



# **Review of RBG Kew Science**

## **Report of an independent panel**

**August 2019**

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# 1 Introduction

1. This Review of science at the Royal Botanic Gardens, Kew (RBG Kew) was commissioned by the Board of Trustees in early 2019. The Board appointed an independent Review Panel chaired by Professor Sir Charles Godfray FRS from the University of Oxford to undertake the assessment. The full Panel membership is detailed in the Appendix 1.
2. RBG Kew combines a major visitor attraction, the gardens and living collections, with its position as the UK's premier herbarium, fungarium and plant and fungal biodiversity institute. RBG Kew's scientific vision is "to document and understand global plant and fungal diversity and its uses, bringing authoritative expertise to bear on the critical challenges facing humanity today." RBG Kew's priorities in its current Science Strategy (2015–2020) are:
  - Conducting research into global plant and fungal diversity and its uses.
  - Curating data-rich evidence from RBG Kew's collections as a global asset.
  - Disseminating scientific knowledge.
3. At the heart of the research RBG Kew conducts is its scientific collections. RBG Kew houses one of the largest and most diverse botanical and mycological collections in the world, containing over 8.5 million items and representing 95% of the world's vascular plant genera and 60% of fungal genera. RBG Kew's major scientific collections include the herbarium, fungarium and xylarium (wood collection) as well as material stored in spirit, on microscope slides and as DNA & tissue samples. There is an extensive economic botany collection and the living collection is both a visitor attraction and a science resource. The seed bank at RBG Kew's Wakehurst site is one of the biggest in the world. RBG Kew has an extensive library and increasingly houses digital resources and databases. RBG Kew's Science Collections Strategy (2018–2028) aims to guide the management and development of the collections in line with RBG Kew's scientific priorities and the Convention on Biological Diversity.
4. Over 400 scientific staff, postgraduate students and honorary research associates deliver RBG Kew's strategic priorities through six research departments (Collections, Identification & Naming, Natural Capital & Plant Health, Comparative Plant & Fungal Biology, Conservation Science, Biodiversity Informatics & Spatial Analysis) supported by the Office of the Science Directorate and Library, Art and Archives, which provide the necessary scientific infrastructure.
5. RBG Kew has an extensive international network of over 400 individual partners with scientific activities and collaborations spanning 110 countries. Since its inception and continuing today, RBG Kew has played a major role in discovering and documenting plant and fungal diversity in all the world's tropical regions.
6. The Review had the following Terms of Reference:
  - To provide independent advice on the quality, impact and environment of Kew Science to the Board of Trustees, the Director and Director of Science, and the Science Advisory Committee.
  - To establish output, impact, environment and overall quality profiles plus narrative commentary for Kew Science.
  - To assess progress to date in achieving RBG Kew's Science Strategy 2015–2020 ambitions and targets and progress in implementing the Science Collections Strategy 2018–2028.
  - To articulate the review findings, conclusions and future recommendations in the form of a short report authored by the Review Panel.
7. RBG Kew is part of the Department for Environment, Food and Rural Affairs' (Defra) family of agencies and institutes and in the past its science has been reviewed quinquennially by a panel set up by Defra. The last Defra-organised review was published in 2012. Although this review was commissioned by the Trustees rather than Defra, it was with the Department's support, and Defra's Chief Scientific Advisor, Professor Sir Ian Boyd, was part of the Review Panel.
8. The Review is structured as follows. Section 2 describes our methodology and this is followed by (3) our assessment of the major global and national challenges likely to face RBG Kew in the next ten years. In Section 4 we discuss institution-wide issues while Sections 5–7 explore progress to date and make recommendations in the three Science Strategy priority areas. Section 8 considers training. Throughout, we make suggestions and recommendations for the future and these are collected together in Section 9 with concluding remarks.

## 2 Methodology

9. The Review Panel convened at RBG Kew on the evening of April 14th 2019 and spent the next two days in the Gardens. Previously, a secretariat led by Dr Clive Hayter had provided extensive background material. The Panel first met with the Director and Director of Science and then over the two days met over 60 of the senior science leaders at RBG Kew, toured the facilities and took part in a poster session with early career researchers and PhD students. A subset of the Panel visited the Millennium Seed Bank at Wakehurst, West Sussex on April 14th.
10. The Panel reviewed a selection of 460 research outputs (mostly scientific papers but also floras, books and digital databases) as well as 20 examples of RBG Kew's broader impact on environmental protection, society, government and the economy, and "environment statements" from each of RBG Kew's nine science departments describing the infrastructure, training, support and human capital that underpins RBG Kew science. This review was loosely based on that adopted by the UK's Research Excellence Framework (REF 2021) process. Initially, RBG Kew suggested that the Panel scored the outputs as would be done in the REF but the Panel felt that this approach would not accurately reflect the unique character of research at RBG Kew and chose instead to provide a narrative report assessing research outputs against appropriate measures of originality, significance, rigour and impact. Similarly, the environment statements were judged against measures of viability and sustainability appropriate for a collections-based biodiversity institute. The results of this assessment are presented in Appendix 2.
11. The secretariat provided various data benchmarking RBG Kew against related organisations around the world. They arranged for a letter to be sent to the directors of many of these organisations requesting their views on RBG Kew's scientific standing, science outputs and their experience of RBG Kew as a collaborating organisation. The Panel is grateful for these valuable inputs.
12. The Report was written by the Panel with the support of the secretariat. A penultimate draft was shared with RBG Kew to correct any areas of fact and to comment on the recommendations. The final draft was prepared by the Panel in the light of these comments.
13. The Panel would formally like to note its appreciation to Clive Hayter and the secretariat for their excellent support and to everyone they interacted with at RBG Kew, who without exception engaged very constructively in the Review process.

### 3 Future opportunities and challenges

14. The biological sciences in general, and biodiversity science (here including taxonomy and systematics) in particular, are evolving rapidly. These changes provide new opportunities for RBG Kew science but also pose very significant challenges to the organisation and its approach to science delivery. RBG Kew occupies a special position in the UK science landscape because of its institutional structure and long history; it is an important scientific and cultural part of the nation and its capabilities are of national importance. But past success must not lead to inertia and the trope “business as usual is not an option” is literally true if RBG Kew science is to survive and flourish. The science leadership team and Science Advisory Committee at RBG Kew are of course aware of these challenges but the Panel recommends that discussion of what RBG Kew will look like in several decades is given greater salience at Board of Trustees and Executive Board levels. The Panel hopes the content of this Report will assist in this debate, and this section provides some of the background arguments.

#### Recommendation 1

RBG Kew's Board of Trustees and Executive Board clearly articulate the organisation's unique position in national and international research given the changes occurring in the biological and biodiversity sciences, and provide a clear vision of how it will develop its scientific mission across basic and applied research, policy, education and public outreach.

