

Annual Report 2018–2019



Cambridge University Botanic Garden (CUBG) supports University teaching and research while also being a place of enjoyment and inspiration to visitors of all ages. The Botanic Garden is one of the largest University-owned botanic gardens in the world. Opened to the public in 1846, the 40-acre Garden has an unparalleled living collection of over 8,000 species, including nine National Collections, with glasshouses, experimental plots, lake, herbarium and botanical library.

The Garden offers year-round inspiration for gardeners as well as an exciting introduction to the natural world for families through a programme of family, school and adults' activities and events. CUBG also collaborates with national and international researchers from a wide range of partner organisations, including universities, conservation bodies and botanic gardens worldwide, to promote the conservation and scientific understanding of global plant biodiversity.

Director's Report



The core goals of Cambridge University Botanic Garden stay constant from year to year – to support a globally excellent network of research and teaching around plants while providing stimulating opportunities for educational groups and visitors to engage with our living collection.

This year we have been particularly focused on two aspects of delivering that mission. First, we have been refining the Garden's first ever "Collections Strategy", which we will formally launch in November 2019. And secondly, we have been pulled very firmly into discussion around the current climate emergency, as a result of recording the hottest day on record in the UK in July 2019. At the same time we have been celebrating a happier record, with over 300,000 visitors enjoying the Garden during the calendar year 2018, and even more in 2019.

Visitors are the life blood of the Garden, bringing questions and ideas, encouraging us to develop better plantings, better interpretation and ever more engaging activities, and of course providing the financial support that the Garden needs in order to fulfil its potential to support research and teaching. Our visitor numbers have been steadily rising over the last few years. This is no doubt due to the increasing urbanisation of Cambridge and the desire to access green spaces for health and relaxation, although we hope that our own activities have also contributed to this rise. But even we were surprised when, on 9 December 2018, the 300,000th visitor of the year arrived at the ticket office. The Peachey family from Fenstanton were duly greeted with a celebratory bottle of fizz and some free tickets for a return visit, but we also took the opportunity to chat to them. It was their first visit to the Botanic Garden, and like so many of our visitors they had been encouraged to come by hearing positive things about our work and the gorgeous landscape and great facilities we offer. It is a real pleasure to hear these comments – one of my happiest moments of the last 12 months was overhearing a conversation in a shop, in which one person told the other that "there is always something exciting going on at the Botanic Garden"! We take feedback from our visitors very seriously, and monitor various online comment to ensure we are meeting people's expectations. Since at least one of those expectations is apparently of a range of exciting events, we continued to offer our Science on Sundays series of drop-in talks, Festival of Plants, Apple Day, and Sounds Green summer music series this year, and extended our free drop-in guided tours to additional days. To encourage more self-led engagement, we produced new trails for the Garden, including a very popular "prehistoric plants" trail complete with dinosaur footprints and a more adult-focused tour round our ever-popular collection of snowdrop varieties. Work is in hand at the moment to expand our range of interpretation, to provide the opportunity for even more visitors to learn even more about the amazing world of plants.

Following 2017's very dry summer we had hoped for a year in which the weather could largely be ignored. However, it was clear in July that it was very hot indeed. On Thursday 25th July the heat was unbearable, and the Garden itself emptied of visitors as everyone sought shade. We closed our ticket offices, which were too hot to work in, allowing the few brave visitors who arrived free entry. After a variety of attempts to keep cool by potting up with their feet in buckets of water, we sent the horticultural team home early. But it was not until the next day, when we made our daily report on the previous 24 hours of weather to the Met Office, that we realised that we had recorded the highest ever UK temperature of 38.7 degrees Centigrade. The media response was astonishing, with the BBC, ITN and various local outlets all converging on the Garden to film our weather station and interview our staff. It became increasingly challenging to find new ways of describing the situation, beyond "really very hot". But the interest was not limited to local and national media. Our weather recording was part of the gathering storm of concern around what has now become known as the Climate Emergency. While we were distressed to be responsible for such an extreme temperature recording, we are also proud that our careful and detailed long term data collection can contribute to discussions around this most urgent of issues facing humanity. We have made a number of immediate responses: updating our interpretation near the weather station to highlight the new record; revising our strategy for irrigation and capturing rainwater to futureproof the living collection; and reflecting on our own activities and their sustainability. In the long term we hope that the research we support will contribute to finding solutions to the Climate Emergency, and that our education and outreach programmes will equip new generations to respond to the challenges ahead.

One way in which we can ensure that our living collection is in as good shape as possible to support climate and other research is to develop a strategy for its maintenance and development. Our Curator, Sam Brockington, has been thinking about these issues for the last few years, and has conducted an analysis of the living collections held across the global network of botanic gardens. This analysis has shaped our new Collections Strategy, which we will be launching formally in November 2019. Without wanting to pre-empt next year's Annual Report, I think it is safe to say that considerations about changing climate will be one of the factors to be considered as we plan for the Garden's future as a living laboratory that plays a crucial role in addressing the world's challenges.

Professor Beverley Glover – Director

A Year in Pictures



October 2018: An interview with Director, Beverley Glover, about bees and pollination, helps launch the new Plant Based podcast series which reached No. 1 in the iTunes leisure charts



November 2018: The transformation of the Stream Garden begins



February 2019: Twilight welcomed over 1,000 visitors and highlighted the plight of endangered plants



March 2019: The Rising Path wins the Cambridge Forum for the Construction Industry (CFCI) Landscape Award – only presented every 3 years



July 2019: A new online ticketing system contributed to successful queue management at the five Sounds Green concerts



July 2019: CUBG records the highest ever temperature in the UK – 25 July 38.7 degrees C



December 2018: The Garden welcomes 2018's record breaking 300,000th visitor on 9 December – a family from Fenstanton, Cambridgeshire



January 2019: Happy 40th Birthday to our Winter Garden



April 2019: The Director plants her first tree, *Cedrus atlantica*, on the Main Walk



May 2019: Visitors to the Festival of Plants enjoyed learning about plant science and exploring the Garden on a perfect spring day



June 2019: 160 baby titan arums are successfully nurtured through their first dormancy by the Glasshouse team



August 2019: Over the summer CUBG trainees learn about pollination of the *Victoria cruziana*



September 2019: Having reached a height of 4.43m over the summer months, our agave finally flowers and is verified as *Agave vivipara* by the Curation team

Research

The diversity of roles the Garden plays in Research, both across the University and more widely, always amazes our visitors and Friends. Pages 15-19 of this Annual Report provide a summary of Research conducted in 2018-2019. As well as our primary role in providing access to plant collections and offering horticultural support for botanical projects, the Garden also provides underpinning facilities supporting research in Archaeology, Architecture, Biochemistry, Chemistry, Earth Sciences, Engineering, Geography, Physics and Zoology. We welcome requests for material and resources from colleagues from all academic and research organisations, and are delighted to be able to support such a diversity of projects.

The diversification of big data science

Each year in this annual report we select a subset of our supported research to discuss in more detail. This year we have chosen to focus on a number of projects that use big data approaches, or “omics” approaches, to explore plant diversity. Access to a diverse and well curated living collection is essential for researchers exploring the diversity of chemical compounds plants make (metabolomics), for researchers exploring the different genes expressed in different plants (transcriptomics), and for researchers exploring how genomes have evolved (genomics). We are proud to be supporting a range of these exciting projects, and look forward to the big discoveries that will come from them.

Plants as factories for high value chemicals

Plants produce an astonishing array of compounds known as “secondary metabolites”. These are chemicals that are not essential for the plant to survive in a glasshouse (essential metabolites are known as “primary metabolites”) but that contribute in some way to its function in its natural environment. Classic examples would include fragrances to attract pollinators, pigments to make fruits attractive to dispersers, and anti-herbivore defences such as bitter feeding repellents and even toxins. The average plant’s genome is thought to consist of around 20% genes encoding enzymes of secondary metabolism, and because they are not essential for plant survival they are often very flexible in evolutionary terms, rapidly mutating and frequently generating new compounds. For humans, these compounds can be of intrinsically high value, as medicines, flavours and fragrances. For example, artemisinin, produced by the daisy species *Artemisia annua* as a herbivore-deterrent, is also a very effective frontline anti-malarial agent.

Our knowledge and understanding of these secondary metabolites is surprisingly erratic – plants have been studied because they have traditional roles as herbal medicines, or because they have strong and apparent fragrances. But more systematic approaches are now being taken to properly describe the diversity of metabolites that plants produce and the ways in which they might be useful. For example, the

Biotechnology and Biological Sciences Research Council supports the High Value Chemicals from Plants network (HVCfP), led by Professor Ian Graham at the University of York. This project aims to make the UK a leading producer of high value chemicals in plants, by sequencing the genomes and exploring the metabolomes of medical plants to identify key compounds and the genes that regulate their production. Researchers in the network have sampled material from a range of species in the CUBG collection for both metabolite and DNA extraction. We were delighted that our little-loved *Crataegus laevigata* (Midland Hawthorn) trees, which punctuate the Systematic Beds and are considered by many of our staff as rather unattractive, were one of the focal species for the network’s activities this year.

Learning from nature to enhance production

One of the ways in which science has changed in recent years is the rise of synthetic biology. At its simplest, synthetic biology consists of bringing together DNA components from different sources to generate new products, or the same products more efficiently. The principle of the approach is that of active design – components are selected rationally to achieve a desired outcome. However, in order for synthetic biology to be possible, we need to understand how plants make products in the first place.

This combined approach is a key part of the work of Professor Anne Osbourn, at the John Innes Centre, who explores how terpenes are made in plants so that she can then test synthetic biology approaches to build novel terpene molecules. Terpenes are very widespread in plants, and have a very important role in plant defence against herbivores. For humans, terpenes may be most noticeable for the aromas they give plants – many of the strong floral and foliage scents of our garden plants come from terpenes, including the distinctive scents of citrus, lavender and pine. This can be useful in its own right – the oils used in aromatherapy are often terpene based, and the distinctive taste of hops (and therefore beer) is a product of its terpenes. However, medically terpenes are perhaps best known for their role in moderating the properties of the cannabinoids in *Cannabis sativa* to



Artemisia annua



Crataegus laevigata or Midland Hawthorn

determine their active effects. The John Innes Centre team have been exploring the genomes and metabolomes of a variety of terpene-producing plants in the Botanic Garden, including several species of *Aesculus* and of *Camellia*, to inform the next steps in their study.

In a related study, the Lavender Genome project, which is an international sequencing consortium from the Universities of York and Florida, is sequencing the genomes of many of our lavender accessions, again with a focus on the terpenes that they produce. In this case, these terpenes contribute to the varied scents and medicinal properties of different lavender species and cultivars. This is a great example of the way our collection's use changes over the years. We hold an enormously diverse collection of lavenders because former curator, Dr Tim Upson, is the world expert on their taxonomy and developed the collection in Cambridge as the basis for his taxonomic monograph. Years later the same plants are now part of a thoroughly modern project using high throughput genomics and metabolomic analysis. It is always exciting to wonder what the next project that uses these plants will be!

Teaching old plants new tricks: the evolution of new compounds

One of the exciting outcomes of collecting these large scale datasets is that they sometimes lead to some completely unexpected findings. Our Curator, Sam Brockington, has been interested in the evolutionary relationships of members of the Caryophyllales, a diverse and species-rich order of flowering plants, since his PhD. His interest initially focused on the evolution of flower development within the group, where petals had been lost ancestrally and regained repeatedly. However, sampling transcriptomes of diverse species across the order has led him to a whole new interest, and exciting set of discoveries, about pigment production.

Members of the Caryophyllales are unique among flowering plants in making a set of pigments called the betalains – these produce colours in the yellow-red range, and are most familiar in the distinctive pigment of beetroot. However, not all members of the group produce betalains, as some species produce the more usual anthocyanins which are the same pigments that colour red roses. No species in Caryophyllales produces both – the two pigment types, betalains and anthocyanins, are mutually exclusive. Analysis of the transcriptome datasets generated from species across the order held in our living collection, coupled with synthetic biology techniques, led the researchers to the realisation that a gene encoding an enzyme central

to betalain biosynthesis had evolved repeatedly in betalain-producing plants. In a recent paper published in *New Phytologist* they were able to show that the DODA genes in the betalain-producing plants had particular combinations of sequence that enabled them to produce betalains, while the similar genes in the anthocyanin-producing plants did not. By mapping these genes onto an evolutionary tree of relationships of the Caryophyllales they were able to show that betalain production has evolved multiple times because the underlying changes to this key gene have also occurred multiple times. In this case having the information to hand about what genes are expressed in a diverse set of plants allowed the researchers to see patterns that would not have been visible if they had taken a more targeted approach to the work – an example of the plants themselves telling their own story.

