friendly species, and the Edinburgh Shoreline project which helped coastal communities explore their relationship with the sea and find solutions to the challenges facing both people and nature on the shoreline.

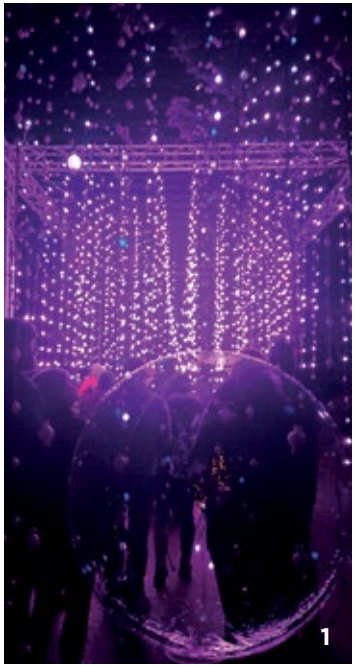
We provide training through action, such as creating a species-rich urban greenspace at the Scottish Government's Victoria Quay, and through free all-age gardening workshops in community gardens at Granton Hub in north Edinburgh and Lochend Secret Garden in the east of the city. Our annual Harvest Festival showcases a spectacular range of produce from groups around the capital.

13 | Successful for Scotland

Cementing Scotland's place in the global green recovery

Our Gardens are a reason for people to come to Scotland and, in 2020, RBGE was Scotland's most visited attraction. Beyond the garden sites, our work in the natural environment is fundamental to the nation's identity, health, quality of life and global influence. Our actions protect and restore Scotland's biodiverse ecosystems, help Scotland meet crucial international commitments, demonstrate Scottish scientific excellence across the world, strengthen Scotland's economy, and support the wellbeing of its people.

Left: Sharroch, Cairngorms National Park



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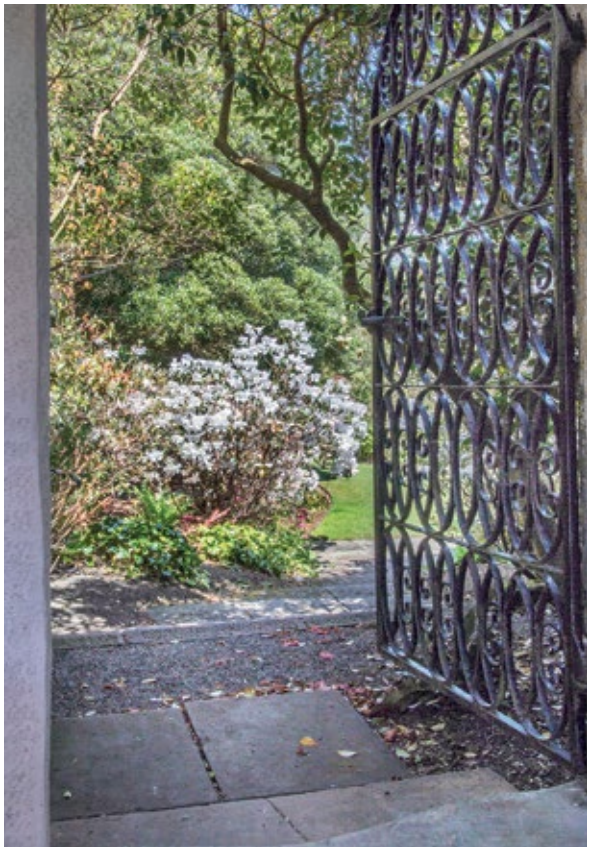
■ RBGE's contribution to the Scottish economy is independently estimated at £52 million per year, and our self-generated revenue increased by 44 per cent over five years, to over 40 per cent of our income. We provide more than 300 jobs and apprenticeships across the nation, including in areas of economic hardship. We have a strong focus on equality and diversity, holding a Bronze Athena SWAN Award for gender equality from Advance HE, and we have an active Racial Justice Working Group seeking to acknowledge our history and build a fairer and more inclusive environment in our workplace and the wider fields in which we work.