15. A key function of RBG Kew since its inception has been the identification of plant and fungal species. Historically, in most geographical regions around the world, species identification could only be carried out by expert botanists with access to extensive collections. One Kew scientist said to the Panel “there will always be a need for plant identification” – but the issue is, will there always be a need for Kew to do it, and will identification always be carried out using current methods? Already we are beginning to see identification by experts replaced by identification using molecular methods. The cost of sequencing, and the advent of cheap portable sequencing and identification machines (prototypes exist) mean that molecular identification is highly likely to be routine in 20 years and probably far sooner. This will be possible first in developed countries, such as the UK, where complete (or near-complete) DNA barcode libraries for plants are already available, but

is likely to spread rapidly to other regions. There is a significant opportunity here for RBG Kew to work with other organisations globally to facilitate accurate molecular identification while ensuring a seamless connection with the information accumulated over centuries of morphological plant studies. While the Linnaean schema will remain the bedrock of naming and communication, there is a possibility that species-agnostic classification systems emerge (where operational taxa are clusters of sequences that may or may not correspond to Linnaean taxa). Should they do so, RBG Kew, working with its partners, should play a major role in ensuring the coherence and unity of plant and fungal biodiversity studies.

16. RBG Kew has been a world leader in using DNA sequencing to construct the tree of life for plants. As a major partner in the Angiosperm [flowering plants] Phylogeny Group (APG), RBG Kew scientists and their colleagues have, over four releases (1998, 2003, 2009, 2016), systematically re-classified the families of flowering plants. This effort has reached a consensus that is unlikely to change significantly. Current work is extending the phylogeny to lower taxonomic levels; related projects, in which RBG Kew is closely involved, are targeting non-flowering plants and fungi. RBG Kew should be hugely proud of its contributions to the leadership and execution of these projects, which have produced many of the organisation's most flagship papers. But the organisation also needs to consider what will follow on from this work now that higher-level plant phylogeny is essentially “done” at the family level and the time when it nears completion at genus level is not far off. What other questions about plant phylogeny are likely to be fundamental in the coming decade? What are the major questions about pattern and process in plant evolution that only the synoptic approach of RBG Kew can answer?

17. The phylogeny of fungi and their relatives is less resolved than that of higher plants. It is clear that for these groups the community will adopt a whole-genome approach (as opposed to the marker gene surveys used in the APG). For RBG Kew to contribute to this enterprise it will need to invest significantly in genomic and bioinformatic capacity. Given the importance of RBG Kew's fungal collections the organisation has the opportunity to play a very significant role, but only if the investment can be made.

## Recommendation 2

That part of RBG Kew's next Science Strategy should be a plan of how it will contribute to the next phase of the development of the fields of plant and fungal phylogeny and genomics.

18. Much of RBG Kew's activities over the last 200 years can be conceptualised in modern terms as the organisation and dissemination of information about plant diversity. RBG Kew was dealing with "big data" long before the term was invented. Today, there is an expectation in the research community and increasingly amongst wider uses of RBG Kew's outputs that all data are available digitally over the web. The future for RBG Kew is as a digital organisation and failing to embrace this reality is a major threat to the organisation. There is an irony that those parts of biodiversity science that long ago embraced what were then efficient means of disseminating large amounts of information (for example, morphological taxonomists producing floras) have found it harder to transition to digital dissemination than more recently established parts (molecular taxonomy). RBG Kew needs to have an open, active, engaged and forward-looking digital policy that delivers RBG Kew's unique data without restriction and working in partnership with other global data sources.
19. The technological advances described above suggest that many more people than at present will soon have access to accurate species identification, including many in developing countries. But knowledge of a species' name and evolutionary relationships is of limited value in itself. There will be a huge demand for further information about plants and fungi, which could be provided by a portal such as Plants of the World Online (POWO). RBG Kew needs to decide how to position itself in the plant biodiversity "information space". Does it have an ambition to be (with partners) the authoritative broker of accurate information about plant and fungal diversity on the web? What types of information should such a portal provide access to? What are the risks of not being proactive in this area – especially given that it is the nature of modern web platforms and information resources that one comes to dominate in each sphere, often the one with first mover advantage?
20. RBG Kew must respond to, and also help shape, global trends in plant and fungal biodiversity science. First, as low-income countries develop their own science capabilities there will many opportunities for RBG Kew to foster capacity building in these countries. Kew has a proud tradition of supporting research development upon which it can build. Second, countries are understandably becoming assertive about the rights to exploit their own biodiversity, as witnessed by discussions around the Convention for Biological Diversity (CBD) and the Nagoya Protocol. Continuing sensitivity to this agenda will be important for RBG Kew, and the organisation can build on the alliances and trust it has already established across many countries. Making its global collections available digitally will be critical in supporting the development of plant science in low- and middle-income countries.
21. This Panel is reporting at a time when the future of the UK's relationship with the European Union is uncertain. RBG Kew has greatly benefitted from research support from European research initiatives. It is stating the obvious that the Board of Trustees and Executive Board must closely monitor what happens and use every opportunity to argue for a science settlement favourable to the organisation.
22. A final trend that is of importance to the future of RBG Kew is the rise in the number of citizen scientists and the growing appreciation by governments and other funding bodies of their potential to contribute to the research enterprise. There are major opportunities for RBG Kew to be a leader in supporting citizen science, especially through knowledge outreach and provision of freely available digital information.

## 4 The state and organisation of science at RBG Kew

23. The Panel was asked to assess recent RBG Kew science outputs using a methodology (paragraph 10) loosely modelled on the UK Research Excellence Framework (REF). The Panel found some difficulty in doing this fairly to an organisation with the unique character and mission of RBG Kew and elected to produce a narrative report that is Appendix 2. It found that the science outputs were a mixture of the highest quality international science (the type published in the major interdisciplinary journals); very good disciplinary science (published in leading plant science journals); and research that would not be judged as “REF returnable” in the University sector for which the process was designed. Overall, the Panel believed that the profile of the types of research outputs was appropriate for an international plant biodiversity organisation, and that the number of very high-profile outputs was impressive. However, as discussed elsewhere (paragraph 27), it cautions the organisation against too narrowly setting “REF-type” publication targets that may distort recruitment policy and achievement of its core mission.
24. Over most of RBG Kew’s history, the Director has been a practising plant scientist. This tradition was broken in 2012 when Richard Deverell was appointed Director, a move that reflected the enormous importance of RBG Kew being led by someone with the skills to run a complex organisation that needs to deliver in a number of spheres, of which scientific research is just one. A plant scientist may have these skills but insisting the Director has this background dangerously narrows the field of candidates. This change prompted the creation of the position of Director of Science, which was held from 2013 to 2018 by Professor Kathy Willis and since 2019 by Professor Alex Antonelli. The Panel felt that these arrangements had worked very well and were impressed by the leadership displayed both by Richard Deverell and Alex Antonelli and their close working relationship.
25. In 2014, RBG Kew conducted a major restructuring of its scientific activities led by Kathy Willis. The restructuring was needed both to bring RBG Kew’s research in line with modern plant and fungal science and because of a reduction in core government funding. The restructuring involved redundancies and was painful, as was pointed out by several people who provided information to the Review. We greatly sympathise with the people negatively affected, yet believe the process was unavoidable and has produced significant benefits for the organisation. The Panel admires the very strong science leadership shown by Kathy Willis during this period.
26. Funding for RBG Kew science comes from three principle sources: directly from UK government through RBG Kew’s sponsoring Department, Defra (both unrestricted Grant-in-Aid and line-item allocations); from philanthropic money raised by the RBG Kew Foundation and related activities; and from competitively won research grants from Research Councils and major foundations and trusts. In most years, only a small amount of money is raised from the private sector (though see paragraph 46). Table 1 shows how total research income has changed over the last four years, broken down into the different components. The biggest change for RBG Kew has been a reduction in core funding from Defra, though the organisation has buffered the consequences for research by maintaining a flat allocation to the science budget. The reduction in Defra funding has occurred because of the substantial fall in government allocations to Departments over the last decade. RBG Kew has been partly spared the full impact of this fall, but nevertheless has suffered a major reduction in this funding stream. Income from competitive research grants has been level over the last four years but it is projected to rise in the next three years (see Note 2, Table 1).