Understanding the biodiversity of the UK

A new project that we are particularly thrilled to be part of is the Wellcome Trust-funded Darwin Tree of Life Project. Led from the Wellcome Sanger Institute on the outskirts of Cambridge, this ambitious project aims to sequence the complete genomes of all eukaryotic species native to the UK. A eukaryote is an organism with a complex cell – so in simple terms this project encompasses all plants, animals, fungi and non-bacterial single celled organisms like *Amoeba*. There are estimated to be 66,000 such species in the UK, and the project is predicted to take at least 10 years, with the speed increasing throughout the project as sequencing and data processing technologies continue to improve. The project is part of a global initiative to sequence the genomes of all living species, and is designed to improve our understanding of biodiversity and our ability, ultimately, to protect it. The Botanic Garden will play a key role in the provision of plant material from our British Wild Plants collection, and Beverley Glover, CUBG Director, is one of the 8 members of the Plant Working Group for the project, advising on strategy with regard to which plants to sequence in which order. We have supplied the first material for this project with the provision of 8 species from our liverwort collection. This project is another great example of the diverse ways in which a collection can be used – our British Wild Plants collection was primarily developed for teaching, allowing botanists to learn how to identify the plants they meet in the local countryside. It would be a source of great delight to the early botanists who established this collection that it was now to play a role in such a historic enterprise.

*Professor Beverley Glover, Director and
Dr Samuel Brockington, Curator*



Macarthuria australis, a member of the Caryophyllales



British Wild Plants collection on the Ecological Mound

Horticulture

The horticultural team have continued to maintain and develop the Botanic Garden landscape, plantings and collections throughout the year.



The newly repaired stream and marginal plantings

Stream Plantings

The ornamental stream running through the western end of the Garden provides not only a suitable habitat for the display of moisture-loving marginals, but is also critical for feeding the Lake. The stream and the Lake were both installed as key features when the site was developed in the 1840s, and today the Lake continues to be fed by water extracted under licence from Hobson's Conduit. Running through the stand of *Pterocarya fraxinifolia* at its western end, the stream includes two small weirs, and also feeds the Bog Garden before joining the Lake. Over time the streamside banks had begun to subside; water had begun to erode the bases of the weirs, allowing water to pass beneath these, rather than collect in pools behind them and trickle over their tops to the adjacent pool; silt had built up in the base of the stream; and the invasive horsetail *Equisetum telmatei* had grown ever more dominant in the streamside plantings.

During early autumn the Alpine and Woodland team lifted existing plantings from the beds at the eastern end of the stream beds. In early November the stream was drained allowing the Landscape and Machinery team access to the site for hard landscaping and repairs. Silt was dredged from the bottom of the stream and the old weirs removed to be replaced with bespoke new ones. The bank edges were rebuilt using sandstone blocks repurposed from their previous use as bed edging in the tropical glasshouses. Once in place the stream was lined with puddled gault clay to seal it. With the structural elements in place the Alpine and Woodland team were able to focus on the horticultural elements of the project, extending existing beds and installing new ones. In the new bed to the north of the stream the bishop's hat, *Epimedium x warleyense*, provides low ground cover beneath the larger structural forms of *Ligularia japonica* and *Rodgersia 'purdonii'*. The enlargement of the bed to the south of the stream allowed us to extend the range of moisture-loving species grown, but also to include larger and more architectural elements. Plantings now include the thistle *Cirsium rivulare 'Atropurpureum'*, *Thalictrum rochebrunianum*, *Osmunda regale*

'*Purpurascens*' and *Habenochloa macra 'Aureola'*. The new plantings have taken off with renewed vigour in the improved soils and moisture rich margins of the stream and are thriving to provide a more florific display. Perhaps the highlight is the repeat plantings of the giant rhubarb (*Gunnera manicata*), which has flourished with this treatment.

The Limestone Rock Garden and Installation of Barriers

In recent years we have been following a rolling programme of horticultural work to improve the geographical plantings on the Limestone Rock Garden. Work commenced in the highest section of the Rock Garden, which is dedicated to the Americas, and has progressed through to the European Alps. This year our attention turned to the hollow at the centre of the Rock Garden. This feature arose during the construction of the Rock Garden in the 1950s, when a block and tackle hoist was used to manoeuvre heavy limestone boulders on to the American section to create the high point of the Rock Garden. In order to create enough leverage to do this, a hollow needed to be dug out as a counterpoint for the hoist, and it was decided that this should be adapted to emulate a doline (a closed depression occurring where karst or limestone landscapes collapse into underground stream and cave networks). Dolines are particularly prevalent in the Balkan region, so it seemed fitting that the plantings in this section of the Rock Garden represent the flora of this eastern European area.

Throughout winter the Rock Garden team lifted the old, tired, and poorly defined plantings, having propagated much of this material in summer 2018. Once the excavation of the poor soil had been completed they were able to introduce fresh compost, a task which is particularly demanding on the Rock Garden where the compost needs to be worked around the rock work and into cracks and crevices, to ensure there are no air holes. With the compost settled, planting was able to commence. The Bulgarian endemic *Haberlea rhodopensis* was planted in the shade of the *Catalpa x erubescens 'Purpurea'*, alongside *Galanthus elwesii* var.



Recomposting the doline on the Balkan section of the Limestone Rock Garden



New plantings on the Balkan section of the Limestone Rock Garden

elwesii and *Paeonia mascula* ssp. *arietina*. The vertical faces of the doline have been planted with crevice-loving species such as *Saxifraga paniculata*, *Sempervivum soboliferum* and *Moltkia fruticosa*, while the sunnier, southern plantings include the Albanian *Halascya sendtneri*, *Saxifraga ferdinandi-coburgi* var. *rhodopea* from Bulgaria, and *Campanula versicolor* from Greece, the Balkans and southern Italy. The new plantings are already establishing well to produce a representative display of species from this unique flora, and also provide better definition to the plantings to distinguish individual species as well as helping define the paths on the Rock Garden.

We have been conscious for some time of the conflict between increasing visitor numbers and protecting our plant collections. This issue has been most prevalent on the Limestone Rock Garden, where delicate plants inhabit a landscape designed to emulate a natural feature. We have worked to address this on the Rock Garden by carefully positioning plants to create a defined bed edge, and by also ensuring that species are clearly labelled. Despite this it had become more apparent that this was too subtle, and we were still experiencing issues with visitors straying from paths and damaging valuable plant material and labels. After much discussion and deliberation this year we began installing barriers around the individual beds on the Rock Garden to more clearly distinguish the beds and the paths, and to guide visitors around this intricate feature. The barriers are constructed from brushed steel posts inserted into the limestone rock work, with connecting chain link. We were able this year to install this in the northern half of the Rock garden and will roll this work out across the remaining southern half of the Rock Garden next year. Although we would have rather not taken this step to protect this delicate and valuable collection, we have already experienced a steep decline in the number of people accessing all areas of the Rock Garden, and subsequently damaging plants and labels. This measure, in conjunction with the introduction of fresh compost and new plantings, has resulted in a reduction in the amount of horticultural and curatorial input required on this feature.

The Chalk Grassland

Constructed in the 1960s, both the Ecological Mound and Fen Display serve to highlight the local and wider landscape and plants, and to bring to the fore conservation issues relating to these. The original Fen Display was replaced in 2000, and the Ecological Mound has remained structurally unchanged, although there have been minor adjustments to the plantings.

The original concept for the Ecological Mound was to display plants from calcareous habitats. It was originally constructed using carboniferous and oolitic limestone, and displays a range of wild, endemic species, and showcases local, plant-rich habitats. The displays here include plants from ancient coppiced woodland, carboniferous limestone and chalk grassland. This last area was developed in 2004-5 to show some of the plants that can be found locally on herb-rich grassland, a once prevalent local habitat predominantly lost to agriculture in the last 200 years. Although now confined to a few small areas such as the Devil's Dyke near Newmarket, this remains an important local habitat. Today this 2004-5 development supports some 40 species of plants, mosses and liverworts. This year we undertook work to extend this feature on the southeastern corner of the Ecological Mound.

Early winter work involved the removal of the existing rock work and soil, which is too rich to support chalk grassland species. Once down to the subsoil we back-filled the hole with raw-quarried, local chalk, a nutrient-poor substrate which will support a chalkland flora. As time progresses the chalk surface will break down to provide the perfect soil for chalkland species. As spring progressed we were able to begin planting to show the progression from grassland to woodland, a process which occurs over time if the grassland remains ungrazed, or in a garden environment, unmown. Given the nature of the substrate, we opted to plant young, immature specimens of herbaceous elements to optimise their chances of success in this habitat. Chalk grassland plants introduced include the Cambridgeshire county flower *Pulsatilla vulgaris* (Pasque flower), *Cirsium acaule* (stemless thistle) and *Asperula cynanchica* (squincancywort). In the northern end of this new feature, where we are trying to emulate the scrubland and woodland that would evolve on unmanaged i.e. ungrazed chalk grassland, plantings include *Crataegus monogyna* (hawthorn), *Rosa rubiginosa* (sweet briar) and *Juniperus communis* (juniper).

Although stark when first developed, the chalk has mellowed during the year and the plants have begun to establish. We anticipate that as this feature matures, species will naturalise and soften this stark landscape to resemble the original, carefully managed chalk grassland display here.

Sally Pettitt, Head of Horticulture

Learning

Educational visits

We welcomed 9,515 students via 344 educational visits to the Garden in the reporting period. The bulk, 5,385 students, were from Primary schools, with 2,719 from Secondary schools and 1,411 from Tertiary establishments.

A Conservation Biology Masterclass for 50 A-level and undergraduate students from across the region ran in March, in collaboration with the Gatsby Plant Science Education Programme and the Sainsbury Laboratory. Talks and tutoring from scientists and postgraduate students from the University were complemented by practical activities out in the Garden.

In July we ran three Plant Response days to support 360 A-level Biology students from Hills Road Sixth Form College in collaboration with the college. Students attended lectures, workshops and hands-on activity stations out in the Garden.

Our student passes scheme has expanded yet again, with 515 issued in autumn 2018 to local sixth form students and for the first time, 184 passes to students at Anglia Ruskin University.

For a week over the summer we worked with four enthusiastic work experience students to create a new resource for A-level age students visiting the Garden.

We supported a new horticultural enrichment course for students at Hills Road Sixth Form College. Sessions included sowing, growing and harvesting plants, putting up bat and bird boxes, planting bulbs at the Botanic Garden and garden design.

Families at the Garden

We have increased our offer for families by running more activities during the school holidays, often including storytelling. Activities over the last year have included Plants from Pips, Plant Fossils, Nature Weaving and Messy Mud. Thanks to the newly developed Dell area we have run several of these sessions outdoors.

This year we created two new trails for families – Crazy Cone Caper and Prehistoric Plants – both of which proved very popular. Matthew's Library, the little bookshelf of nature picture books located in the Café, was updated in the summer to include many new titles. Visitors to The Dell area of the Garden may have had a surprise at the arrival of a fairy village, complete with post office and school. These mini-world installations were created by local charity, Rowan Humberstone.

Lifelong learning

Our adult programme delivered 68 courses to 661 participants across topics including identifying conifers, making paper flowers, poisonous plants and illustrating squashes and pumpkins. This year we added five new tutors to the programme, introducing a number of new topics. Almost half of participants (322) were new to our course programme, demonstrating that the diverse range of courses we offer continues to support new engagement with the Garden and its collections. Some wonderful new horticulture courses were developed including Rose Care taught by the experts at Peter Beales Roses, Growing Meadows and Rewilding your Garden.



Marin Bond

Exploring The Dell

Garden Sketchbooks, including instructional art postcards, aimed at adults were launched, and the Science on Sunday talks series continued to attract a keen audience, with 222 participants attending the six talks from March to August.

Community engagement projects

To share our knowledge with the wider Cambridge community, we have set up and support a local community gardening network, where interested individuals and organisations can come together to share knowledge, access training and raise the profile of community gardening and its benefits. <https://cambridgecommunitygrowinggroup.org> Looking forward we hope to engage with staff and students across the University sites interested in setting up gardens as part of the University's biodiversity engagement project.

Involvement with our nearest community gardening project at Hanover and Princess Court is now in its fifth year and continues to be a great link with our local community. We have worked together to begin work on a memorial rose garden, developed a dedicated space for growing vegetables and purchased new tools to allow residents to garden at any time during the week.

We have been involved in a number of one off community events during the year, including Chelsea Fringe and Big Biology Day. As part of Cambridge Veg Fest in July, St Paul's Primary Gardening Club created a mobile vegetable garden highlighting vegetable families and crop rotation which made its way to a number of Cambridge locations including Cambridge Market.

We welcome many different community groups to the Garden. The Thursday Group at St Paul's Centre, Cambridge City Council Exercise Referral Walks, Wintercomfort, Cambridge Cyrenians, various Community Gardening Groups and CAMSIGHT are just some of the groups who have regularly visited over the past year.