■ Our spectacular light show *Christmas at the Botanics* welcomes over 78,000 visitors each year and is a key element of Edinburgh's Christmas [**1**]; The new 'Bonnie Botany Tour' – a 380-mile route through southern Scotland, featured in Martin Dorey's *Take the Slow Road: Scotland* (Conway, 2018) – supports Scotland's tourism economy while linking all four Gardens.

■ With collaborators in almost 130 countries, and major partnership projects in over 40, we enhance Scotland's global profile and play a vital role forging links with scientific institutions, governments, senior diplomats and political leaders, sometimes over decades. Our acclaimed 'plant diplomacy' activities strengthen Scotland's position and enhance its influence in global negotiations.



Case study | RBGE on show

Our show gardens – at Gardening Scotland and around the UK – are always spectacular. 2017 was a particularly successful year for our Garden Design students, whose 'Living Landscape Design' garden received a silver gilt medal at Gardening Scotland and 'Chinese Hillside' garden won both a gold medal and Best in Show.

In 2019 our stunning 'Coffee Garden' swept the board, winning a gold medal, Best in Show, and the People's Choice Award. We also helped develop the Genetics Society's centenary garden, 'The Flowering of Genetics', which received a Silver Medal at the RHS Chelsea Flower Show.

A GLOBAL RESOURCE

The Living Collection, Herbarium, Library and Archive we care for, established and maintained over centuries, are at the heart of our work. They underpin fundamental scientific research, provide vital resources for teaching, are crucial to the visitor experience, and engage communities with the wonders of nature.

The collections reflect a diverse legacy of exploration and collaboration. As their custodians, we are committed to transparent communication regarding our history, to addressing racial inequalities across our organisation, and to facilitating equitable and fair access to specimens and data in support of conservation and sustainable use of biodiversity in their countries of origin, particularly those in the global south.

Ongoing actions towards improving racial equity include:

- a programme to communicate the colonial history of our living and preserved collections;
- accelerating digitisation and repatriation of herbarium specimens to enhance access to researchers in their countries of origin;
- developing a new Research Ethics Policy reinforcing our commitment to safety, dignity and human rights;
- creating new opportunities for under-represented groups to enter, progress and lead in plant science and horticulture; and
- involving all staff, students, volunteers and stakeholders in building an inclusive and anti-racist culture at RBGE.

Left: Redwood Avenue, Benmore

14 | The living collection

A world of plants in less than a square mile

Encompassing more than 130,000 plants of 13,600 species from over 160 countries, our Gardens are centres of horticultural expertise, vital research, endangered species conservation, and hands-on training. They safeguard the future of hundreds of threatened taxa, including several Extinct in the Wild, and support collaborative restoration, reintroduction and repatriation programmes around the world.

Left: Temperate Palm House, Edinburgh


1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■ Exceptional standards of display demonstrate close integration of horticulture with science. Featuring flood-resilient pathways, a refurbished bothy and a beautiful dry-stone bench, our new Experimental Garden, developed with Edinburgh University, uses Scottish native plants and innovative interpretation to highlight cutting-edge research, from cell biology and plant form to evolution and ethics [**1**].

■ As world leaders in practical conservation horticulture, we are accredited Advanced Conservation Practitioner status by Botanic Gardens Conservation International. Our genetically-diverse collections of threatened species support active *in-situ* conservation programmes, with a particular focus on conifers and Scottish rarities. For example, in 2020 we repatriated 40 Near Threatened catkin yews, *Amentotaxus argotaenia*, to boost natural populations in Hong Kong. We manage the Global Conservation Consortium for *Rhododendron*, bringing together scientists, horticulturists and conservationists to prioritise and facilitate *in-situ* and *ex-situ* conservation of these iconic and often threatened species [**2**]. Eye-catching red labels now highlight rhododendrons of conservation concern throughout our Gardens.


3

■ We continue to enrich the collections – in line with international protocols on export, access and benefit-sharing – and enhance the visitor experience across our Gardens, adding 8,269 accessions over the past five years, from over 70 countries, 96 of them threatened and two Extinct in the Wild. At Benmore, for example, expanded Chilean rainforest plantings based on three decades of research and conservation are complemented by striking new interpretation panels, backed with local timber, and a beautiful Rainforest Viewpoint Refuge, inspired by the UNESCO World Heritage-listed churches of Chiloé Island [**3**]. At Edinburgh, the heritage Alpine House has been restored to protect our rich alpine plant collections, and we have now embarked upon an ambitious restoration programme, Edinburgh Biomes, to safeguard the living collections for the world and ensure they reach their full potential as a resource for science, conservation, learning and public engagement.