**Table 1:** Overall funding (£million) for science at RBG Kew since the foundation of the Science Directorate

	2015/16	2016/17	2017/18	2018/19
<b>Core RBG Kew income</b>				
Defra grant-in-aid	20.4	19.5	18.3	17.1
Other sources <sup>1</sup>	45.2	58.4	93.4	75.9
<b>Total income (Kew)</b>	65.6	77.9	111.7	93.0
<b>Kew Science expenditure</b>				
Research grants <sup>2</sup>	3.6	3.2	3.5	3.3
Philanthropic sources	4.4	6.1	5.8	5.2
Defra (specific projects)	0.2	1.0	1.3	0.9
Core Kew science allocation	8.5	9.4	9.7	9.6
<b>Total expenditure (Science)</b>	16.6	19.7	20.3	19.0

**Notes:**

<sup>1</sup> Figure includes recent one-off allocations to the Estates Capital Development Programme and Temperate House refurbishment.

<sup>2</sup> Recent success in competitive grant awards leads to projected income of £5.9m in 2019/20; £6.3m 2020/21 and £6.9m in 2021/22.

27. The Panel was very impressed by the recent increase in competitively won research funding by RBG Kew. All RBG Kew scientists should be alert to the possibility of attracting external research funding and follow up all relevant opportunities. Success in competing for research grants is an important indicator of research quality and shows that RBG Kew is an international research organisation at the forefront of its field. RBG Kew should continue to support its scientists in applying for such funding wherever possible and to mentor those scientists whose research might attract this type of support but who have not yet been successful. However, the Panel strongly counsels against the view that competitively won research funding can maintain RBG Kew's unique position as the UK's foremost plant biodiversity institute. Competitive external funding should not be seen as a means to support Kew's core roles or deliver core services. Kew's National Capability (indeed global capability) role has to be funded as such. By their nature, Research Councils and related organisations fund science that can potentially be carried out in the multiple institutions that engage in the competition. Much of RBG Kew's fundamental systematic and collections-based work can only be carried out in the UK at RBG Kew (and to a lesser extent the Natural History Museum and RBG Edinburgh) and will not be seen by Research Councils as suitable for responsive mode funding, and especially not for repeat or renewal funding. Reliance on competitive funding could lead to recruitment and retention of only those likely to be successful in this realm. This will change the institution and undermine its ability to provide the unique contribution to National Capability that no other organisation can fill (we return to exactly what this is below). Research grant funding is volatile and reliance on this as the major source of supporting RBG Kew science is a dangerous strategy (universities are able to buffer this volatility due to their size and teaching funding streams). The funding model adopted by RBG Kew needs to take account of funding volatility and develop explicit goals for core National Capability and additional research grant funded components. Management effort should have a strong focus on establishing long-term, core funding, which will have the added benefit of providing fertile ground in which competitively won research can flourish.

### Recommendation 3

RBG Kew provides National Capability in plant and fungal biodiversity that services the needs of both the UK's science and policy communities as well as having an important international dimension. This National Capability is supported by direct government funding, which has reduced over the last decade. RBG Kew should develop a clear narrative about the National Capability provided by the organisation and engage in a discussion with Defra and BEIS (the department responsible for the science budget) to articulate clearly the threat to UK science of a continuing fall in support. The Panel expresses its concern about the likely consequences of further cuts and hopes its recommendations will help build a case for continuing support.

28. The Director and Director of Science outlined plans, very much at an early stage, for a consolidation of RBG Kew science on its main site in a "Science Quarter" in the area of the Herbarium. This would involve a new building to house work currently carried out in the Jodrell Laboratory building. The Panel was positive about these plans, as co-location will continue to break down internal barriers between different sectors of RBG Kew science and because parts of the Jodrell building are beginning to near the end of their natural life. Having visionary plans and a dedicated project team in place is desirable as the development may be attractive for philanthropic support. The Panel's one caveat is that this development should not take up management energy or investment in the short term to the exclusion of some of the critical priorities we discuss below.

29. In the context of the Science Quarter, the Panel discussed the relationship between the RBG Kew and NHM herbaria. In terms of the number of specimens, the NHM's collection is 68% of the size of the RBG Kew collection, but the number of systematic botanists working at the NHM is, we estimate, only about 15% of the number at RBG Kew. The Panel has no mandate to advise the NHM but encourages RBG Kew to engage in discussions with the Museum to explore working even more closely together in future. Such discussions should consider that Government will almost certainly ask why it supports two herbaria, which could be seen as overlapping and redundant. RBG Kew should have a prepared response to such a critique. It should also consider the possibility that the relatively few botanists at the NHM may benefit from being co-located with the much larger community at RBG Kew. Finally, we stress that a full integration of the two herbaria would only make sense if sufficient resources were available to do this properly.
30. RBG Kew scientists are ineligible for certain science funding because they work at an institute rather than a university. Similarly, RBG Kew cannot award master or doctoral degrees, and PhD students must be registered at a university and have at least a nominal supervisor from that institution, a procedure that significantly adds to the cost of RBG Kew hosting a doctoral student. These considerations have led RBG Kew to consider whether it might seek to apply for university status itself. Although (as the name suggests) most universities teach multiple subjects, the existence of veterinary and agricultural colleges with more narrow subject areas provides some precedent. The Panel debated this idea but firmly advises RBG Kew not to pursue this possibility in the immediate future (of course the arguments may change over the longer term). It was not convinced that university status made sense for an organisation of RBG Kew's size and degree of specialism; it was concerned that the many consequences of university status would change the character and focus of RBG Kew and risk detracting from its uniqueness and special status, and it worried that the amount of management time required to effect the change would detract from other pressing priorities. It was concerned at the level of charges universities levied on RBG Kew and encourages the organisation to be more assertive at negotiating a bespoke relationship with a reasonably local university to the benefit of both parties. The RBG Kew 'brand' is so strong in itself that it does not need to borrow the prestige of any particular university.

#### **Recommendation 4**

That RBG Kew does not seek university status, at least in the short term, but develops a bespoke, equitable partnership with a local university to the benefit of both organisations.