Martin Bond

Bioblitz workshop 2018



Science Detectives 2018

Working with University of Cambridge Museums (UCM)

As part of the UCM, funded by Arts Council England, we undertook a number of collaborative projects this year. These included the annual Twilight at the Museums event in February. This night-time family adventure highlighted the plight of plants on the IUCN Red List. Red-Listed plants in the Glasshouses were bathed in red light and volunteer explainers, many from the Department of Plant Sciences, talked to visitors about conservation and the role of botanic gardens in caring for species.

In conjunction with the Museum of Zoology, late April saw 30 experts come together for a BioBlitz aiming to record as much wildlife in the Garden as possible over a 24-hour period. Members of the public were able to join in and learn more about local biodiversity by attending any of 32 different workshops. Sadly, the event was affected by poor weather, with the Garden closing due to high winds on the first day, but the enthusiasm of the surveyors was not dampened and 269 species were recorded. 112 members of the public attended and the feedback was very positive, with 100% of respondents saying they had enjoyed the event. The event will be repeated in 2020.

In March we worked with colleagues from the Fitzwilliam Museum to run a Science Festival event for preschool children called Plant Journeys. Children listened to stories and facts about plants and were invited to look closely at plant imagery within the Fitzwilliam collection.

In August we again ran a 'Science Detectives' day for 8-11 year olds. This involved educators and volunteers from the Botanic Garden, the Sedgwick, Whipple, Zoology and Polar Museums. The morning was spent learning scientific techniques from each collection. In the afternoon participants used these new skills to solve puzzles at activity stations out in the Garden.

We have also collaborated with our UCM colleagues on a number of smaller events and projects throughout the year. The Museum of Archaeology and Anthropology came to our Festival of Plants family event bringing objects made out of plants from the Pacific Islands and the Sedgwick Museum loaned us a box of plant fossils to use at our Prehistoric Plants family events and assisted us with the creation of our Prehistoric Plants summer trail.

Supporting University public engagement

During the University's Festival of Ideas, in October 2018, we hosted a talk on Extreme Plant Hunting, with garden historian, Twigs Way, Glasshouse Supervisor, Alex Summers, and Assistant Curator, Dr Angela Cano.

For the Science Festival we launched our Science on Sunday talk series as well as a Plants and Chemicals Exploration trail to celebrate the International Year of the Periodic Table of Chemical Elements and a Tree Trail focusing on identification for citizen science projects. Research pop up stands at the Garden over two weekends enabled visitors to talk to researchers from the Department of Plant Sciences about their work. We hope to develop this research spotlight format further.

Interpretation

Interpretation panels and adult trails across the Garden now fall within the remit of the Learning team. New boards were installed in the Bee Borders and Understanding Plants Area. Progress is being made on designing new panels and updating older ones across the Garden, so look out for these next year.

Staff and conferences

In March 2019 we bid a sad farewell to Flis Plent after seven years as Head of Learning for the Garden. Hannah Elkington has been supporting the team in the interim as temporary Learning Officer while recruitment to fill the Head of Learning position is ongoing.

The Learning team relies on dedicated volunteers to help deliver events and activities across the programme. This year we welcomed a number of new volunteers and we thank all our volunteers for over 530 hours of time given generously to our programmes throughout the year.

BGEN Conference 2018 'Talking Plants: How to Communicate Plant Science'

In November the annual Botanic Garden Education Network (BGEN) conference came to Cambridge. Hosted jointly by the Botanic Garden and the Sainsbury Laboratory, the conference focused on communicating plant science and research to a wide range of audiences. With 69 delegates plus 30 additional speakers, volunteers and support, a total of 99 individuals took part. Delegates joined plant scientists, the team at the Garden and other plant science communicators and educators from across the UK, for three days of 'Talking Plants'.

Feedback was overwhelmingly positive and we would like to thank everyone involved for making it such a successful event. 'This has been the best BGEN Conference to date. It was a great opportunity to explore and further develop plant science knowledge and skills.'

Curation



Expedition to the Swiss Alps with colleagues from the Geneva Botanic Garden



Linaria alpina collected at Sanetsch (Valais Canton, Switzerland) in September 2019

During this year the Curation team has been able to build upon the efforts of previous years towards modernising the collection management of the Garden. We have achieved this through participating in international expeditions, by digitising and equipping our Herbarium, by upgrading our collection management practices, and in the final production of our Collections Strategy.

Modern plant sourcing from wild populations involves conducting expeditions in collaboration with local botanists, following international agreements on how to ethically collect plants, and keeping precise records for each new accession. We are committed to follow these good practices and this year we have taken part in four expeditions. Our Assistant Curator and official plant hunter, Ángela Cano, travelled to Colombia in December 2018 to participate in an expedition aiming to collect passion flower (*Passiflora*, Passifloraceae) species, organised by the Colombian specialist in these beautiful and interesting plants, Dr John Ocampo, and colleagues. They explored a locality in the Antioquia department, where they found numerous species, including one that is possibly new to science. This expedition was the first step towards developing a joint collection of Colombian passion flowers in the Quindío Botanic Garden and CUBG. Ángela then travelled to Mexico, where, together with other palm specialists, she collected and documented the genus *Brahea* in the north of the country. Some hardy species of this genus are now being cultivated in the Garden. Later this year, in September, she travelled to Switzerland together with Paul Aston, Alpine and Woodland Section Supervisor, following an invitation from the Conservatoire et Jardin botaniques de la Ville de Genève. They spent a week in the Canton of Valais, collecting alpine plants in different environments of the rich landscape of the Alps. As in previous years, our Curator, Sam Brockington, also travelled to South Africa with his postdoctoral student, Loubab Zedane, looking for *Eriospermum* species. We now have over 50 species of this enigmatic genus in the living collection, despite its rarity in cultivation elsewhere.

Our Herbarium (CGG) has also reached international standards this year via two approaches: digitisation and equipping. Digitisation of the collections has been completed thanks to the meticulous and efficient work of our Technician, Laura Housden. This means that all of our 11,542 herbarium specimens are now documented in our database. The most precious specimens in CGG are those collected by J.S. Henslow, founder of the Garden. We produced high-resolution images of the 135 sheets collected by Henslow. Our Herbarium is now fully equipped and functional, thanks to the acquisition this year of a modern dryer for green specimens, the in-house manufacture of numerous presses, and the establishment of a vouchersing process. Indeed, the Garden's staff and volunteers now regularly collect herbarium specimens in the Garden and during expeditions. The records of these are efficiently included in our database following a new protocol, which

allows us to print herbarium labels. Once the specimens are dry and labelled, they are mounted and included in the Herbarium. This process is essential to support research conducted with plants grown at the Garden, since each living plant that has been used for research should be vouchered as a future reference for scientific studies.

Modern practices have also been implemented for managing our living collection. In December 2018 we concluded the 2-year long exercise of labelling our living plants based on the modern classification system of the Angiosperm Phylogeny Group (APG). This involved relabelling about 4,000 plants in our collection. This year we also tackled a long-standing issue with record keeping, which is that the plants are outside, while the computers and database are in the offices. Fortunately, this problem has been solved by the developers of our database, IrisBG, who created an application for mobile devices that allow our staff access to our database and allow them to modify information while outside and working with the plants. Consequently, we have invested in tough handheld computers that can resist outdoor conditions, and come with a barcode scanner. Both curators and horticulturists have added this smartphone to our tool belts and we can now access and modify data efficiently while on the move. Tasks that were previously extremely time-consuming, such as audits and inventories, are now much quicker, and it is also possible to request a new label for a plant, see where it is located in the Garden and modify its location using the GPS of the handheld computer. Having brought these improvements to our practices and to the quality of our collections, we are now focusing on certifying the high standards of our Garden by applying to the Botanic Gardens Conservation International (BGCI) Botanic Garden accreditation scheme. Finally, we have taken our Collections Strategy to its final stage, a graphically designed 80-page document to be launched on November 20th, 2019. This strategy document represents an important moment for the living collection, and for CUBG as a whole. The strategy includes a comprehensive assessment of the current state and quality of our collection, and outlines a series of initiatives to both enhance the content of the collection through new acquisitions, and to ensure their improved management. In the publication of this strategy, we will set out a blueprint to ensure closer alignment of the CUBG with the University's pursuit of excellence in education, learning, and research.

Dr Samuel Brockington, Curator, and Dr Ángela Cano, Assistant Curator

Friends

This year saw the number of Friends' memberships continue to rise, with the highest number of memberships to date. The figures suggest that we will exceed 7,000 again by the end of 2019, which is fantastic.



Stowe Hall



Beth Chatto Gardens

The Friends enjoyed another busy events programme in 2018-19, both in the Garden and (sometimes much) further abroad. We would like to take this opportunity to thank the volunteers who put together the Friends' external events, Leslie Jakubowska and Jennifer Egbe, who organised such an interesting and successful programme of events.

Within the Garden, the Friends' Annual Lecture was a fascinating talk from horticulturalist, Christine Walkden, and our Christmas wreath-making workshop sold out (again). John Kapor hosted a behind-the-scenes tour of the Systematic Beds and on a sunny January morning, Pete Kerley took the Friends for a 40th anniversary tour of the Winter Garden. The Sainsbury Laboratory hosted two more tours of the building, and we preceded the hugely popular Early Bird Tours with a Guide to Birdsong talk with Dr Julia Mackenzie. The summer saw Chantal Helm hosting a Friends' Bat Walk around the Garden. Mark Crouch and Adrian Holmes gave a behind-the-scenes tour of the Garden's trees and shrubs. We had a beautiful evening for the

Friends' Evening Highlights Tour on 27 June, enjoying an early evening glass of Prosecco on the Main Lawn.

Further afield, Friends visited Stowe Hall, Beth Chatto and Green Island Gardens, Michael Heseltine's Thenford Arboretum, Sandringham, Norfolk Lavender, Upton House, Canons Ashby and Highgrove Royal Gardens. Head Gardener, Sergio Ballarin, took the Friends for a tour of Christ's College Garden; Head Gardener, Richard Gant, took the Friends on a tour of Madingley Hall gardens and two happy coach loads of Friends went to North Wales in late June.

The new Corporate Friends programme is establishing well and we now have 11 Redwood Friends (the higher tier of membership at £1,000/year) and 91 Oak Friends (£350/year). The Garden hosted the first Corporate Friends Late Night Opening in June and we were delighted to welcome many Corporate Friends' employees with their families to exclusively enjoy the Garden after hours.



Highgrove Royal Gardens



Madingley Hall

A Garden for all seasons

Here in the Garden we are very aware of the changing seasons and all that this brings, from the cold, biting winds of winter to a warm summer's day, and the impacts that these changes have on our landscape and collections. This year the variation between summer and winter was highlighted by two events here in the Garden, which also served to remind us of climate change and its potential impacts on the Garden and its collections. The first was the 40th anniversary of the Winter Garden, and plans had long been in place to celebrate this landmark. The second was the recording of the highest UK temperature, something which we could not have planned for. Both events put the Botanic Garden firmly on the media radar.



The scented flowers of *Daphne bholua* 'Jacqueline Postill' at the entrance of the Winter Garden

Winter Garden 40th Anniversary

Since its inception in 1979 the Winter Garden has proved a firm favourite with visitors, horticultural and landscape students, and the horticultural media. It was designed in the late 1970s by Peter Orriss (Garden Superintendent) and Norman Willis (Garden Supervisor) to celebrate the diverse range of plants providing seasonal interest at what is perceived to be a horticultural down time. Replacing an existing, formal 1950's Winter Garden along the northern boundary of the Garden, the new Winter Garden was deliberately planted in an informal style. Shaped to create a shallow hollow with gentle valleys and undulations, and with a south-facing aspect, the garden was designed to maximise the impact of low, winter sunlight. Plants were displayed in meandering drifts to provide rhythm and flow. On bright winter days the coloured stems of *Cornus* (dogwoods), arching canes of *Rubus* (brambles) and the shaggy bark of the paperbark maple (*Acer griseum*) are highlighted to great effect. The whole site was surrounded by hedges to help capture the scent released by many winter shrubs including wintersweet (*Chimonanthus praecox*) and *Daphne bholua* 'Jacqueline Postill'. Comprising a diverse range of plants selected for their winter flower, scent, colour and form, the Winter Garden has remained a source of inspiration to many for 40 years.

Although structural elements such as the hedges and paths remain as they were when conceived, the plantings in the Winter Garden have inevitably matured, with many shrubby specimens becoming dominant. Inevitably with time we have appraised the plantings and sought opportunities to enhance the landscape. Dense, shrubby plantings have been regularly coppiced to keep them in check, or removed entirely to retain balance and to open up views across the garden. Plantings have also evolved to reflect changing horticultural fashions, and to introduce species which were unavailable in the late 1970s. Carpets of heather, which originally lined the path, have been replaced with *Cyclamen hederifolium* and *Acorus gramineus* 'Ogee', and this year we introduced the challenging *Edgeworthia chrysantha* 'Grandiflora'. In its 40th year changes included the removal of a dominant stand of *Taxus baccata* 'Sempervirens' which allowed us to introduce a greater diversity of plants including the evergreen *Pinus mugo* 'Ophir', shrubby *Lonicera elisae*, and herbaceous *Miscanthus* 'September Rot' and *Agastache nepetoides*. To celebrate the anniversary of this area our guides offered free public tours of the Winter Garden on Sundays throughout January and February, and these proved to be a welcome addition for our hardy winter visitors.