■ Future-proofing the collections: we built new isolation houses at Benmore, Dawyck and Logan to minimise disease transmission during introductions to the collection or reintroductions to the wild; created an innovative raingarden with Heriot Watt University, showing how design and planting can reduce flooding and benefit native biodiversity, and carried out extensive work to mitigate climate change impacts, including access, drainage and infrastructure improvements, and a programme to reduce soil compaction and waterlogging in Benmore's iconic Redwood Avenue.

Case study | *Rhododendron* resurrection

Our Gardens hold an internationally-important heritage collection of *Rhododendron* species, many dating from the early 20th century when they were introduced from Asia by collectors such as George Forrest, Joseph Rock and Ernest Wilson. These centenarian plants are now sadly declining due to age, pests, and the dry Edinburgh climate.

Over the last five years RBGE horticulturists developed an ambitious programme using sterile 'micropropagation' techniques learned at Cornwall's Duchy College, to conserve the heritage *Rhododendron* collections.

Sterilised flower bud tissue of priority *Rhododendron* species is grown in agar gel with a precise mix of nutrients and hormones, specific to each stage of growth and development, until it develops into tiny whole plants. The process is painstaking, but by 2017 the first micropropagated plants, genetically identical to their parents, were successfully planted out at Benmore, and there are many more to come.

15 | The Herbarium

A unique archive of life on Earth; a vital resource to combat contemporary challenges

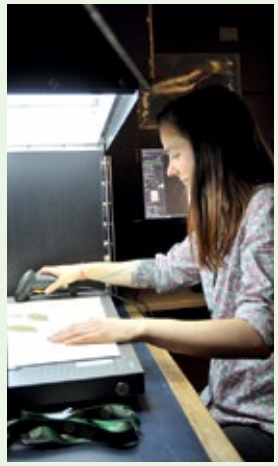
The RBGE Herbarium contains over three million dried specimens representing more than half the world's plant species, each providing an array of morphological, locality, phenology and habitat information. Many rare and threatened species are known only from herbaria, and many as-yet undescribed species lie in the cabinets waiting to be identified. As we begin to address the colonial history of many items in the collections, we recognise our duty to share their beauty and scientific value as widely as possible, with a particular focus on digitisation to make specimens and data available to researchers in their countries of origin.

Left: Herbarium, Edinburgh

■ This *Primula chrysophylla*, collected by George Forrest in Szechuan, China, is one of many historic specimens we care for, some dating back to the 17th century [**1**]. Today, the collection grows by around 10,000 specimens each year, with herbarium sheets now accompanied by a rapidly-expanding collection of silica-dried material for molecular research. Almost all specimens will comprise multiple duplicates, of which some will be left in the country of collection and others shipped to herbaria around the world. We have made it a priority to repatriate duplicate sheets of older specimens to their country of origin: for example, we recently sent many herbarium duplicates of Chinese collections to Beijing.

■ Over the past five years our collection was studied, in person, by over 700 scientists from 145 countries, and thousands of specimens were loaned around the world. Our online database, which now covers over a million specimens – almost a third of the collection – is accessed by around 500 external users each month, with over five million specimen records and over 2.25 million images downloaded across 72 countries. We continue to play a major role in the pan-European 'Distributed System of Scientific Collections' (DiSSCo) Research Infrastructure initiative, broadening access to natural history collections across 115 organisations.

Case study | Going Digital



Collections-based research depends increasingly upon digital access. The last five years saw more than 228,000 specimens imaged and their handwritten labels transcribed and databased. Over one sixth of the collection (around 521,000 specimens) can now be viewed and downloaded in high resolution. In just one year more than two million records and 180,000 digitised images were downloaded.

Our digitisation programme prioritises research need. We have already completed digitisation of all 'type specimens' (those to which the name and description of a species is tied), our focal research groups *Begonia*, Gesneriaceae, Sapotaceae and Zingiberaceae, and all temperate South American and Australian collections. Our current foci are specimens from Nepal and Scotland, to facilitate production of the *Flora of Nepal*, and to engage new audiences of citizen scientists and increase awareness of Scottish plant biodiversity.