31. One of RBG Kew's traditional strengths has been its numerous interactions with organisations and institutions around the world, and the Panel was presented with impressive statistics about the number and geographical range of collaborations. The Panel celebrates this achievement while making the obvious points that it is quality rather than quantity of interactions that counts, and that the nature of these collaborations needs to evolve as countries build and strengthen their own plant and fungal science capabilities.
32. Another traditional strength of RBG Kew has been its engagement in policy, both within the plant and general systematics communities and more broadly in biodiversity policy forums. Members of the Panel and some people we spoke to felt that RBG Kew's reach and influence in these arenas had diminished somewhat in recent years. We do not have quantitative data to support this but raise it as an issue for the Director and Director of Science to consider. Engagement in policy areas within Defra's brief – for example, the Convention on International Trade in Endangered Species (CITES), UK biodiversity, the Convention on Biological Diversity (CBD), biosecurity – is especially important. Similarly, RBG Kew previously played a leading role in global taxonomic initiatives – for example as a founding member of AETFAT (Association for the Taxonomic Study of the Flora of Tropical Africa) – and continued and renewed participation in such organisations is important to maintain RBG Kew's global influence.
33. The relationship between RBG Kew and Defra is especially important. Rightly, RBG Kew and its governance is at arm's length from government and it is important that RBG Kew retains its independence. RBG Kew already provides valuable support to Defra on UK biodiversity and biosecurity, CITES and CBD. Nevertheless, RBG Kew is a considerable public asset and the public mission of RBG Kew would benefit greatly from it working differently with Defra to develop a richer relationship across many different policy areas. Many of the scientific problems RBG Kew is tackling, such as biodiversity loss, have their ultimate causes and solutions within public policy and RBG Kew's voice could be far more influential within this arena.

## 5 Global plant and fungal diversity and its uses

34. RBG Kew's Science Strategy Strategic Priority 1 is *To document and conduct research into global plant and fungal diversity and its uses for humanity.* This priority involves all science (and non-science) departments at RBG Kew but, in particular, Identification & Naming, Comparative Plant & Fungal Biology, Conservation Science, and Natural Capital & Plant Health. Many of its goals are based on the excellence of RBG Kew's science collections (Strategic Priority 1) and require modes of dissemination that maximise impact (Strategic Priority 3), which we return to below.
35. RBG Kew remains one the foremost centres of plant and fungal morphological taxonomy in the world. In the UK it is by some measure the largest institution working in this area, followed by RBG Edinburgh and the NHM. A small and diminishing number of morphological taxonomists work in university departments. RBG Kew continues to produce monographic studies of the highest quality, which increasingly embrace input from molecular and other fields. The Panel believes there will be a continuing need for first-rate plant and fungal taxonomy, though, as outlined in the Future Opportunities and Challenges section above, its content and mode of dissemination must evolve to reflect users' needs and expectations.
36. Traditional taxonomy is time-consuming and can produce outputs with limited circulation (because of availability or price). In a competitive science funding environment this can make it difficult to raise funds. These are problems that affect taxonomy everywhere in the world, but the Panel feels that RBG Kew is in a position to be a leader in their solution because of the high respect that its taxonomic work commands. The institution has an opportunity to lead a transformation in floristic and monographic work by developing creative ways to increase the throughput of its taxonomists and make the most effective use of their expertise. For example, while the process of species delimitation requires the knowledge and skill of a taxonomic specialist, other aspects of monographic and floristic work (e.g., measurement of plant parts, preparation of formal descriptions, validation of nomenclature, annotation of specimens, or assembling specimen citations) could be automated via appropriate image analysis or text mining. Kew can also lead by example through making the taxonomic outputs widely accessible and available on the web (see also paragraph 66 et seq.).
37. The greatest challenges in documenting and understanding plant and fungal diversity centre on the extremely species-rich, yet highly threatened, tropical regions of the globe, including the large remaining blocks of rainforest in Africa, Asia and the Americas. The Panel agrees with RBG Kew's decision to prioritise these areas.
38. An increasing number of countries around the world are now developing their own plant taxonomy and systematics capabilities and RBG Kew has a proud track record of training overseas scientists and capacity building in their home countries. Over the last few years there has been a readjustment of UK science funding to support more capacity building in countries eligible for Official Development Assistance (ODA) as defined by the OECD (for example, the Grand Challenges Research Fund, GCRF). Working with strategic partners, this represents opportunities for increasing RBG Kew's science volume and impact.
39. Much taxonomy and biodiversity monitoring in high-income countries is now conducted by citizen scientists. Major biodiversity organisations such as the RBGs and the NHM now engage far more with this sector than historically; for example, the NHM has set up the Angela Marmont Centre for UK Biodiversity to cater to increasingly expert non-professionals, and the British Mycological Society has a base at RBG Kew. The Panel asks whether RBG Kew can more proactively support UK citizen botanists and mycologists. Such help is particularly needed by mycologists given the increasing primacy of molecular methods in this subject. Such an initiative would help align RBG Kew with Defra's policy of engaging and facilitating citizen sciences both as a good in itself and to help it deliver the monitoring goals of its 25 Year Plan for the Environment. It would also tie RBG Kew more firmly into UK biodiversity initiatives such as the Darwin Tree of Life Project led by the Wellcome Sanger Centre.

### Recommendation 5

That RBG Kew continues to see itself as a global leader in plant taxonomy, shaping the field, seeking ways to increase throughput in response to the urgency of the biodiversity crisis, and responding to changes in users' needs and expectations.

## Recommendation 6

That RBG Kew seeks to increase its facilitation and coordination of citizen science, both in the UK and abroad; it might do this by making more of its information resources available to non-technical audiences and providing some access to molecular facilities for amateur mycologists.

40. RBG Kew has made very important contributions to the study of plant and fungal diversity using DNA sequences, particularly as a major partner of the Angiosperm Phylogeny Group (paragraph 16) and working with the Plant and Fungal Tree of Life project. The Panel is confident that under strong leadership this excellent work will continue into an era when the most interesting plant phylogenetic questions have been resolved, and when whole-genome data is available for an increasing number of plant species. The resolution of the fungal tree of life is behind that of plants and may offer the greatest opportunities for novel findings in the immediate future.
41. In thinking about future strategy for molecular plant biology, the Panel encourages RBG Kew systematically to consider where it has the strongest comparative advantages and suspects that this will be in areas where access to a taxonomically broad range of plant and fungal species as well as a detailed knowledge of their biology and ecology is most important. Issues around evolutionary development highlighted in the Science Strategy are likely examples of this. Important logistic questions for RBG Kew include the extent to which it will host genomic data on site, the degree to which it will invest in in-house bioinformatics capacity, and how it will contribute to the efficient dissemination of information that exists on multiple platforms and is poorly linked to morphological and other resources.
42. Much literature published by RBG Kew stresses the critical role of plants in feeding the global population, and producing other valuable products. Kew has of course played a historically very significant role in applied plant sciences, as the Economic Botany Collection attests. Recently, its research on coffee and yams has been highly influential.
43. Addressing the challenges of food security presents research opportunities for RBG Kew but the organisation has to identify exactly where it can make the most impact in a crowded field with many very large players. The Panel believes the organisation has got this largely right by concentrating on crop wild relatives but notes that the most important crops already attract considerable attention from the major crop-specific organisations (for example, the International Rice Research Institute, IRRI; and International Maize and Wheat Improvement Center, CIMMYT). Research on orphan crops and their wild relatives, and how they may contribute to more varied and nutritious diets, may have the most impact. RBG Kew should of course be proud of its contributions to ensuring food security, but not overstate its capacity or achievements in this area.
44. Similar comments apply to RBG Kew's contribution to plant health, especially through its expertise in fungal biology. It is unlikely that Kew can successfully compete for resources to study the most important plant pathogens given the number of specialised laboratories and institutions around the world dedicated to individual diseases. RBG Kew's comparative advantage is not in "vertical" studies of particular plant-pathogen interactions but harnessing its profound "horizontal" understanding of the diversity of fungal pathogens and their interaction with multiple host plants.
45. The study of natural product chemistry is important in increasing our fundamental understanding of plant biology, in particular their interactions with other organisms (such as herbivores and pollinators), and also in discovering new products of value to humanity. RBG Kew has well-equipped laboratories to conduct competitive plant chemical research and has produced a series of impressive basic-science publications in this field. Much of this work has been with partners and to some extent lacks a coherent theme, and the Panel suggests the Director of Science explores RBG Kew's niche in this field.
46. Part of the reason for RBG Kew's investment in natural product chemistry is the hope that it may discover novel pharmaceutical and other products that are both useful and can generate intellectual property. The success of the latter is relatively easy to assess using economic metrics – a good example of success is the recent award of £1M from Procter and Gamble for research into the diversity and mode of action of plant- and fungal-derived compounds for skin, scalp and cardiovascular health. The Panel did not contain expertise in product development and IP exploitation and believe it would be worthwhile for RBG Kew to review its activities in this area using appropriate experts. The review should also consider the implications of industrial collaborations on current and future access and benefit sharing agreements with countries providing bioresources for RBG Kew.