Old Winter Garden 1974



New Winter Garden with meandering path and drifts of new plantings in early 1980s



Winter Garden at 40, an exemplar of winter colour, structure, texture and fragrance

When we first started contemplating how to progress the Winter Garden we considered whether we should completely clear the site and start from scratch. In opting to work on small pockets of the Winter Garden on an annual basis, we have been better able to remain true to the concept and spirit of the original design. This has also allowed us to keep the Winter Garden accessible, rather than having to close it for a major redevelopment and establishment. We will continue to evolve the plantings here to bring in new species and interest, while ensuring that the Winter Garden remains an exemplar of winter colour, structure, texture and fragrance well into the future.

Hottest Day on Record

The activities within the Garden are varied and constantly evolving, but one task has remained part of our daily routine for over 100 years, and that is taking meteorological readings. The University holds readings from our weather (or met) station dating back to 1904, and since then a member of staff has taken daily readings from our weather station on the Experimental Plots at 9am Greenwich Mean Time (10am British Summer Time). Katie Martyr, Experimental Section Assistant, currently takes these readings, and she follows a long line of dedicated weather observers, including John Kapor (Supervisor, Systematics). The daily readings provide weather recordings for the previous 24 hour period, and they include maximum and minimum temperatures, ground temperatures, rainfall, cloud cover, wind speed and direction. Most of these readings are made using relatively simple technology, such as standard thermometers, measuring cylinders and visual observations. Only the maximum temperature is recorded using an electronic thermometer housed in a Stevenson screen to ensure consistency of measurements. The measurements from this thermometer are charted on to a computerised data logger, from which we manually record the peak maximum temperature from the preceding 24 hour period. The station is overseen by the Met Office which provides equipment and monitors our readings to ensure we meet their rigorous requirements to qualify as a recognised met station. Daily readings are logged both here in the Garden and with the Met Office, which uploads the information onto the publicly accessible Weather Observers Website (WOW).

As horticulturists and plant scientists with responsibility for a 40 acre garden we remain constantly mindful of the weather and its impacts on our activities, landscape and plantings, and visitors. During the summer we were all conscious of warm, dry days and low rainfall. In late July forecasts indicated exceptionally high temperatures. As the week beginning 22 July progressed, the temperature began to rise, and it was evident that we were experiencing exceptionally high temperatures. Plants were wilting and being scorched, and the Glasshouses and ticket offices were closed as the heat was unbearable to work in.

As normal, the readings for 25 July were taken at 10am on the following day, 26 July, when Katie measured a temperature of 38.7°C on the maximum thermometer. This was duly recorded on the Met Office database. Later that day the Met Office indicated that this could be a record temperature for the UK. On 29 July the Met Office came to calibrate the maximum thermometer, and to verify that none of the equipment in the met station had been tampered with. It was only at this stage that the Met Office declared that we had officially recorded a new maximum temperature for the UK of 38.7°C.

Inevitably this created a great deal of media, and subsequently, public interest. For us though the real significance of this chance occurrence was not in reaching this temperature, but in knowing that our continued monitoring of weather here at the Botanic Garden was valuable in defining this heatwave. Our long history of gathering weather data is valuable to the Met Office and climate change scientists in analysing weather patterns and in predicting climate change. Such evaluation is valuable to us as a botanic garden in informing decisions about what we grow in the future. If high temperatures such as this, coupled with low summer rainfall, become the normal, we need to be considering adapting what we grow to better cope with changing weather. In the future we may need to grow a greater proportion of plants originating from places such as the Mediterranean and California, whose present climates are similar to those predicted in the UK.

Sally Pettit, Head of Horticulture



Data records



Hottest day temperature recording



John Kapor & Katie Martyr at the CUBG met station

Communications



BBC News Online



Channel 4 Extreme weather

This year has been yet another busy one for the Communications office. Major projects have included the relaunch of the Garden’s website, making it clearer, more dynamic and hopefully more accessible. The 40th birthday of the Winter Garden was a successful multi-media campaign, resulting in good, broad coverage and has provided a template for future, similar campaigns. The press attention from the recording of the UK’s hottest ever temperature was huge, creating national and international interest including being the lead mention in the prestigious scientific journal, *Nature*, as part of their special ‘climate week’ feature about the people who record temperature extremes around the world, as well as reports on BBC News, ITN, Sky television and Channel 4’s Extreme Weather special.

The Garden continues to use Twitter and Facebook as effective ways of communicating with supporters and the public. In the last year, our Facebook followers increased by 19% to 9,871 and our Twitter followers rose from 10,459 to 11,478 (an increase of 10%). Our average reach (the number of people seeing our posts but not necessarily following us) on Facebook was 65,000 (up from 46,500 the previous year). The most popular posts were about the Winter Garden’s 40th anniversary, the record highest temperature in July and the flowering of the *Agave vivipara* after 57 years. On Twitter, our monthly impressions (interactions of any sort with a tweet – views, likes, replies, etc.) is averaging 111,000, with a peak of 179,000 in March as we shared images of the Yoshino cherry tree coming into



BBC Gardeners’ World crew and presenter with Sally Pettit

flower. The agave flower was also extremely popular, the BBC news coverage helping to raise interest on Twitter with 30,000 impressions on their tweet. Our Instagram following also continues to build from 2,696 to 5,241 (almost doubling for the second year in a row) and the last year saw the addition of our trainees’ Instagram account.

We continue to develop the Garden’s profile in the media industry so that producers think of us when they are looking for a location for filming botanic gardens, plant science research or conservation. In the past year we were delighted to welcome film crews from local and national BBC programmes including BBC Gardeners’ World as well as independent film companies and ITV.

Summary of News Coverage

Type of news cover	Number of appearances
National & Local Press	62
National & Local Radio	30
National & Local Television	17
Internet	28
Total	137

Research Supported & Facilitated

The Botanic Garden maintains and makes accessible the living plant collection of the University of Cambridge. Research and teaching is supported through the plant collections of over 8,000 species, the Experimental Section which provides supported glasshouse and open ground research plots, and through use of the 40-acre landscape. In addition to home-grown research the Garden supports a wide range of projects throughout the University of Cambridge and collaborates with a great many external partners.

Cambridge University Botanic Garden

Professor Beverley Glover, Director:

Research programme focused on the evolution and development of flowers, plant/pollinator interactions, and plant surface properties, funded by the BBSRC, NERC, HFSP, EU Marie Curie Actions, Leverhulme Trust, Isaac Newton Trust, and the Cambridge University Botanic Garden Research Fund. Material maintained at CUBG, analysed in the experimental plots, or accessed from the living collection, for projects including:

- Stamen evolution in *Solanum* with Dr Sandy Knapp (The Natural History Museum) and Gwen Davis (PhD student).
- The relationship of floral morphology to pollination success in *Vicia faba*, with Dr Jane Thomas (National Institute of Agricultural Botany), Roger Vickers (PGRO) and Jake Moscrop (PhD student).
- Molecular evolution of key developmental pathways in plants, with Dr Sam Brockington (Curator, CUBG) and Dr Chiara Airoidi (post-doc).
- Development and evolution of insect-mimicking petal spots in *Gorteria diffusa*, with Dr Paula Rudall (RBG Kew), Dr Allan Ellis (Stellenbosch University), Dr Boris Delahaie and Dr Roman Kellenberger (postdocs) and Roisin Fattorini (PhD student).
- Development, function and evolution of iridescence in plants, with Dr Paula Rudall (RBG Kew), Professor Richard Bateman (RBG Kew), Professor Ulli Steiner (Adolphe Merkle Institute, Switzerland), Professor Jeremy Baumberg (Department of Physics, University of Cambridge), Dr Silvia Vignolini (Department of Chemistry, University of Cambridge), Dr Edwige Moyroud (Sainsbury Laboratory Cambridge University), Dr Chiara Airoidi and Dr Carlos Lugo-Velaz (postdocs) and Jordan Ferria (PhD student).
- The effect of plant viral infection on pollinator attraction, with Professor John Carr (Department of Plant Sciences, University of Cambridge), Dr Alex Murphy (postdoc) and Netsai Mhlanga (PhD student).
- Evolution and development of nectar spurs in *Linaria*, with Erin Cullen (PhD student).
- Conservation of *Potentilla porphyrantha* in Armenia with Lydian International, Dr Peter Carey, Dr Jo Trewick and Chris Davis (PhD student).
- Petal epidermal cell morphology and the association with insect pollinators in *Nicotiana*, with Gabriela Doria (PhD student).
- The relationship of floral morphology to pollination success in strawberry, with Hamish Symington (PhD student).
- The role of pollination in ethylene production and fruit development in tomato, with Dr Saumya Sand (postdoc).
- Provision of liverworts, mosses, ferns, lycophytes and cycads for undergraduate teaching.

Dr Sam Brockington, Curator:

Research programme focused on the evolutionary genomics of the order Caryophyllales, funded by NERC, the NSF and the Isaac Newton Trust, and using material grown in the experimental glasshouses, and across the living collections:

- Sequencing transcriptomes in Caryophyllales in collaboration with Professor Stephen Smith (University of Michigan) and Professor Michael Moore (Oberlin College, Ohio).
- Reconstituting the betalain pathway in heterologous host systems with Alfonso Timoneda (PhD student) and Dr Hester Sheehan (postdoc).
- Exploring the evolution and regulation of arogenate dehydrogenase

(TyrA), the key enzyme for the production of the essential aromatic amino acid tyrosine (Tyr), in Caryophyllales, with Dr Samuel Lopez Nieves (postdoc).

- Sampling the diversity of liverwort specimens in the Garden to extract high quality DNA for genome sequencing by BGI (Beijing, China), as part of the 10KP genome sequencing project, with Nathaniel Walker-Hale (PhD student).
- Studying the phylogeny, evolution and diversity of tulip species with Brett Wilson (PhD student) and Fauna and Flora International (FFI).
- Analysing the fog-capturing properties of South African curly-wurly plants in the genus *Eriospermum* with Dr Loubab Zedane (post-doc).
- Sampling material for genomic sequencing projects in Caryophyllales.

Department of Plant Sciences, Cambridge

Professor Sir David Baulcombe, FRS (RNA Silencing and Disease Resistance Group)

Use of the Experimental Glasshouses to propagate the progeny of *Solanum lycopersicum* x *S. pennellii* hybrids through to the F4 generation, to investigate segregation in hybrid plant populations. Transgressive segregation results in plants that have heritable properties that are outside the range of the parents, and this work aims to understand the molecular biology of this important trait so that it can be harnessed more efficiently for crop improvement.

Professor John Carr (Plant Virology Group)

We have been using a bay of the glasshouse, and part of the outdoor Experimental Plots, to investigate the effects of virus infection of the interactions of tomato and bean (*Phaseolus vulgaris*) with bumblebees (*Bombus terrestris*). The work suggests that virus-infected plants are more attractive to pollinators than healthy or resistant plants and findings may be useful for improving pollinator service in gardens and for understanding how plants, pathogens and pollinators coevolve in the wild. We are expanding the work to include peppers.

Professor David Coomes (Forest Ecology and Conservation Group)

Exploring the properties of organic fertilisers and their consequences for plant growth. Also using weather data collected at CUBG to inform studies of the impact of drought on UK woodland.

Professor Howard Griffiths (Plant Physiological Ecology Group)

Maintaining collections of succulent plants for analysis of those with Crassulacean acid metabolism. The diversity and evolution of epiphytic bromeliads from the neotropics are being investigated. The compromise between water use and carbon gain is also being used to infer evolutionary origins and biomass production potential in succulents and grasses. In grasses, many savanna species have evolved the C4 pathway to enhance productivity, and the selection pressures leading to changes in leaf vein anatomy and metabolic partitioning are being investigated. These processes led to the development of highly productive crops such as sugar cane, sorghum and maize. *Agave tequilensis*, *Aechmea*, *Guzmania* (Bromeliaceae); *Jatropha*, *Kalanchoe*, *Mesembryanthemum* and rice plants all are maintained at the Botanic Garden. Various moss species are also used from the collection in the Garden and cultured in shade for analysis of moss metabolism.

Professor Jim Haseloff and Dr Jennifer Deegan (Synthetic Biology for Engineering Plant Growth Group)

Anatomical studies of fern gametophytes and of liverworts, requiring access to the living collection.