We work with other institutions to digitise at-risk groups. A recent project with the Royal Botanic Gardens, Kew, and the Natural History Museum, London, funded by UK Official Development Assistance, focused on the world's most widely-traded illegal wildlife product – tropical rosewood (*Dalbergia*). Many rosewoods are threatened with extinction, while illegal logging for their timber, particularly in biodiversity hotspots such as Madagascar, puts whole ecosystems at risk. Using high-throughput workflows and with the help of volunteer 'citizen scientists', this project digitised and databased 37,000 specimens, liberating taxonomic, ecological and geographic data and protecting delicate plant material from the risks of transport. The data – available via GBIF – are used to determine species' past and present ranges and to determine conservation priorities in these poorly-understood and threatened plants.


PLANT LIFE
ECOLOGY 2000
MAYR
Evolution
SPECIATION

16 | The Library and Archive

Science, history and art collide in this botanical treasure trove

With over a million items, the RBGE Library and Archive is one of Scotland's largest research libraries. Open to anyone*, our Library is the National Reference Collection for specialist botanical and horticultural resources and a vital foundation for our research. Our archive of historical correspondence, maps, drawings and photographs often provides new information about the plants on which we work, contributing to a range of active research projects.

* See https://www.rbge.org.uk/science-and-conservation/library-and-archives/ for any Covid-19-related entry restrictions

Left: Library, Edinburgh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■ Around 2,000 items are added to the collection annually, recently including an important set of 20th century Saudi Arabian botanical slides [**1**] and a series of 18th century Scottish nursery catalogues, containing information on historical uses of crop plants and ornamentals, thanks to the Friends of the National Libraries of Scotland.

■ Recent research on the archive has included documents and photographs relating to all those remembered on the RBGE war memorial, bringing this important part of the Garden's history to life in exhibitions, talks and online [**2**]. Our Archive items are also regularly used on TV, in books or in exhibitions, recently being loaned to Paxton House, East Lothian and the Royal Academy of London, and as far afield as Berlin and India.


2

■ Maintaining the collection is a huge task, and we are extremely grateful to the many volunteers who help with this: the Edinburgh Decorative and Fine Arts Society have cleaned more than a kilometre of books and journals, and have now moved on to our artworks.

An ongoing project to catalogue our rare books – some dating back to the 15th century – is helping the future accessibility of this valuable collection. We also transferred our existing library catalogue to Koha, the world's first open-source integrated library system, providing increased functionality for users.

Above: *Pelargonium insularis*, by Gülnur Ekşi, 2015, in the RBGE Florilegium

Case study | Inspirational alliances

Regular collaborations with artists spark exciting new ways to access and display the collections:

In *Art and Science – a Natural Relationship*, ceramicist Lorna Fraser worked closely with the Herbarium team and Sapotaceae researcher Dr Peter Wilkie. Lorna's installation *Scaphium* was shown at Patriothall Gallery, Edinburgh, Meffan Gallery, Forfar, and the British Pavilion at the Cheongju International Craft Biennale in South Korea, engaging new audiences with botanical collections.

Knitwear designer Sarah Clarkson of *Woolly Originals* drew inspiration from the Herbarium and our conservation work with rare Scottish woolly willow (*Salix lanata*) and alpine blue sowthistle (*Cicerbita alpina*) to create two ranges of designer bags, with 10 per cent of sales going to Garden funds.

The RBGE Florilegium Society was launched in 2019 to create a permanent, visual record of RBGE's botanical and horticultural work through illustrations of the plants cultivated, collected, studied and described, and to raise the Garden's profile as a centre of botanical art.

Top: *Scaphium,* by Lorna Fraser

OUR TEAM

17 | Our people

A vibrant, dedicated team of staff, students and volunteers and a global network of collaborators

From being suspended 20 m above the ground replacing the glass in our heritage structures, to standing waist-deep in water cleaning the leaves of the *Victoria amazonica*, and from manning the phones to mounting herbarium specimens – not to forget the annual pantomime! – our 270 staff work hard behind the scenes. Around sixty research associates, 250 interns and volunteers and in excess of 100 students all also play vital roles, supported by a Board of Trustees appointed by Scottish Ministers. Collaboration and partnerships are fundamental to our work.