47. The increasing realisation of the threats to biodiversity from habitat loss and other human activities, and the growing dangers from climate change, pose many challenges that RBG Kew is already addressing and it is well-placed to do more in the future. RBG Kew can especially make major contributions in areas where a broad understanding of plant and fungal biodiversity is required (monitoring, prioritising etc.) as well as in the conservation of individual species (seed biology, horticulture).
48. Major synoptic work in this area by RBG Kew has included the Sampled Red List Index for Plants and the identification of Tropical Important Plant Areas. Utilisation of data embedded in the collection has provided insights into changes in the distribution of threatened species on the ground. RBG Kew scientists, working on the ground in tropical countries, have contributed to practical conservation initiatives and have helped build local capacity for action. The Panel agrees with RBG Kew's continuing emphasis on science underpinning conservation.
49. RBG Kew also provides critical expertise in plant and fungal identification to combat illegal trade in wildlife. This expertise may involve traditional morphological naming, identification of timber using microstructure, and molecular diagnosis. The development of new tools (such as field molecular DNA identification devices and the use of automated species identification apps) will change the nature of the demand for RBG Kew expertise and it will be important for the organisation to remain flexible to react to this evolution.
50. Through the contingencies of geography, the UK Overseas Territories contain more globally threatened plant species over which the UK has direct administrative responsibility than are present in Great Britain and Northern Ireland. As a Non-Departmental Public Body sponsored by Defra, scientific research on the challenges of conserving plants in these territories is particularly appropriate for RBG Kew.
51. RBG Kew's living seed collection at the Millennium Seed Bank, Wakehurst Place, now contains seeds from over 40,000 species and is the largest seedbank in the world. A particularly impressive aspect of the project is the Millennium Seed Bank Partnership, which shares expertise and organises parallel collections in local seedbanks throughout the world. The Science Strategy set a target of banking the seeds of 25% of the world's plant species by 2020, which is not going to be met. One reason for this has been a switch to more strategic banking of species based on multiple collections (to preserve genetic diversity). The Panel agreed that it was sensible to give up this target but recommends the development of a new strategy for the project with revised targets.
52. The Panel appreciates the challenges of finding new research funds but hopes that the major resource that is the seedbank can be used to support more research on seed biology, ideally at Wakehurst but, if not, at partner organisations. It also highlights the importance of making data easily accessible and linked to other molecular and morphological databases.
53. RBG Kew has in the past considered initiatives in restoration ecology. This is not currently a priority for RBG Kew, correctly in the Panel's view, as the best work in this area has a strong geographical focus. However, there are specific areas in which RBG Kew does have leading expertise, for example around seed biology associated with the Millennium Seed Bank and *ex situ* propagation and horticulture associated with the Living Collections. Transforming craft skills and cultural knowledge into evidence-based practice (there is a parallel in the evidence-based movement in clinical medicine) might be an interesting challenge for RBG Kew.

### Recommendation 7

That RBG Kew continues to emphasise its fundamental and applied scientific research in plant diversity, conservation and useful plants; in further developing its strategy it should identify and prioritise areas where it has a strong comparative advantage compared with other organisations working on plant biology, which are likely to be topics where the ability to access resources and knowledge about plant diversity is key.

54. Though developing a science strategy is important, allowing RBG scientists to show creativity in contributing to all areas of plant and fungal science (either just themselves or in collaborations with outside scientists) should continue to be encouraged.
55. The Panel is concerned that the impact and influence of much of the work discussed in this section is reduced by the poor development of digital portals and returns to this point in Section 7.

## 6 RBG Kew's collections

56. RBG Kew's Science Strategy Strategic Priority 2 is *To curate and provide data-rich evidence from Kew's unrivalled collections as a global asset for scientific research.* To do this, the organisation has developed a Science Collections Strategy for the period 2018–2028. Its key components are:

- Within the ten-year period audit the collection and develop a coherent means of assessing collection information.
- Collaborate more with partners to identify gaps and to reduce duplication of effort.
- Align the prioritisation of new material with RBG Kew's Science Strategy.
- Contribute to the development of best practice in response to the evolving legislative framework governing access to genetic resources and benefit sharing.
- Improve the physical protection of the collections and their resilience to hazards.
- Implement a major programme of mass digitisation with the results disseminated through RBG's Plants/Fungi of the World Online portal (POWO & FOWO).

The Panel was impressed by the Strategy and considered it an important and useful document even if, as discussed below, some aspects are overly ambitious. We think it may be desirable for a future Strategy to adopt multiple time horizons, for example a five-year perspective with stretching but realistic quantitative goals, and a twenty-year perspective to allow exploration of responses to major drivers of change in biodiversity science (see Section 3) as well as ambitious long-term projects such as the "Science Quarter" (see paragraph 28).

57. The Science Collection Strategy's target for digitisation is as follows: *By 2020, we therefore aim to initiate a mass digitisation programme to image all herbarium specimens and capture at least the essential data from 80% of our Science Collections. By 2028, we aim to complete the databasing of the Science Collections and to image all our fungarium type specimens, all fungarium specimen labels and selected microscope slide, seed and economic botany specimens.* The Panel discussed this issue with relevant RBG Kew scientists; the responses suggested no confidence that digitisation could be completed in the foreseeable future. Though, understandably, lack of resources was raised as a limiting factor, the Panel was concerned about a general Sisyphean despondency and absence of belief that full digitisation can ever be achieved.
58. It is helpful to consider RBG Kew's progress in digitisation against that of its most similar institutions worldwide (Table 2).

**Table 2:** Comparison of digitisation progress in the world's ten largest herbarium

Institution	Number specimens	Rank (size)	Number digitised*	% specimens digitised*	Rank (% digitised)
RBG Kew	8,125,000	1	1,602,738	19.73%	6
Muséum National d'Histoire Naturelle, Paris	8,000,000	2	5,481,375	68.52%	3
New York Botanical Garden	7,800,000	3	4,200,000	53.85%	4
Naturalis Biodiversity Center, Leiden	6,900,000	4	4,897,000	70.97%	2
Missouri Botanical Garden	6,000,000	5	4,440,000	74.00%	1
Conservatoire et Jardin Botaniques, Geneve	6,000,000	5	700,000	11.67%	8
Komarov Botanical Institute	6,000,000	5	100,000	1.67%	10
Natural History Museum, Wien	5,550,000	6	276,171	4.98%	9
Natural History Museum, London	5,200,000	7	729,970	14.04%	7
US National Museum of Natural History (Smithsonian)	5,100,000	8	1,732,256	33.97%	5

\*Digitisation figures include specimens that have been databased, imaged, or both. Data comes from RBG Kew, Index Herbarium, GBIF, and institutions' websites.