Professor Julian Hibberd (Molecular Physiology Group)

Rice, millet and wheat are grown for anatomical analysis, RNA isolation and deep sequencing as part of a project to understand the genetic differences between the more common C3 photosynthesis and the more efficient C4 photosynthesis.

Professor Uta Paszkowski (Cereal Symbiosis Group)

The mutually beneficial arbuscular mycorrhizal (AM) symbiosis is the most widespread plant-fungal association between roots of terrestrial plants and fungi of the Glomeromycota, in which the fungus receives photosynthates from the plant and enhances its mineral, particularly phosphate, nutrition. This research focuses on the identification and characterisation of molecular mechanisms underlying the development and functioning of AM symbioses in the crop plants maize and rice. Maize and rice lines are grown in the Botanic Garden's Research Glasshouses and Experimental Plots for genetic characterisation and seed amplification. Also exploring the presence of mycorrhizal associations in diverse grass species from the Garden's collection.

Professor Alison Smith and Dr Matt Davey (Plant Metabolism Group)

The Botanic Garden has provided space for the Algal Innovation Centre glasshouse facility, to allow different algal species to be grown to establish what role algae can play in the development of a low carbon economy.

Dr Edmund Tanner (Tropical Ecology Group)

Exploring root herbivory in different soil types.

University of Cambridge

Dr Edwige Moyroud (Sainsbury Laboratory)

The bullseye patterns in the centre of many flowers attract pollinating insects, but we do not know how plants control their formation. We are working with *Hibiscus trionum*, which creates a central bullseye of pigmented tissue in the middle of the flower, to understand the development of these patterns. In the Experimental Glasshouses we are screening a large population of mutagenised *H. trionum* plants to identify mutants with altered floral patterns.

Dr Sebastian Schornak (Sainsbury Laboratory)

Plants engage with fungi to improve access to nutrients such as phosphate. We sample liverwort species from the Botanic Garden and stain them to detect fungal structures. Comparing early land plant symbiosis with the root symbiosis of higher plants will allow us to highlight evolutionary aspects of symbiosis establishment in different parts of plants.

Dr Raymond Wightman (Sainsbury Laboratory)

Working with CUBG Alpine and Woodland Section to study hydathode development in *Saxifraga* using cryoSEM microscopy and to analyse their secretion products with Raman microscopy. Another project focuses on the control of phyllotactic patterning in *Saxifraga* species. I am also exploring surface patterning mechanisms and the development of wood using the living collection.

Professor Paul Dupree (Department of Biochemistry)

Use of the greenhouses to grow thermotolerant plants for biochemical analysis. Provision of species with polysaccharide gums. Pilot investigation of the presence of polysaccharides of interest. Eventually, the polymer could be used to study enzyme activity from microbes involved in digestion.

Jan Lyczakowski (Department of Biochemistry)

Analysis of wood polysaccharide and cell wall structure in wood from *Malus* species. We are sectioning bark, phloem, xylem and leaf material. In addition to the biochemical analysis, we are analysing with scanning electron microscopy.

Dr Paolo Bombelli (Department of Biochemistry)

In collaboration with the Zoological Society of London we have created plant bio electrochemical systems. Several prototypes have been located and tested in the tropical house at London Zoo. In the long run, those electrochemical systems will be used to power environmental sensors (e.g., camera traps) for monitoring the population of wild animals in remote, off-grid locations. We are using plants from the CUBG collection able to live in tropical locations and in water saturated soils to test our prototypes.

Professor Peter Leggo (Department of Earth Sciences)

Experiments using digested food waste pelletised with finely ground zeolitic tuff and diatomite as soil improvers using *Nicotiana*. This work aims to find the mixture giving maximum plant nutrients.

Professor Nick Davies (Department of Zoology)

Feeding behaviour of blue tits and great tits in the Botanic Garden, studied over many years.

Dr Walter Federle (Department of Zoology)

Biomechanical measurements of *Nepenthes alata* to explore pitcher plant evolution and function. *Nepenthes* pitchers used for outreach activities.

Ki Woong Kang (Department of Zoology)

We are investigating how pitcher plants manage to capture and retain insect prey. Some species secrete a viscoelastic fluid into their pitchers that acts to not only digest but also to help capture and retain the prey. Our objectives are: (1) Quantifying the forces exerted by the fluid on insects as they fall into and struggle within the fluid; (2) measuring how the fluid interacts with insect cuticle; (3) comparing fluid properties between lower and upper pitchers, as well as comparing how the properties evolve over the life history of a pitcher.

Patrick Brechka (Department of Zoology)

The waxy epicuticular stem surface of many species of *Macaranga* trees is too slippery for most insects to climb, thereby isolating the specialised "wax-running" ants that live on the trees from predators and competitors. Interestingly closely related generalist ants adhere better to smooth Perspex surfaces than these specialised wax-runners, suggesting a trade-off. As the foot pads of ants mediate adhesion to smooth surfaces, this suggests that wax-runners rely on a different, possibly novel form of attachment when they climb their host trees. My research focuses on determining the biomechanics of how "wax-runner" ants climb their host trees and other factors that mediate the specificity between Ants and *Macaranga* species.

Professor Ulf Buentgen (Department of Geography)

Although highly valued as a culinary delicacy around the world, our understanding of the biological and ecological requirements of truffles (*Tuber spp*) is still limited, because of the species' hidden belowground lifecycle. Growing in symbiotic association with the fine roots of their plant partners, ectomycorrhizal truffles have never been successfully cultivated under laboratory conditions. In this interdisciplinary project, "Lucy" – a trained truffle dog that started its scientific career about ten years ago in Switzerland – has for the first time detected Burgundy truffles (*Tuber aestivum*) in the Botanic Garden. With a wide range of differently sized fruit bodies growing at various sites with diverse plant communities throughout most of the year, the Botanic Garden offers unique "living laboratory" conditions for illuminating the mysterious world of truffles. We will also compare the findings from Cambridge with data from similar observations in southern Germany and Switzerland where wild Burgundy truffles are growing under different climatic conditions.

External collaborations

Glen Powell (NIAB EMR)

Surveying the presence of brown marmorated stink bugs in urban sites with tree diversity. Sentinel pheromone traps are set out for these invasive bugs in trees and checked every week for signs of shield bugs.

Maximillian Tercel (Cardiff University)

Invasive ants: the ecology of invasive ants on an Indian Ocean island. My PhD investigates the ecology of invasive ants on an oceanic island by analysing their diet using molecular methods, which has never been investigated before. To build a reference collection for use in the field and to practice and trial my laboratory protocol, I am collecting as many invasive ant specimens across a range of species from tropical glasshouses in the UK as possible.

Dr Ed Hawkins (Department of Meteorology, University of Reading)

Weather data provided for climate science work.

Dr Julia Mackenzie (Department of Life Sciences, Anglia Ruskin University)

Blue tits and great tits breeding in the Cambridge University Botanic Garden have been studied for over 15 years. The project involves monitoring breeding birds and colour ringing of adults to identify breeding pairs. This year's work focused on the effect of urban noise on nest box selection and nest parasite load.

Dr Thomas Ings and Stephanie Maher (Anglia Ruskin University)

Studies of bee populations, foraging behaviour and ecology in CUBG. This year's work focused on bee parasite loads, the influence of bumblebees on honeybee foraging, and the prevalence of bee nest sites in different soils.

Claire Gay (Anglia Ruskin University)

Study of the ecology of fossorial solitary bees – particularly *Andrena fulva* and *A. cineraria*. The project focuses on assessing floral resource use by the bees, and on assessing how parasites interact with different densities of bees.

Abigail Chillingworth (Anglia Ruskin University)

Comparison of plastic pollution from the Hobson's Conduit and Cambridge University Botanic Garden.

Zachariah Wynne (University of Edinburgh, Institute of Infrastructure & Environment)

Vibration measurements were collected from the Rising Path to allow comparison of the true and theoretical dynamic structural behaviours. These measurements were made using a small, wireless accelerometer which is temporarily held in place using a magnet. Ambient vibration (footfall, wind) was relied on for exciting the Rising Path structure.

Dr Tim Pankhurst (Plantlife)

The Fen Orchid, *Liparis loeselii*, is the principal focus of a collaboration between Plantlife and CUBG, also involving RBG Kew, Norfolk Wildlife Trust, Suffolk Wildlife Trust, Butterfly Conservation and Natural England. We have been trying to understand better the reproductive strategy of this European protected species. This has involved a programme of seed-baiting to a) locate and identify the symbiotic fungus that it relies upon for germination, b) assess the suitability of potential reintroduction sites, and c) develop an *ex-situ* population, both for study and as stock for reintroduction. I am also working to develop *ex-situ* stock of *Artemisia campestris* (Sched 8, Critically Endangered) for study and introduction stock, as part of strategy to rebuild UK distribution of the plant and repopulate former sites, now returned to suitable condition.

Dr Peter Stroh (Botanical Society of the British Isles)

I am a Scientific Officer for the BSBI, based at Cory Lodge. In 2017 I co-authored '*Threatened Plants in Britain and Ireland*' (Walker et al., 2017), interpreting data collected for the BSBI's Threatened Plants Project. This was the most extensive sample-based survey of threatened plants ever undertaken in the British Isles, and focused on 50 of our least studied threatened plant species. The main aims of the project were to quantify the extent of recent losses, why they had taken place and gather information on their local abundance, habitats and ecological and management requirements.

Jonathan Shanklin (Cambridge Natural History Society)

The Cambridge Natural History Society continued its annual series of visits to the Garden to record the fungal population. A description of the conclusions from visits made since 2000 was published in *Nature in Cambridgeshire* (Shanklin & Tribe, 2017) and a one-page checklist of the more common species prepared for the use of visitors. Shanklin, J. & Tribe H. (2017) Fungi in the Cambridge University Botanic Garden. *Nature in Cambridgeshire* 59, 3-5.

Eliot Jan-Smith (John Innes Centre)

Exploration of the biosynthesis of plant triterpenoid saponins, with a goal towards production of industrially relevant molecules through synthetic biology techniques.

Vicky Kleanthous (CNAP, Department of Biology, University of York)

The High Value Chemicals from Plants (HVCfP) network will undertake the management of sequencing the genomes of a series of important British medicinal plants. The genomes are to be made openly available as a research resource to the Industrial Biotechnology community, for the study of medicinal compound metabolism and the potential development of pharmaceuticals. Plants to be sequenced include *Crataegus laevigata*.

Benjamin Lichman (University of York)

Lavandula angustifolia (English lavender) are commercially important shrubs from the mint family (Lamiaceae) prized for their essential oil, as they produce an abundance of fragrant monoterpene natural products. We will assess the genome sequences of multiple wild and cultivated accessions in order to understand how the genome impacts on oil composition.

Dr Olwen Grace (Royal Botanic Gardens, Kew)

The genus *Aloe* (Asphodelaceae) is one of the largest and most iconic succulent plant genera of the palaeotropical drylands. Aloes support substantial horticulture and medicinal plant industries but are gravely threatened by unsustainable wild harvesting. Once harvested, Aloe leaves are difficult to identify using morphology and traditional DNA barcodes, making trade regulation and conservation of threatened Aloe species problematic. This project will investigate the application of extended barcodes developed by probe-based sequence capture. These data will be used to infer an evolutionary framework with which to assess patterns in the properties of Aloe species.

Angelo Moerland (Royal Botanic Gardens, Kew)

Solar radiation affects plant internal temperature and short-term response of plants to mitigate heating varies. In this study we investigate how *Saxifraga* respond as they are often adapted to alpine habitats, unique in their relatively cool climate with intervals of strong solar radiation. Measurements are made of solar radiation, air and leaf temperature, among other plant traits and climatic variables, through a mostly non-destructive approach.

Phoebe Miles (Natural England, Shifting Sands Brecks Team)

Genetic relatedness of UK populations of the Endangered Field wormwood (*Artemisia campestris*) to inform reintroduction plans (part of the Shifting Sands project). We will carry out sequencing work to establish whether the populations found in the UK are genetically distinct.

Debi-Sara Wilkinson (Central Saint Martins)

This project is looking at pollinator preferences in the bee borders to inform practical research in examining the interdisciplinary nature of Art and Science.

Kalman Konyves (RHS Garden Wisley)

This project will develop ecological niche models for all *Narcissus* species and further develop the *Narcissus* phylogenetic tree through genomic data. Using the techniques of phyloclimatic modelling the project will bring together *Narcissus* phylogeny, niche preferences, and Cenozoic palaeoclimate models offering the opportunity to understand more general patterns of distribution in Mediterranean species. To root the climate models we will need sampling across all Amaryllidaceae.

Joel Chatain (Agence pour la Terre, Crouy-sur-Ourcq, France)

Library data about the native roses of Israel, accessing floras.