Previous left: Logan

Previous right: Field team in Mitarure, Tanzania

Left: Cleaning *Victoria amazonica* in the Glasshouses

1

■ Our team support one another through a mental health first aid network, march together at Edinburgh Pride every year [**1**], advocate in an Equality, Diversity and Inclusion group, and build each other's skills through a mentoring programme.

■ We were delighted recently to bestow the RBGE Medal, recognising outstanding individual contributions in biodiversity and botany, on Dr Saw Leng Guan of the Forest Research Institute Malaysia, and Sanjeev Kumar Rai, of the Department of Plant Resources of Nepal [**2**], in 2018.


2

Case study | Ways of Working

In all our work, we adhere to the following principles:

Social justice: We will work to ensure equity and inclusion in all dimensions of our work, locally and globally.

Accessibility: We will promote open access to our research to maximise global benefits, and ensure fair and equitable access to our collections while ensuring that all our work is compliant with national and international legislation.

Respect: We will seek to understand local cultures and customs, and ensure we act responsibly and with respect.

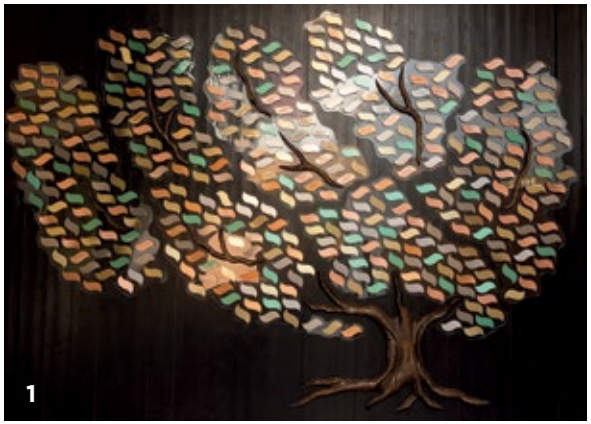
Relevance: We will strive to ensure our work addresses societal and environmental needs and maximises benefits to stakeholders and partners.

Sustainability: We will minimise the environmental impacts of our work.

18 | Our supporters

Our work is made possible by the generous support of organisations and individuals who share our passion for plants and concern for the planet

RBGE is funded by the Scottish Government Rural and Environment Science and Analytical Services Division. However, a large proportion of our work is enabled through our growing self-generated income streams. Grants, legacies and donations are crucial to secure the national collections, conduct vital research and conservation, and continue our learning and engagement activities.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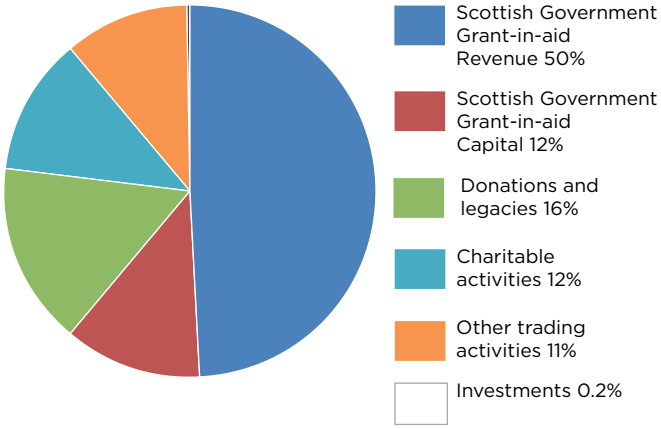
■ Over the last five years we generated over £2 million in legacy gifts, £1.7 million from the players of the People's Postcode Lottery, £880,000 from the National Lottery Heritage Fund, over £100,000 towards our Education Programme, £47,000 to support our horticultural apprenticeship scheme. We also received over 5,000 contactless donations and 180 commemorative gifts [**1**].