59. The Panel views the lack of progress in digitisation, and the lack of a realistic timescale, to be a major threat to the maintenance of RBG Kew's pre-eminence in collections-based plant biodiversity science. It understands that new resources (a one-off capital investment) will be required to achieve this but believes that finding these resources should be a Board and Management Team priority – the challenge to RBG Kew science is akin to the challenge that the Temperate House posed to RBG Kew estates.

### Recommendation 8

That finding resources to accelerate the imaging and digitisation of RBG Kew's collections should become a major institutional priority, with completion of that of the herbaria in the next few years. The Panel places great emphasis on the importance of RBG Kew's digital portal and advises the Executive and Board that a major investment in POWO should be a very high priority.

60. Ideally digitisation of the collection should proceed in parallel with that of the collections at the NHM and RBG Edinburgh, as described in the Science Collections Strategy. However, if this desirable concerted effort should prove difficult to achieve or risks delay then it is more important that RBG Kew proceeds independently. Learning the lessons from successful digitisation campaigns in equivalent organisations will reduce costs and improve efficiency.

61. The Panel discussed amongst itself and with RBG Kew scientists the merits of taking samples from each herbarium sheet for molecular analysis (probably DNA "barcoding") at the time of digitisation. We recognise that these are two entirely separate activities and that the reason to do them at the same time is to maximise scientific impact. Establishing the first digitised plus barcoded major herbarium would immediately cement the global importance of RBG Kew's collection. It would be important to understand whether there are any savings in costs or handling of the specimens for two purposes simultaneously (locating herbarium sheets and entering data, for example) or whether the pairing might make both activities less efficient. The Panel did not have sufficient information to resolve this issue but strongly believes it warrants further study. The arguments for DNA barcoding fungal specimens when digitising are stronger and not questioned.

### Recommendation 9

That Kew investigates taking a sample from each specimen at the time of imaging for subsequent DNA sequencing.

## 7 A global resource for plant and fungal knowledge

62. RBG Kew's Science Strategy Strategic Priority 3 is "To disseminate our scientific knowledge of plants and fungi, maximising its impact in science, education, conservation policy and management". The organisation does this in multiple ways: through the production of scientific papers and monographs published on paper and/or on line, through specific reports and report series, and through the creation of a digital hub for plant knowledge.
63. In 2016 RBG Kew published for the first time the State of the World's Plants, "a baseline assessment of our current knowledge on the diversity of plants on earth, the global threats these plants currently face, and the policies dealing with them". An update was produced in 2017, and in 2018 the State of the World's Fungi was published. Initially intended as an annual publication, RBG Kew's current plans are to issue updates every three years. The Panel applauded this initiative and felt that it had both raised the profile of the threats to plants and fungi and underlined RBG Kew's research and influence in this area.
65. In the pre-digital era, RBG Kew maintained a database of published plant names that has been of great value to plant taxonomists. This information is now available on the web through Kew's International Plant Names Index (IPNI) and Plants of the World Online portal (POWO), as well as other portals such as the Catalogue of Life. It is a considerable achievement getting this information online. The Panel encourages RBG Kew to work with partners to deliver a costed business plan for ensuring this important resource is kept updated.
66. POWO contains a novel and important checklist of all vascular plants (including information on geography), providing the best current estimate of vascular plant species numbers and distributions. Beyond the checklist, POWO contains a rather miscellaneous assemblage of material: some digitised specimens, some material imported from other databases (for example, eMonocot, PalmWeb and GrassBase), and some material from regional floras (for example, the Flora of Tropical East Africa, though without the keys – arguably the most useful part) and journals (Kew Bulletin). There is very little material relevant to the UK flora. Not all RBG Kew's digital information can be accessed through POWO, and RBG Kew publishes material in books and journals with no link to POWO. The Panel found the site unintuitive to use and hard to search, and were unclear who the targeted users were. We were informed that it was hard to link molecular data with POWO. There are similar issues around the fungi portal.

### Recommendation 10

That RBG Kew continues the successful State of the World's Plant and Fungi series though on a triennial rather than annual basis; in going forward, and with RBG Kew's brand firmly established, bringing in further partners in future editions is desirable.

64. As discussed in paragraph 19, the Panel strongly believes that RBG Kew's future as "A Global Resource for Plant and Fungal Knowledge", the title of the Science Strategy, is essentially digital. Its users and customers will demand information in this form, as will its funders. Unless RBG Kew can establish a strong digital presence, it will fail to achieve its science ambitions and risks irrelevance. If it succeeds, and especially if it leads in becoming a digital hub for plant and fungal knowledge, the resource created will be as important as the collections in cementing RBG Kew's value and irreplaceability into the future.

### Recommendation 11

The Panel advises that the Plants of the World Online portal is currently failing as a global resource for plant and fungal knowledge and that in its present state it represents a reputational risk for RBG Kew. The Panel places great emphasis on the importance of RBG Kew's digital portal and advises the Executive and Board that a major investment in POWO should be a very high priority.

67. The Panel believes three things need to happen for POWO (and by extension the fungi portal) to be a success:

- First, establishing POWO so that it has a level of functionality appropriate for RBG Kew's ambitions and its end-users' needs, as well as the flexibility to allow expansion, requires significant capital investment beyond RBG Kew's normal annual budget. The Board of Trustees and Executive Board should consider combining investment in this and collection digitisation (paragraph 59) in a single request to Government to create a Digital RBG Kew.
- Second, a business plan needs to be developed for POWO's maintenance and update, the equivalent of that underpinning the support and development of the herbarium and library. This may involve difficult resource allocation decisions between competing demands. If RBG Kew's future is really digital then a clean-sheet review of priorities is required that does not privilege, for instance, library and archives, just because they have been of traditional importance.
- Lastly, there would need to be a cultural change throughout the institution. Scientists should come to see disseminating results electronically and producing digital content to be a major part of their job, and promotion and advancement should reflect this. More generally, RBG Kew from the Board down would need to view the creation and maintenance of POWO as a part of the organisation as integral as the collections and gardens.

The following paragraphs do not propose a strategy to create this but hopefully provide suggestions that might contribute to its development.

68. To build a community using POWO, the Panel believes it is critically important to make it easier for people to access its content in different ways. Potential users need to be identified (use-case scenarios) and the site designed for their different needs. For example, it should be made far easier to use only content relevant to particular countries or geographical regions, or that derived from different resources (for example, particular floras or databases). In addition to RBG Kew's traditional constituency of plant systematists, it is important that the site is used by a broader community of plant biologists and other biodiversity scientists. POWO should support citizen scientists and consider novel user communities such as "plants(wo)men", gardeners and teachers.
69. Many sites purport to hold important biodiversity information but very few actually hold significant content; too many big international initiatives have come to nothing or have not been maintained after initial funding has ended. The Panel believes Kew should migrate as much of its digital and non-digital resources to POWO as quickly as possible – "content is king" is more than a slogan, and the nature of digital resources is that sites rich in content attract both users and further content. RBG Kew should not be afraid of mounting on POWO the type of high-quality illustrated content that it publishes in (often very expensive) books – in addition to garnering a broader audience, evidence suggests web exposure can actually enhance print sales. RBG Kew should also consider developing POWO as a platform that other botanic gardens and research institutes without RBG Kew's resources can use to disseminate their plant diversity information. By providing more digital resources to facilitate research in emerging economies, and a platform for this research to be seen, RBG Kew could make a major contribution to the development of plant diversity science.