Joana Amaral (Instituto Politécnico de Bragança, Escola Superior de Tecnologia e Gestão, Bragança, Portugal)

Development of methodology for the authentication of laurel (*Laurus nobilis*). The aim is to develop methodologies, either based on volatile analysis or DNA analysis, for laurel authentication. *Umbellularia californica* will also be studied as it is used as a possible substitute of laurel leaves.

Nikos Krigas (Inst. of Plant Breeding & Genetic Resources, Balkan Botanic Garden of Kroussia Mts, Thessaloniki, Greece)

Studying Mediterranean biodiversity hot-spots and their potential for sustainable exploitation in three economic sectors (agro-alimentary, medicinal-cosmetic and ornamental-horticultural sectors). The MULTI-VAL-END project aims to: (i) Provide solid documentation for these plants in selected economic sectors; (ii) Explore and evaluate the existing potential of the targeted plants in selected economic sectors using multiple attributes and commonly agreed methodology; (iii) Identify basic opportunities, main barriers and steps needed to build and establish new product supply chains in the selected regions; (iv) Facilitate the sustainable exploitation of selected endemic plants by bridging gaps with targeted actions.

Ju Nam-Gung, (Gachon University, Seongnam-si, South Korea)

Amaryllidaceae, comprising 19 tribes and three subfamilies, are distributed extensively from Africa to America. Relationships among tribes and monophyly remain uncertain. In this project, we are investigating the phylogeny and biogeography of Amaryllidaceae using 3 kinds of DNA genomes.

Jung Joonhyung (Gachon University, Seongnam-si, South Korea)

Commelinaceae consist of approx. 750 species of monocotyledenous herbs in 41 genera. The goals of this study are to (1) develop a molecular phylogeny of Commelinaceae, with particular focus on within genus sampling; (2) compare molecular tree results with morphology data; (3) confirm accurate position of Commelinaceae with respect to other families using genomic data.

Olha Ishchenko (Yuriy Fedkovych Chernivtsi National University, Chernivtsi, Ukraine)

Phylogenetic studies using molecular markers.

Ewout Van Oost (Institute for Agriculture, Fisheries and Food Research, Melle, Belgium)

Development of bioassays to test frost tolerance and pathogen resistance of lavender species. In this project we are developing and optimising bioassays to screen for frost tolerance and pathogen resistance in different lavender species and cultivars.

Ha-Neul Chae (University of Freiburg, Germany)

Studying the diversity of hair patterns on plant surfaces to inform studies of the functionality of hairy artificial surfaces.

Professor Michael Donoghue and Miranda Sinnott-Armstrong (Yale University, USA)

Structural colour is common in birds, insects, leaves and flowers but poorly known in fruits. *Viburnum tinus*, a plant with metallic blue fruits, may have structural components to its blue colouration. In this project we are comparing the structural colour in *V. tinus* to other *Viburnum* fruits in order to assess how common structural colour is, and how widespread the traits underlying it are in *Viburnum*.

Rosie Earwaker (Cambridgeshire County Recorder, bees, wasps and ants)

Analysing hymenoptera and hoverfly populations and working on a small book on the bees of the Botanic Garden.

Kevin Hand (National Bat Monitoring Project)

The Garden was included in surveys as part of the National Bat Monitoring Project. I found good numbers of the 2 target species, pipistrelle and noctule, as in past years. Very few are found in the surrounding streets, so the Garden is important for feeding bats.

Rachel Fosberry (Oxford Archaeology East)

Seedheads supplied to create a botanic reference collection for archaeological research.

Chris Preston (Biological Records Centre)

Recording the presence of various naturally occurring species in the Garden.

Plant material supplied to other Gardens

CUBG supplied 317 accessions of plant material to 41 sources.

Botanischer Garten der Universität Bern, Switzerland

1 accession (Seed)

Bristol Botanic Garden, United Kingdom

3 accessions (Plants)

National Botanic Gardens Glasnevin, Dublin, Ireland

1 accession (Cuttings)

Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences, Menglun, Yunnan, China

1 accession (Seed)

Stellenbosch University Botanical Garden, South Africa

5 accessions (Cuttings)

FossilPlants, Caernarfon, United Kingdom

7 accessions (Plants)

Springfield Horticultural Society, Spalding, United Kingdom

1 accession (Fruit)

Sir Harold Hillier Gardens, Romsey, United Kingdom

2 accessions (Cuttings)

Jardin Botanique et Arboretum Henri Gaussen, Université Paul Sabatier, Toulouse, France

1 accession (Cuttings)

Oxford University Botanic Garden, United Kingdom

12 accessions (Plants)

Hortus Botanicus Amsterdam, Netherlands

51 accessions (Plants)

25 accessions (Seeds and Cuttings)

Madeira Botanical Garden, Funchal, Portugal

28 accessions (Cuttings), 1 accession (Seed)

Botanischer Garten Der Universität Bonn, Germany

3 accessions (Plants)

Hortus Botanicus Leiden, Netherlands

25 accessions (Plants)

Conservatoire et Jardin botaniques de la Ville de Genève, Chambesy-Genève, Switzerland

13 accessions (Seed)

Royal Botanic Gardens, Kew, Richmond, United Kingdom

3 accessions (Plants)

Bentworth Hall, Alton, England, United Kingdom

12 accessions (Plants)

Laboratoires de Biologie Végétale Yves Rocher, Jardin Botanique de La Gacilly, France

2 accessions (Seeds)

Botanical Garden of Tartu University, Tartu, Estonia

4 accessions (Seeds)

Giardino Botanico Alpino Rezia, Bormio, Italy

19 accessions (Seeds)

Botanic Garden Universitatis Comenianae, Bratislava, Slovakia

4 accessions (Seeds)

Polish Academy of Sciences Botanical Garden Center for Biological Diversity Conservation in Powsin, Warsaw, Poland

3 accessions (Seeds)

Botanischer Garten der Ruhr-Universität Bochum, Germany

3 accessions (Seeds)

Nantes Botanic Garden, France

1 accessions (Seeds)

Botanic Garden of the University of Latvia, Riga, Latvia

4 accessions (Seeds)

Chelsea Physic Garden, London, United Kingdom

3 accessions (Seeds)

Jardin des Plantes de l'Université de Montpellier, France

11 accessions (Seeds)

Botanischer Garten München-Nymphenburg, München, Germany

3 accessions (Seeds)

Botanischer Garten der Universität Leipzig, Germany

3 accessions (Seeds)

The Botanical Garden of Teplice, Czech Republic

6 accessions (Seeds)

Institute for Botany and Ecology, Centre for Ecological Research, Hungarian Academy of Sciences, Vácrátót, Hungary

2 accessions (Seeds)

Botanischer Garten Chemnitz, Germany

4 accessions (Seeds)

Šiauliai University Botanic Garden, Lithuania

2 accessions (Seeds)

Botanical Garden of Wrocław University, Wrocław, Poland

2 accessions (Seeds)

Palacký University Botanic Garden, Olomouc, Czech Republic

1 accessions (Seeds)

Eötvös Loránd University Botanic Garden, Budapest, Hungary

4 accessions (Seeds)

Volgograd Regional Botanical Garden, Volgograd, Russian Federation

3 accessions (Seeds)

King's College, Cambridge, United Kingdom

15 accessions (Cuttings)

RHS Wisley, Woking, United Kingdom

12 accessions (Plants)

Thomas Abeli, Roma Tre University, Department of Sciences, Rome, Italy

3 accessions (Seeds)

Prof Faith M Williams, Sunderland, England, United Kingdom

9 accessions (Cuttings)

Plant material supplied for teaching

The Garden supplied 53 plant accessions plus 100 seeds for teaching to 10 sources.

Plant material accessioned

During the period 1st October 2018 to 30th September 2019 the Garden accessioned 672 plants, of which 224 were of wild origin. In addition, we accessioned 117 seed lots and databased 541 herbarium specimens.

Publications by Botanic Garden staff

- HA Symington, BJ Glover (2019) SpotCard: an optical mark recognition tool to improve field data collection speed and accuracy. *Plant methods* 15 (1), 19.
- C Giorio, E Moyroud, BJ Glover, M Kalberer (2019) Direct Depolymerization Coupled to Liquid Extraction Surface Analysis-High-Resolution Mass Spectrometry for the Characterization of the Surface of Plant Tissues. *Analytical Chemistry* 91 (13), 8326-8333
- M Fernández-Mazuecos, J L Blanco-Pastor, A Juan, P Carnicero, A Forrest, M Alarcón, P Vargas, B J Glover (2019) Macroevolutionary dynamics of nectar spurs, a key evolutionary innovation. *New Phytologist* 222 (2), 1123-1138.
- CA Airoidi, J Ferria, BJ Glover (2019) The cellular and genetic basis of structural colour in plants. *Current opinion in plant biology* 47, 81-87.
- M Fernández-Mazuecos, PP Ferrer-Gallego, M Miguel, BJ Glover, L Sáez (2018) A synopsis of the Iberian clade of *Linaria* subsect. Versicolores (Antirrhineae, Plantaginaceae) based on integrative taxonomy. *Plant systematics and evolution* 304 (7), 871-884.
- B D Wilts, P J Rudall, E Moyroud, T Gregory, Y Ogawa, S Vignolini, U Steiner, BJ Glover (2018) Ultrastructure and optics of the prism-like petal epidermal cells of *Eschscholzia californica* (California poppy). *New Phytologist* 219 (3), 1124-1133.
- EJ Bailes, BJ Glover (2018) Intraspecific variation in the petal epidermal cell morphology of *Vicia faba* L. (Fabaceae). *Flora* 244, 29-36.
- B Glover (2018) *Current Biology* 28 (6), R248-R249.
- EJ Bailes, JG Patrick, BJ Glover (2018) An analysis of the energetic reward offered by field bean (*Vicia faba*) flowers: Nectar, pollen, and operative force. *Ecology and evolution* 8 (6), 3161-3171
- E Cullen, M Fernández-Mazuecos, BJ Glover (2018) Evolution of nectar spur length in a clade of *Linaria* reflects changes in cell division rather than in cell expansion. *Annals of botany* 122 (5), 801-809.
- J P Carr, R Donnelly, T Tungadi, A M Murphy, S Jiang, A Bravo-Cazar, J-Y Yoon, N J Cunliffe, B J Glover, C A Gilligan (2018) Viral manipulation of plant stress responses and host interactions with insects. *Advances in virus research* 102, 177-197.
- R Fattorini, BJ Glover (2018) Joining the dots. *Nature plants* 4 (1), 10.
- H ter Steege and 149 others, including A Cano (2019) Rarity of monodominance in hyperdiverse Amazonian forests. *Scientific Reports*, 9(1), 1–15. <https://doi.org/10.1038/s41598-019-50323-9>.
- O Loiseau, I Olivares, M Paris, M de La Harpe, A Weigand, D Koubinova, J Rolland, C D Bacon, H Balslev, F Borchsenius, A Cano, T LP Couvreur, C Delnatte, F Fardin, M Gayot, F Mejía, T Mota-Machado, M Perret, J Roncal, M J Sanin, F Stauffer, C Lexer, M Kessler, N Salamin (2019) Targeted Capture of Hundreds of Nuclear Genes Unravels Phylogenetic Relationships of the Diverse Neotropical Palm Tribe Geonomateae. *Frontiers in Plant Science*, 10. <https://doi.org/10.3389/fpls.2019.00864>.
- H Sheehan, T Feng, N Walker-Hale, S Lopez-Nieves, B Pucker, R Guo, W C Yim, R Badgami, A Timoneda, L Zhao, H Tiley, D Copetti, M J Sanderson, J C Cushman, M J Moore, S A Smith, S F Brockington (2019) Evolution of L-DOPA 4,5-dioxygenase activity allows for recurrent specialisation to betalain pigmentation in Caryophyllales. *New Phytologist*. <https://doi.org/10.1111/nph.16089>.
- A Timoneda, T Feng, H Sheehan, N Walker-Hale, B Pucker, S Lopez-Nieves, R Guo, S Brockington (2019) The evolution of betalain biosynthesis in Caryophyllales. *New Phytologist* 224 (1) 71-85.
- G Yao, J-Jun Jin, H-T Li, J-B Yang, V S Mandala, M Croley, R Mostow, N A Douglas, M W Chase, M JM Christenhusz, D E Soltis, P S Soltis, S A Smith, S F Brockington, M J Moore, T-S Yi, D-Z Li (2019) Plastid phylogenomic insights into the evolution of Caryophyllales. *Molecular phylogenetics and evolution* 134, 74-86.
- D F Morales-Briones, G Kadereit, D T Tefarikis, M Moore, S A Smith, S F Brockington, A Timoneda, W C Yim, J C Cushman, Y Yang (2019) Disentangling Sources of Gene Tree Discordance in Phylotranscriptomic Datasets: A Case Study from Amaranthaceae sl. *BioRxiv*, 794370.
- B Pucker, T Feng, S F Brockington (2019) Next generation sequencing to investigate genomic diversity in Caryophyllales. *BioRxiv*, 646133.
- B Pucker, S F Brockington (2018) Genome-wide analyses supported by RNA-Seq reveal non-canonical splice sites in plant genomes. *BMC genomics* 19 (1), 980 6.
- A Timoneda, H Sheehan, T Feng, S Lopez-Nieves, H A Maeda, S Brockington (2018) Redirecting Primary Metabolism to Boost Production of Tyrosine-Derived Specialised Metabolites in Planta. *Scientific reports* 8 (1), 17256.
- N Wang, Y Yang, M J Moore, S F Brockington, J F Walker, J W Brown, B Liang, T Feng, C Edwards, J Mikenas, J Olivieri, V Hutchison, A Timoneda, T Stoughton, R Puente, L C Majure, U Eggli, S A Smith (2018) Evolution of Portulacineae marked by gene tree conflict and gene family expansion associated with adaptation to harsh environments. *Molecular biology and evolution* 36 (1), 112-126.
- J F Walker, Y Yang, T Feng, A Timoneda, J Mikenas, V Hutchison, C Edwards, N Wang, S Ahluwalia, J Olivieri, N Walker-Hale, L C Majure, R Puente, G Kadereit, M Lauterbach, U Eggli, H Flores-Olvera, H Ochoterena, S F Brockington, M J Moore, S A Smith (2018) From cacti to carnivores: Improved phylotranscriptomic sampling and hierarchical homology inference provide further insight into the evolution of Caryophyllales. *American Journal of Botany* 105 (3), 446-462.
- R Mounce, M Rivers, S Sharrock, P Smith, S Brockington (2018) Comparing and contrasting threat assessments of plant species at the global and sub-global level. *Biodiversity and conservation* 27 (4), 907-930.
- S Cheng, M Melkonian, S A Smith, S Brockington, J M Archibald, P-M Delaux, F-W Li, B Melkonian, E V Mavrodiev, W Sun, Y Fu, H Yang, D E Soltis, S W Graham, P S Soltis, X Liu, X Xu, G Ka-Shu Wong (2018) 10KP: A phylodiverse genome sequencing plan. *Gigascience* 7 (3), giy013 41.
- Y Yang, M J Moore, S F Brockington, J Mikenas, J Olivieri, J F Walker, S A Smith (2018) Improved transcriptome sampling pinpoints 26 ancient and more recent polyploidy events in Caryophyllales, including two allopolyploidy events. *The New Phytologist* 217 (2), 855-870.
- S A Smith, J W Brown, Y Yang, R Bruenn, C P Drummond, S F Brockington, J F Walker, N Last, N A Douglas, M J Moore (2018) Disparity, diversity, and duplications in the Caryophyllales. *The New Phytologist* 217 (2), 836-854.