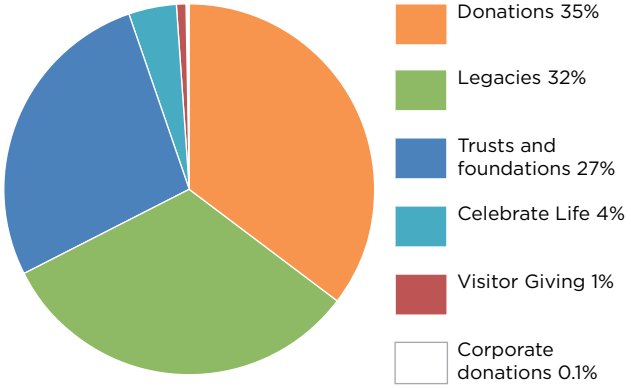
■ These gifts have supported our discovery science in Southeast Asia, conservation work with rare Scottish plants, and capital works including restoring the Botanic Cottage and constructing Edinburgh's new Alpine House. They have funded free learning to primary children across all four Gardens through the Schools Gardening Project [**2**], and our apprentices are entirely funded by external donations. Contributions also support those living with dementia, through social activities and our new Garden of Tranquillity.

■ Over five years our more than 10,000 Members have raised funding for 65 diverse projects, ranging from a study of the impact of climate change upon Scotland's lichens, to building a beautiful Nepalese Gate at our Edinburgh Garden [**3**].

Our income, 2016–2017 to 2020–2021



Our philanthropic income, 2016–2017 to 2020–2021



OUR VISION

We want to create a world that increasingly values, protects, and benefits from plants

Humanity has a short, crucial window to address the interconnected challenges of climate change and biodiversity loss, whilst improving human health and wellbeing and the sustainable use of natural resources. RBGE's research, conservation, learning and engagement programmes are well placed to influence the conversation and participate in action on these issues, and as an organisation we are committed to a meaningful and effective response.

1

Arguably the most ambitious and significant project in our history, Edinburgh Biomes is a £90 million, seven-year construction and refurbishment programme to secure the future of the irreplaceable national collections in our care, provide vital facilities for our science and conservation work, support education and skills development, and stimulate public engagement with the natural world [**1**]. Crucially, the programme will also greatly enhance our energy efficiency, with a new Sustainable Energy Centre and replacement and renovation of our glasshouses leading to a substantial reduction in carbon emissions. Edinburgh Biomes will cement our role as a leader in plant science, education and horticulture, whilst generating over a hundred new jobs per year, with a strong focus on socially-inclusive employment opportunities for those from disadvantaged backgrounds, apprentices and the long-term unemployed.

Our *Strategy 2021–2026* and *Science and Biodiversity Strategy 2021–2030* frame and articulate our priorities around the biodiversity crisis and climate emergency. Our activities focus on three pillars: unlocking knowledge of plants and fungi, protecting and developing the botanical collections in our care, and enriching and empowering individuals and communities through learning and engagement.

Many of the programmes, activities and partnerships already described in this book are for the long term. We are also engaged in many exciting new projects, including the ground-breaking collaborative ‘Darwin Tree of Life’ programme to sequence the genomes of all 70,000 species of complex life in Britain and Ireland. As a Genome Acquisition Lab, we are collecting flowering plants, ferns, bryophytes and lichens for whole genome sequencing,

generating unprecedented knowledge of their evolution, ecology, conservation and potential uses. We contribute to two UK Research and Innovation Global Challenges Research Fund Research Hubs, focusing on nitrogen pollution and global trade. We are also developing the UK Crop Diversity Bioinformatics Resource, a high-performance computing cluster meeting the challenge of food security through characterising genetic diversity in crops and their wild relatives. Our new Biodiversity Skills Centre will maximise the reach of our specialist training programmes and expand our online learning programme to meet national and international needs. We will also implement our new Arts Manifesto with an exciting, wide-ranging, high-quality and accessible arts programme.

How you can help

We're working to safeguard our planet for future generations; but we can't do it alone. Please help us achieve more:

- **Become a Member**
https://www.rbge.org.uk/membership/

- **Become a Patron**
https://www.rbge.org.uk/membership/become-a-patron/

- **Remember us in your will**
https://www.rbge.org.uk/support/remember/

- **Donate**
https://www.rbge.org.uk/support/donate/

- **Volunteer**
https://www.rbge.org.uk/support/volunteer/

For more information, please visit https://www.rbge.org.uk/support/

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