70. There are major opportunities for citizen scientists to contribute information and images to enrich the POWO site, today especially in high-income countries but hopefully more widely in the future. POWO could be designed to facilitate this, perhaps by allowing the submission of content that at least initially is flagged as “contributed” but which later might be incorporated in the “curated” part of the site. There is a particular urgency in building significant and useful content about the UK and UK Overseas Territories floras given the importance placed on this by Defra, RBG Kew’s sponsoring department. We note with admiration how RBG Kew’s Library, Art & Archives Department have successfully crowd-sourced activities such as archive transcription, which is evidence of the willingness of volunteers to help the institution.
71. Substantial plant biodiversity information is available in molecular databases covering sequences and phylogenies, geographic distribution databases (for example, GBIF), and in other electronic resources. The Biodiversity Heritage Library includes a significant fraction of the historical literature. POWO should be developed so that it links seamlessly with these other resources which it complements without duplicating. Integration of POWO with the automated molecular identification tools that are likely to be developed in the next decade or so will be important.
72. Concerns about the capacity of RBG Kew’s IT and computer department to support digital expansion were raised several times in the Panel’s conversations with scientists. A particular concern was the lack of understanding of science needs in a department with a primarily non-science focus. We understand that this issue is appreciated by the Executive Board and by the newly appointed departmental head. The importance of excellent technical support cannot be overstated. The Panel hopes RBG Kew will think creatively about possibilities such as partnering with internet platforms and the use of resources in the cloud to overcome these challenges.

### **Recommendation 12**

The Panel advises the Executive Board that current digital support for the science teams is inadequate and hampering the delivery of the Science Strategy.

## 8 Training

73. RBG Kew has long contributed to Masters-level education at the University of Exeter, Imperial College and Kent University and from 2015 has run an MSc course in Plant and Fungal Taxonomy, Diversity and Conservation with Queen Mary University of London, which in the 2018–2019 academic year has 24 students. The Panel encourages RBG Kew to explore a range of partnerships to determine which maximises mutual benefit (see also paragraph 30). It recognises that the market for taught Masters within the UK has been more challenging with the advent of MBiol degrees, but believes that RBG Kew's international reputation is a particular asset for recruiting overseas students. In addition, it runs a series of short courses for adult learning, a number of diplomas and apprenticeships in Horticulture and related subjects, and continued professional development (CPD) courses for teachers and in plant taxonomy and identification. CPD is an area where there is a potential expansion in demand with relatively few UK providers in the plant sciences.
74. There are currently 59 PhD students at RBG Kew who are registered and co-supervised at a variety of different universities; the Panel has endorsed the goal of increasing this number (see also paragraph 30). The Panel discussed with RBG Kew staff the best ways to help support graduate students and to foster a graduate community within the organisation; the creation of an Office of Graduate Studies with a brief to assist student development has been helpful at other institutions. Such an office can provide, for example, a comprehensive induction to Kew for new students, help with accommodation and related issues, a collective voice within Kew for student concerns, and a focus for ensuring student well-being. A shortage of affordable student accommodation, especially for short-term students, was raised as a barrier to increasing numbers, and RBG Kew might explore whether there are any opportunities within its estate to alleviate this.
75. Data presented on recent attendees to courses run by RBG Kew show low numbers from countries containing Tropical Important Plant Areas. The Panel discussed how best RBG Kew might contribute to in-country training in low- and middle-income countries, including specific fundraising to support students from these countries. It believes a multipronged approach to capacity building is needed, ranging from formal taught courses to informal mentoring. Research projects in developing countries should always include capacity building. With funding opportunities in the UK now including far more explicitly ODA (Official Development Assistance) research and capacity building (for example, the GCRF programme), there is an opportunity for RBG Kew to increase its activities in this area.

### Recommendation 14

That Kew should seek funds from Government and other sources to help it build its programme of capacity building in plant biodiversity science in the global south.

### Recommendation 13

That Kew continues to emphasise the importance of student training at all levels and considers creating an Office of Graduate Studies to help foster and enrich the student experience.

## 9 Summary of recommendations

76. Recommendation 1. RBG Kew's Board of Trustees and Executive Board clearly articulate the organisation's unique position in national and international research given the changes occurring in the biological and biodiversity sciences, and provide a clear vision of how it will develop its scientific mission across basic and applied research, policy, education and public outreach.
77. Recommendation 2. That part of RBG Kew's next Science Strategy should be a plan of how it will contribute to the next phase of the development of the fields of plant and fungal phylogeny and genomics.
78. Recommendation 3. RBG Kew provides National Capability in plant and fungal biodiversity that services the needs of both the UK's science and policy communities as well as having an important international dimension. This National Capability is supported by direct government funding, which has reduced over the last decade. RBG Kew should develop a clear narrative about the National Capability provided by the organisation and engage in a discussion with Defra and BEIS (the department responsible for the science budget) to articulate clearly the threat to UK science of a continuing fall in support. The Panel expresses its concern about the likely consequences of further cuts and hopes its recommendations will help build a case for continuing support.
79. Recommendation 4. That RBG Kew does not seek university status, at least in the short term, but develops a bespoke, equitable partnership with a local university to the benefit of both organisations.
80. Recommendation 5. That RBG Kew continues to see itself as a global leader in plant taxonomy, shaping the field, seeking ways to increase throughput in response to the urgency of the biodiversity crisis, and responding to changes in users' needs and expectations.
81. Recommendation 6. That RBG Kew seeks to increase its facilitation and coordination of citizen science, both in the UK and abroad; it might do this by making more of its information resources available to non-technical audiences and providing some access to molecular facilities for amateur mycologists.
82. Recommendation 7. That RBG Kew continues to emphasise its fundamental and applied scientific research in plant diversity, conservation and useful plants; in further developing its strategy it should identify and prioritise areas where it has a strong comparative advantage compared with other organisations working on plant biology, which are likely to be topics where the ability to access resources and knowledge about plant diversity is key.
83. Recommendation 8. That finding resources to accelerate the imaging and digitisation of RBG Kew's collections should become a major institutional priority, with completion of that of the herbaria in the next few years. The Panel places great emphasis on the importance of RBG Kew's digital portal and advises the Executive and Board that a major investment in POWO should be a very high priority.
84. Recommendation 9. That Kew investigates taking a sample from each specimen at the time of imaging for subsequent DNA sequencing.
85. Recommendation 10. That RBG Kew continues the successful State of the World's Plant and Fungi series though on a triennial rather than annual basis; in going forward, and with RBG Kew's brand firmly established, bringing in further partners in future editions is desirable.
86. Recommendation 11. The Panel advises that the Plants of the World Online portal is currently failing as a global resource for plant and fungal knowledge and that in its present state it represents a reputational risk for RBG Kew. The Panel places great emphasis on the importance of RBG Kew's digital portal and advises the Executive and Board that a major investment in POWO should be a very high priority.
87. Recommendation 12. The Panel advises the Executive Board that current digital support for the science teams is inadequate and hampering the delivery of the Science Strategy.
88. Recommendation 13. That Kew continues to emphasise the importance of student training at all levels and considers creating an Office of Graduate Studies to help foster and enrich the student experience.
89. Recommendation 14. That Kew should seek funds from Government and other sources to help it build its programme of capacity building in plant biodiversity science in the global south.