Funding

Financially it was a good year for the Garden with income increasing steadily to help meet rising costs, as we focused on building both the collections and our offering for visitors and researchers, nationally and internationally, with concerns about future funding on the horizon. 2018/19 has seen a positive and sustained increase in new and returning visitors coming to enjoy the Garden and join in with numerous exciting and vibrant events, tours and activities.

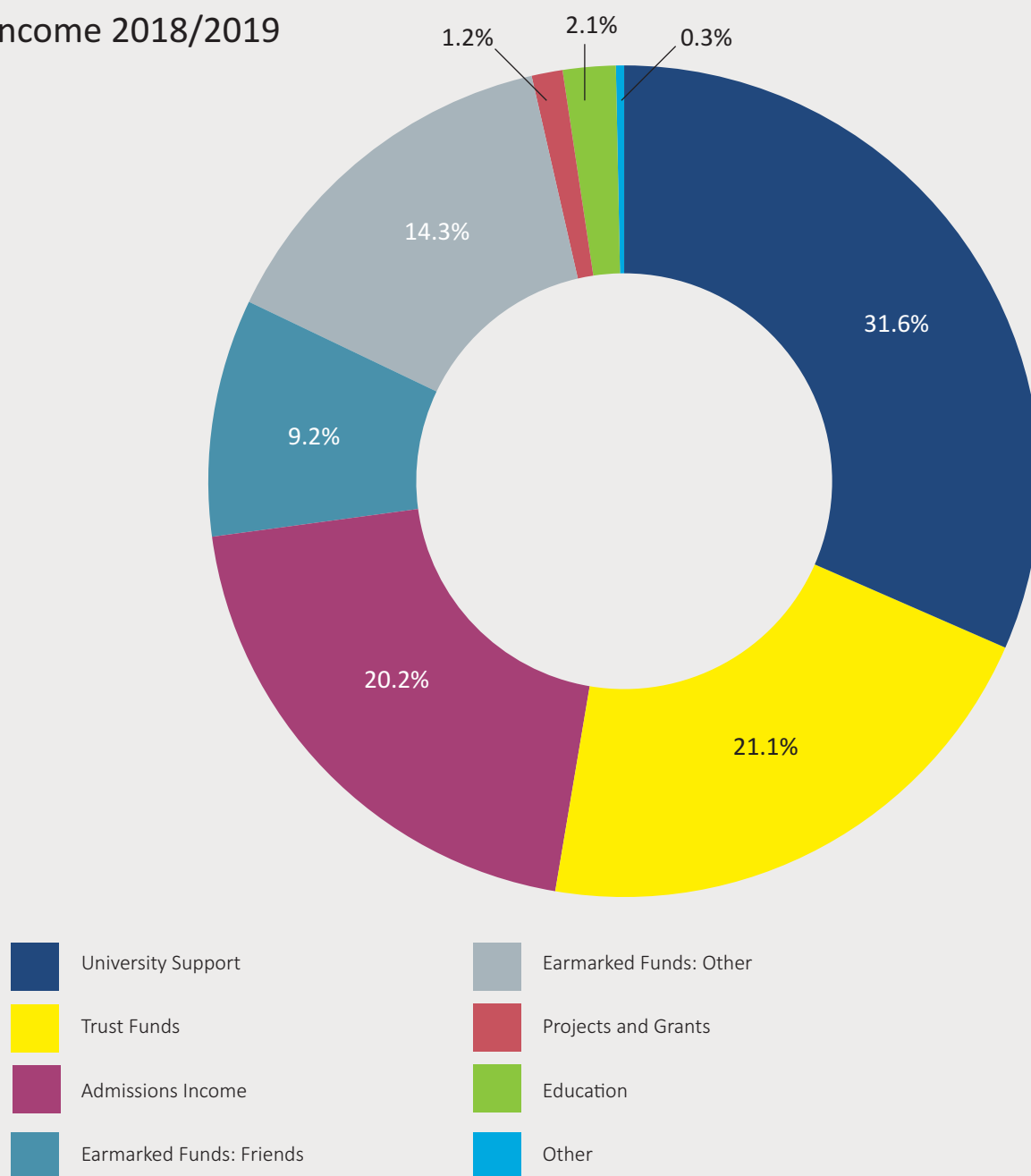
This year we welcomed the patronage of the new Henslow Circle, a new way for our supporters to become involved (see our website for details). We were also delighted to welcome many new and returning Friends and Corporate Friends, increasing much needed core revenue used directly to support both the infrastructure and development of the Garden.

With your support through Admission, Membership, Donations and Gift Aid, amongst many things, we have been able to fund education and engagement projects with local groups, schools and communities, enrich and enliven horticultural displays, make improvements to the Ecological Mound and Limestone Rock Garden, produce new trails and purchase a new telehandler along with various mowers, blowers and trimmers.

Your support and that of Research England has also helped to fund global plant and seed collecting trips, and we have been able to commit funding for improved plant cultivation facilities (important for species care and preservation) and a collections portal (collections database accessible to all).

Funding has also been committed for planned future capital projects.

Income 2018/2019



Income		2018-19	2017-18
Funding Source	Details	£k	£k
University Support	Pay and Non Pay	980.4	964.0
Trust Funds	The Cory Fund	636.2	589.1
	Other Trust Funds	19.4	17.9
	Gate takings (to include tours, guidebooks etc)	628.1	545.3
Admissions Income			
Earmarked Funds	Friends (to include income for events and activities)	286.9	245.5
	Other Specific Donations and Trade	445.2	469.7
Project Grants / Funding	See breakdown below	37.4	42.2
Education Courses, Donations and Events		63.8	56.0
Donations – General		6.8	4.8
Total Income		3,104.1*	2,934.4

Expenditure		2018-19	2017-18
Funding Source		£k	£k
University Support		981.1	880.0
Trust Funds		511.6	539.2
Admission and Tours		561.3	430.8
Earmarked Funds: Friends		237.7	219.8
Earmarked Funds: Other		315.2	245.6
Specific Project Grants / Funding – See breakdown below		198.8	422.0
Education Courses, Donations and Events		62.0	48.4
Donations – General		2.4	2.5
Total Expenditure		2,870.1	2,788.3
Total Income less Total Expenditure:		234.0	146.1
	Less: Earmarked funds held for future planned expenditure	-229.6	-143.8
	Funds reinvested by Cory and Trust Fund Managers	-1.5	-0.1
Funds remaining for discretionary use		2.9	2.2

Breakdown of Income (Project Grants / Funding)		2018-19	2017-18
		£k	£k
The Monument Trust		0.8	1.0
Perennial – Funding towards Trainee Programme		22.5	21.6
Audience and Learning / Strategic Audience Engagement Grant (UCM)		14.0	15.0
Finnis Scott Foundation		0.0	4.5
Interpretation (HEIF5 Funded)		0.1	0.1
Total		37.4	42.2

Breakdown of Expenditure (Specific Project Grants / Funding)		2018-19	2017-18
		£k	£k
The Monument Trust		160.7	377.4
Perennial – Funding towards Trainee Programme		23.2	19.8
Audience and Learning / Strategic Audience Engagement Grant (UCM)		11.9	12.0
Finnis Scott Foundation		0.0	4.5
Interpretation (HEIF5 Funded)		3.0	8.3
Total		198.8	422.0

Notes:

* Calculations include minor rounding differences.

Income figures include interest where funding has been held on deposit.

Syndicate and Cory Managers

Four meetings of the Botanic Garden Syndicate were held during the year under the Chairmanship of Dame Fiona Reynolds. Syndicate members were Professor Paul Brakefield, Professor David Coomes, Professor Nick Davies (to end 2018), Dr Laurie Friday, Dr Ian Furner, Mr Donald Hearn, Professor Nick Jardine, Professor Ottoline Leyser, Dr Mike Rands (to end 2018), Professor Alison Smith and Mr Tom Zille (student member to July 2019). New members who joined from 2019 include Mr Jon Drori (external), Professor Rebecca Kilner, Professor Bhaskar Vira and Mr Charles Li (student member from November 2019). The Secretary was the Garden's Director, Professor Beverley Glover. The Syndicate were pleased to meet the Botanic Garden staff before their July meeting.

The Cory Managers met four times during the year under the Chairmanship of Professor Alison Smith (Head of the Department of Plant Sciences). Managers for the year were Mr Michael Allen, Professor Howard Griffiths and Dr Alan Munro (until end 2018) with Mr Jonathan Appleton as the representative of the Director of Finance. New managers – Professor David Cebon and Dr Kate Maxwell – joined from the February 2019 meeting.

Botanic Garden Staff – October 2018 to September 2019

Director

- Professor Beverley Glover
- PA to Director: Jane Adams

Administration

- Administrator: Wendy Godfrey
- Finance Officer: Rachel Agnew
- Finance Administrators: Elaine Dalton and Anouska Arthur
- Assistant Administrators: Richenda Whitehead and Caty Cooke
- Learning Administrator: Emma Daintrey
- Friends Administrator: Sacha Watson

Curation

- Curator: Sam Brockington
- Assistant Curator: Ángela Cano
- Plant Records Officer: Pete Atkinson
- Plant Records Assistant: Mar Millan
- Cory Library Manager: Jenny Kirkham (to May 2019)

Development

- Head of Development and Communications: Anna Patterson Lee
- Marketing and Communications Co-ordinator: Helen Needham
- Monument Trust Project Manager: Juliet Day (to December 2018)

Estates

- Head of Estates and Operations Manager: Carl Tatterton
- Estates Manager: Phil Starling
- Estates Assistant: Kris Leitans

Horticulture

- Head of Horticulture: Sally Petitt
- Horticultural Learning Co-ordinator: Sandie Cain
- Alpine & Woodland Section: Supervisor – Paul Aston; Assistant – Simon Wallis
- Demonstration & Display: Supervisor- Pete Kerley; Assistant- David Austrin
- Experimental Area: Supervisor- Pete Michna; Assistant – Katie Martyr
- Glasshouse Section: Supervisor- Alex Summers; Assistant- Barbara Griffith
- Landscape & Machinery: Supervisor- Adrian Holmes; Assistant- Alistair Cochrane (to July 2019), Matthew Murawski (from August 2019)
- Systematics Section: Supervisor- John Kapor; Assistants – Julie Clos, Pete Wrapson, Penny Brice (Maternity cover to February 2019)
- Trees & Shrubs Section: Supervisor- Mark Crouch; Assistant – Robert Bradshaw (to November 2018), Alistair Godfrey (from February 2019)
- Weekend Horticultural Assistant: Marie Kårsjö (to January 2019), Alice Riches (from April 2019)

- Trainee Horticultural Technicians: From September 2018 to September 2019: Amy Spencer, Ciaran Bradshaw, Elizabeth Mansfield, Jessica Tyler, Louise Spencer, Matthew Payne, Wendy Watson (to March 2019). From September 2019: Patsy Bigley, Ella Buckley, Bethan Collerton, Jonathan Strauss, Leah Collins, Emily Passmore, Colin Stewart

Learning

- Head of Learning: Flis Plent (to March 2019)
- Learning Officer: Sally Lee
- Schools Learning Officer: Bronwen Richards
- HE and Research Impact Co-ordinator: Chantal Helm

Visitor Services

- Head of Visitor Services: Nicci Steele-Williams
- Deputy Head of Visitor Services & Team Leader (Tuesday-Thursday): Laura Welford
- Team Leader (Friday-Monday): David Evans
- Visitor Services Assistants: Andy Bryant, Amanda Wilkins, Lucinda Fudge, Sue Baker, James Oliver, Kathryn Villanueva (to May 2019), Anca Cojocar, John Neville (to May 2019), Vikas Shinde, Paul Johnson (from January 2019), Laura Middleton (from April 2019), Josephine Leng (from July 2019)
- Visitor Services Receptionist: Heloise Toop

Botanic Garden staff activities

The following members of staff have contributed to external organisations and groups in connection with their posts:

Professor Beverley Glover: fellow of Queens' College; trustee of the Royal Botanic Gardens Edinburgh; member of the Science Advisory Committee of the Royal Botanic Gardens Edinburgh; member of the Council of the European Society for Evolutionary Developmental Biology; member and vice-chair of the Council of Scientists of the Human Frontier Science Programme; member of the Botanical Society of America; member of the British Society for Developmental Biology; Fellow of the Linnean Society; member of the Council of the Linnean Society; patron of the Cambridgeshire Gardens Trust; vice-president of the Cambridgeshire Beekeepers' Association; member of the Advisory Board of New Phytologist; Strategic Advisor, 'Plants, People, Planet'; member of the Editorial Board of Current Opinion in Plant Biology; member of the Natural Environment Research Committee's Peer Review College; serves on the Royal Society's 150K grants panel; gave invited lectures at the Sainsbury Laboratory Students' Retreat and the Max Planck Institute for Plant Breeding Research (Cologne); gave invited talks at the HFSP awardees' meeting in Tsukuba (Japan) and the BGEN (Botanic Gardens Education Network) annual meeting in Cambridge.

Dr Sam Brockington: is an active member of the High Value Biorenewables Network; fellow of the Linnean Society; trustee of the Bedfordshire, Cambridgeshire, and Northamptonshire Wildlife Trust; participated as a member of an international external review panel for the Chinese Academy of Sciences Xishuangbanna Tropical Botanic Garden; gave lectures at the launch of the High Value Biorenewables Network, at the 4th Xishuangbanna International Symposium, at the 3rd Meeting of UK Plant Evolutionary Biologists at the Royal Botanic Gardens Kew; sat as a panel member at the Saw Trust Workshop at the Cambridge Science Festival; and participated in a two-week expedition to South Africa.

Dan Jenkins: member of the UK Plant Sciences Federation committee; serves on the Experimental Science Working Group of the Royal Society; continued as a member of the UK Biology Education Research Group and the Royal Society of Biology's Education Policy Advisory Group.

Dr Charlotte Carroll: member of the Careers Committee of the Royal Society of Biology.

Carl Tatterton continued as a trustee of the Hobson's Conduit Trust.

Helen Needham continued as a member of the Great Days Out In & Around Cambridge committee.

Sally Petitt continued as chair of the Merlin Trust (which provides travel awards to young horticulturalists) and as a member of the Borden Hill Garden Council. She also joined the RHS Qualifications Steering Group.

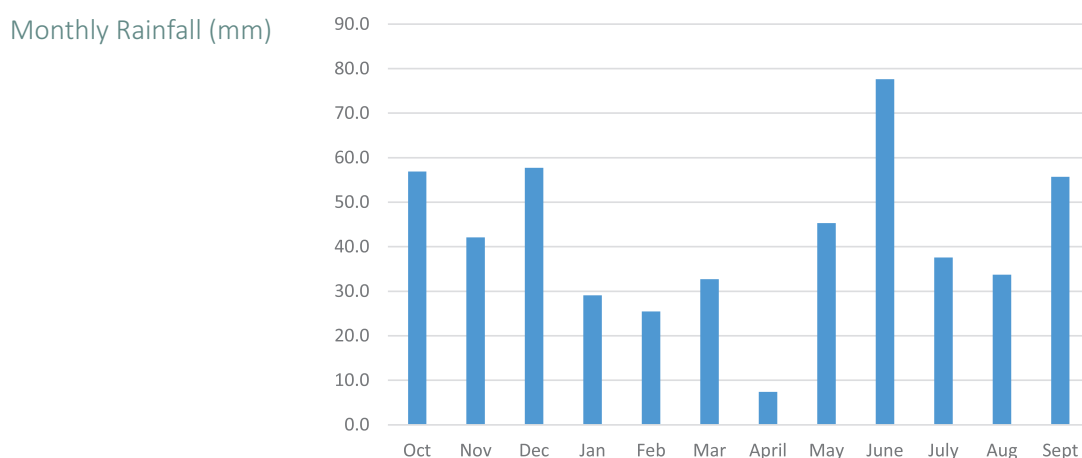
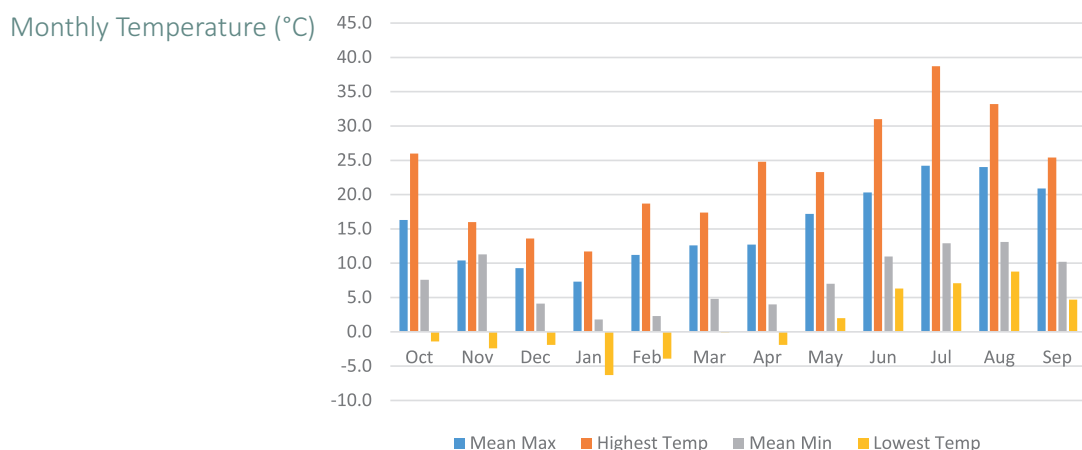
Alex Summers continued as a member of the RHS Tender Ornamental Plant Committee.

Simon Wallis continued as chair of the Saxifrage Society and as a member of the RHS Joint Rock Garden Plant Committee.

Chantal Helm joined Cambridge University's Ecological Advisory Panel; is the Chair of the Herts and Middlesex Bat Group; a Trustee of the Hertfordshire Natural History Society; external examiner in Environmental Science at Northampton University; member of the Chartered Institute of Ecology and Environmental Management; member of the Botanical Society of Britain and Ireland; member of the Mammal Society.

Weather

It was a relatively mild year, apart from January, with an extremely hot summer. The cold spells were short-lived, and overall we will remember the year for its warmth, and particularly for the highest recorded UK temperature in July.



Autumn started gently. October was mild (although the 13th reached 26°C) and mostly dry (although 33mm of rain was recorded on the 15th). The glasshouses were closed due to high winds on the 12th. November stayed mostly mild but with some colder spells. The only air frost was on the 22nd with a minimum of -2.4°C in the air. Rainfall was 42mm. December was surprisingly warm; although the lowest maximum temperature of the winter was on the 16th at 2.4°C. The days were often wet although the highest daily rainfall figure was only 9.9mm on the 15th, the monthly total was 57.7mm.

In the new year, the weather turned colder. In January half the nights gave air frosts and, with the temperature not exceeding -3.4°C, the 20th was clearly the coldest day of the winter. It was in fact the only day of the year when the temperature did not get above freezing at all. The month was mainly dry with a total of 29.1mm of rain, and there were two snow days. February was warmer again, reaching 18.7°C on the 27th, and dry with only 25.5mm of precipitation. March was also dry, with 32.7mm of rain. It was astonishingly mild with only one air frost (just!) on the 26th. On the 8th the glasshouse closed due to high winds.

April was another very dry and mild month, with only 7.4mm of rain and a few slight air frosts. On Saturday 27th the wind got to 40 knots in the garden. Damage was caused to the glasshouse and the Garden

was closed. May saw the the last slight ground frost of the winter on the 13th, at 0.9°C. Much of the month was dry but there was thunder and heavy rain (7.6mm) on the 8th and a welcome 17.2mm of rain on the 11th. In June the very warm weather began, with the temperature reaching 31°C on the 30th, due mainly to changes of air masses throughout the UK. The month was wetter than average with 77.6mm total rain. 19.2mm of this fell on the 11th.

July will be remembered for having the highest maximum temperature ever seen in the UK. The temperature reached 38.7°C on the 26th as recorded by Katie Martyr and verified by the National Climate Information Centre in Exeter. Several days saw the temperature over 30°C. Rainfall was below average at 37.6mm, mostly in small amounts. August continued dry with 33.7mm of rain, and mostly average temperatures, although there was a warm spell with temperatures over 30°C on the 25th and 26th. September started dry and windy with much of the Garden looking drought stressed. Useful amounts of rain began to fall from the 28th with 14.7mm on the 30th. The first ground frost was recorded on the night of the 18th with -1.6°C on the grass.

Katie Martyr, Experimental Assistant, Pete Michna, Experimental Supervisor & John Kapor, Systematics Supervisor

Thank You

Gifts, donations and support received in Annual Report period 1 October 2018 – 30 September 2019

We would like to extend our sincere thanks to all who have chosen to support the Garden whether financially or through the gift of time by volunteering. Volunteer hours totalled 5,597 for the period. Your contributions are hugely appreciated and greatly valued.

In Memory Gifts

- Thank you to all those who kindly donated in memory of Ms Philippa Hill – £1,070
- Donation from Mr R Bates, in memory of his mother, Mrs Margaret Cronin – £85

Individual Gifts and Donations

- Donation from Mr Jonathan Drori – £1,200
- Donation from Mr Henslow, for the Rising Path Project – £500
- We would like to thank the Henslow Circle, Friends and Corporate Friends, for their generous support and to those who continue to make significant gifts over and above the annual subscription.
- We are also delighted to receive visitors' donations, however small, and thank all visitors who choose to make donations to

support the work of the Garden.

- Special thanks also to those who have chosen to Gift Aid admissions, subscriptions, and donations. This makes an enormous difference and allows us to fund so much more.

Grants, Trust and Societies

- Perennial, the Gardeners' Royal Benevolent Society, for the employment of an additional horticultural trainee – £22,461
- Tansy Trust, Mr J Scott, for the Monument Trust Project – £1,000
- The John Innes Centre – £140

Corporate and other support

- BDB Pitmans for the Sounds Green Music Festival – £7,500

- Sainsbury Laboratory Cambridge University for the Festival of Plants – £1,000
- Department of Plant Sciences for the Festival of Plants – £1,000
- University of Cambridge Museums support for the CamLates Botanic Nights – £800
- University of Cambridge Museums, Strategic Audience Engagement Grant – £4,000
- University of Cambridge Museums- Audience & Learning Strategic Partnership Grant (Year 2 of funding – 1 April 2019 – 31 March 2020) – £10,000
- Gatsby Plant Science Education Programme grant awarded for the support of Plant Science Masterclass – £900

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... and thank you to everyone who visited the Garden

Visitor numbers through ticket offices (including Friends, groups and paying visitors) 337,910. Adult education course participants 661. Educational visit participants 9,515.



This publication is produced on sustainably sourced carbon captured materials, helping to plant new native woodland in the UK by the Woodland Trust.

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Front cover image: *Acer griseum* in the Winter Garden by Howard Rice
Back cover image by Howard Rice