## 10 Concluding remark

90. The Panel greatly admires the science programme at RBG Kew and makes a series of ambitious recommendations to a well-led organisation that is at the forefront of global plant and fungal biodiversity science. The organisation will experience major challenges in the coming decade, not all of which it will have control over. Nevertheless, the Panel believes that if RBG Kew can maintain a flexible approach to its core mission – the discovery and dissemination of knowledge about plants and fungi – and if it can build on and celebrate its past while always looking to the future, then the organisation's continued success and relevance will be assured.

## Appendix 1: Review Panel membership

Professor Sir Charles Godfray FRS  
University of Oxford, UK – Panel Chair

Professor Mark Blaxter FRSE  
University of Edinburgh, UK

Professor Sir Ian Boyd FRSE  
Chief Scientific Advisor, Defra UK

Professor Sue Hartley  
University of York, UK – RBG Kew Trustee

Professor Elizabeth Kellogg  
Danforth Centre, St Louis, USA

Associate Professor Muthama Muasya  
University of Cape Town, South Africa

Professor Anne Osbourn FRS  
John Innes Centre, UK

Professor Erik Smets, Scientific Director  
Naturalis Biodiversity Center, The Netherlands

Professor Barbara Thiers  
Director New York Botanical Garden, USA

## Appendix 2: Assessment report

As described above, the Panel was asked to assess RBG Kew's published outputs, impact and environment. The overall structure was suggested by the UK's Research Excellence Framework (REF), which is used to grade the research of different university-subject units as part of the UK's research allocation model. The process involves assigning to each component a ranking on a four-point scale. For outputs, the proposed criteria to be used here were:

- **Four star:** Quality that is world-leading in terms of originality, significance and rigour.
- **Three star:** Quality that is internationally excellent in terms of originality, significance and rigour but which falls short of the highest standards of excellence.
- **Two star:** Quality that is recognised internationally in terms of originality, significance and rigour.
- **One star:** Quality that is recognised nationally in terms of originality, significance and rigour.
- **Unclassified:** Quality that falls below the standard of nationally recognised work; or work which does not meet the published definition of research for the purposes of this assessment.

### For impact:

- **Four star:** Outstanding impacts in terms of their reach and significance.
- **Three star:** Very considerable impacts in terms of their reach and significance.
- **Two star:** Considerable impacts in terms of their reach and significance.
- **One star:** Recognised but modest impacts in terms of their reach and significance.
- **Unclassified:** The impact is of little or no reach and significance; or the impact was not eligible; or the impact was not underpinned by excellent research produced by the submitted unit.

### For environment:

- **Four star:** An environment that is conducive to producing research of world-leading quality and enabling outstanding impact, in terms of its vitality and sustainability.
- **Three star:** An environment that is conducive to producing research of internationally excellent quality and enabling very considerable impact, in terms of its vitality and sustainability.
- **Two star:** An environment that is conducive to producing research of internationally recognised quality and enabling considerable impact, in terms of its vitality and sustainability.
- **One star:** An environment that is conducive to producing research of nationally recognised quality and enabling recognised but modest impact, in terms of its vitality and sustainability.

The Panel experienced some difficulty in applying the REF methodology to RBG Kew's outputs as the organisation is not set up to operate and compete as a university department. Work that is of critical importance and at the forefront of what the Panel believes RBG Kew should be doing might not score particularly highly using criteria designed for a different type of organisation. Quite a large number of outputs were judged as unclassified using the criteria given above. There was also concern that a fair application of this scoring scheme to RBG Kew would require modification to take account of the organisation's goals and missions and that different members of the Panel had done this to a greater or lesser extent, undermining comparability. At the main meeting, the Panel argued that a more nuanced, largely narrative assessment would better express its judgement of the quality of RBG Kew's research output.

## Outputs

After excluding some items that were not easily classified, the Panel placed the vast majority (~80%) of outputs in the two-star and three-star categories: research of international importance. Panel members differed in their allocation of outputs to the two- and three-star categories with overall most agreeing a greater number were in the higher, internationally excellent, pool. RBG Kew has produced some research (5–10%) of the very highest world-leading quality (four star). Some research (10–15%) submitted was of national but not international importance, partly a reflection of the UK-focussed research expected of a Defra-family organisation.

### Quality of RBG Kew's research output

The majority of the research outputs submitted to the Panel were considered of internationally recognised quality, and much of the work was considered excellent. Some outputs were of the very highest world-leading standards. After making adjustments to account for RBG Kew's unique position in the science research landscape, the research quality profile was that to be expected of a major international research organisation.

## Environment

Some Panel members felt unable to grade numerically the evidence for the state of different aspects of RBG Kew's environment and those that did differed as to whether the mode should be at 4 or 3. All Panel members provided extensive glosses to their scores, which have fed into the main body of the report. Consistent messages on environment included:

- The herbarium and fungarium are amongst the best in the world and provide an unparalleled environment in which to do plant and fungal taxonomy.
- The lack of digitised herbarium images with associated e-resources is a threat to the continuing high quality of the taxonomy enabling environment.
- The Jodrell Laboratory is very well-equipped, with excellent support staff (exceptionally so for a biodiversity institute), allowing a wide range of plant biological research to be conducted.
- RBG Kew facilities are not of international standard in the most modern genomic technologies and the bioinformatics support required for modern genomic analysis.
- The facilities for seed banking and associated seed research at Wakehurst are first class.
- Recent management efforts to bring together the different research strands at RBG Kew have already borne fruit, and should continue.

### Quality of RBG Kew's research environment

Overall, RBG Kew provides an exceptional environment in which to conduct plant and fungal biodiversity research. Nevertheless, there is a risk the environment will be degraded and RBG Kew lose its world-leading standing as a place to do plant and fungal biodiversity research unless new investments are made in several areas, as described in the main body of the report.

## Impact

Several Panel members found it difficult to use the proposed marking scheme and provided a purely narrative report, while those that did differed markedly in their allocation with modes at four star or three star. Consistently, Panel members singled out examples of highly important impact, including:

- RBG Kew's role in initiating and being a major player in the Angiosperm Phylogeny Group; as one Panel member wrote "the impact of APG cannot be overrated".
- The importance of RBG Kew in training systematics (a role largely relinquished by UK and many foreign universities).
- Contributions to plant and fungal conservation through work with CITES, the Red Lists, the designation of Tropical Important Plant Areas and the recent State of the World's Plants/Fungi.
- The Millennium Seed Bank and associated seed preservation research.
- Significant work on crops and crop wild relatives, in particular coffee and yams.

### Quality of RBG Kew's research impact

There are many examples of the organisation's research having the highest impact on the international stage. This is particularly true of research arising from RBG Kew's key expertise in taxonomy and systematics. In other areas, such as conservation and food security, some research impacts are of high international significance, while the impact of research on seed banking is world-leading.



Royal Botanic Gardens  
**Kew**