Samara

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Special issue celebrating 20 years of the Millennium Seed Bank and Millennium Seed Bank Partnership

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Celebrating 20 years of the Millennium Seed Bank and Millennium Seed Bank Partnership

Photos left to right: MSB in 2000 – Andrew McRobb / Kenya – Rosemary Newton, RBG Kew / Armenia – RBG Kew / Peru – Daniel B. Montesinos Tubée / Asteraceae – RBG Kew / Vietnam – Rachael Davies, RBG Kew / Mozambique – Kate Gold, RBG Kew / Seed Conservation Techniques training course 2018 – RBG Kew / Burkina Faso – Lassina Sanou / Alpine Plant Conservation and Research Network collectors – Catherine Lambert / Oman – Aisyah Faruk, RBG Kew / Mexico – Wolfgang Stuppy, RBG Kew / Republic of Korea – Michel Van Slagen, RBG Kew / Colombia – Carolina Castellanos / Georgia – Tsira Mikatadze-Pantsulaia / Austria – Christian Berg / Australia – Luke Sweedman / Jordan – Khaled Abulaila / Chile – Kate Gold, RBG Kew / Madagascar – Wolfgang Stuppy, RBG Kew

Millennium Seed Bank Partnership 20th Anniversary

Royal Botanic Gardens Kew

Seeds of hope

PROFESSOR ALEXANDRE ANTONELLI (Director of Science, RBG Kew)

Photos: Magnus Bergström / Knut och Alice Wallenbergs Stiftelse / Tim Pearce

Hajji Suleimani from the Tanzania Forest Service and the University of Dar Es Salaam Afromontane Seed Collection team (retired), showing Professor Antonelli how to select and harvest seeds at Livingstone Mountain Ranges Plateau in Tanzania, popularly known as Kitulo National Park. This is the first National Park in tropical Africa established primarily to protect its flora.

When the Millennium Seed Bank first opened 20 years ago, it came as a response to the unsustainably high rates of natural habitat degradation and increasing threats to plant diversity. Since then, the environmental crisis has worsened, with scientists now estimating that 2 in 5 plant species are at risk of extinction (Nic Lughadha et al., 2020, Antonelli et al., 2020). Therefore, the relevance of the Millennium Seed Bank Partnership (MSBP) has never been greater. Its activities directly support the Global Strategy for Plant Conservation (Targets 8 and 9) and the UN Sustainable Development Goals (SDG 2, 13 and 15).

In this age of extinction, identifying and celebrating success is key. And by all metrics, the MSBP has been a huge success. Over the past two decades, the partnership (with over 260 partners in 97 countries and territories) has worked to bank a staggering 46,664 species of wild plants represented by over 228,000 collections. This represents some 16% of the bankable flora. The focus has been on globally threatened, narrowly distributed and useful species.

Beyond the direct protection of plants, important benefits have followed. MSBP seeds have been the foundation of prolific research programmes investigating seed biology and seed storage behaviour, informing best practice for collecting, processing and storing seeds. Training has also been at the heart of the MSBP mission and its success. Since 2015 alone, more than 1,000 people from 61 countries and territories have received training. This has enabled many people to contribute to the important work of seed banks that conserve their national and regional floras.

Moving forward, Kew is planning to further explore the potential of banked species for developing solutions to some of the greatest challenges facing humanity, such as climate change, food and energy security, global health and environmental degradation. Plants hold untapped resources that could transform our societies. By exploring the properties of wild species, including natural variation among populations, we wish to increase hypothesis-driven research that deploys a fraction of the seeds already gathered and to be collected.

While the number of seeds being deposited each year should remain at a similar or higher level, the selection of species will be guided to a larger extent by conservation, socio-environmental needs and research questions rather than only species counts. We also need to develop scalable solutions to conserve non-conventional seeds, such as those of many threatened tropical trees, which do not survive the traditional storage process. To achieve this, we need to carry out further research and expand the capacity for cryopreservation across the Partnership.

I want to express my deepest gratitude to all those individuals who have joined forces on this critical mission. Having made my first collection of seeds for the MSBP in Tanzania last year, I learned how much careful work is required to ensure a representative and high-quality sample. I cannot think of a more collaborative enterprise, where a single seed passes through the hands of so many dedicated people, and the care and expertise of each person in the chain is critical to final viability. The billions of seeds gathered by the Partnership are all seeds of hope.

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MSB partners 2000–2020

A message from Richard Deverell

(Director, RBG Kew)

It is with great pride that we celebrate the 20th anniversary of the Millennium Seed Bank Partnership (MSBP) and the 20th anniversary edition of *Samara.* The MSBP has been described as the largest and most important *ex situ* conservation project in the world. I agree with this, and I am delighted that RBG Kew plays a central role in this partnership.

Since 2000, it has achieved remarkable things. These include: banking 46,664 species; extensive research resulting in more than 550 scientific papers; the utilisation for research or restoration of c. 16,000 collections; and training more than 1,000 people from around the world. Public awareness of the importance of *ex situ* conservation has been enhanced, as has the capacity of the global plant conservation community. None of this would have happened without the remarkable partnership of over 260 organisations in 97 countries and territories.

This spirit of generosity and collaboration through sharing expertise, genetic resources and access to facilities is, I believe, the most remarkable achievement of the MSBP. The MSBP provides a brilliant case study of conservation success and a beacon of hope

given the urgent need for the global community to accelerate efforts to protect biodiversity. Once a seed is banked, we are a step closer to protecting it from extinction. May I thank very sincerely every individual, and every institution, that has contributed to this success over the past 20 years. I hope you are all proud of what has been achieved; I certainly am.

A message from Colin Clubbe

(Head of Conservation Science, RBG Kew)

What a milestone! Twenty years of effective global conservation, great collaboration, and an internationally successful and productive partnership. To sustain this over 20 years has taken a huge global effort, determination, and a clear aim – to stem biodiversity loss. My first direct involvement with the Millennium Seed Bank Partnership (MSBP) was in 2000 when I persuaded Kew's then UK co-ordinator, Steve Alton, to extend the UK collecting programme to the UK Overseas Territories.

Seed collecting requires dedication, meticulous planning, a bit of luck and a huge commitment from many people, sharing knowledge, experience and trust. It's been a privilege to be part of this great Partnership, and to see how effective it is across many of the world's conservation front lines.

I'm looking forward to enhancing this Partnership as we enter our next decade together. The world certainly needs it more than ever. Thank you all for your past and ongoing commitments to the MSBP.

We gave a joint presentation at a conference in Gibraltar which was enthusiastically received and kick-started our still active programme across the territories. The absolute urgency for seed banking was brought home to me very early in my career at Kew when we unsuccessfully fought to save the St Helena olive, *Nesiota elliptica*, from extinction. Sadly, invasive rats ate the last seeds before we could collect them, and the last plant died. Each time I see a new accession entering the MSB and partner seed banks I breathe a sigh of relief that one more species will not go the way of *Nesiota*.

Photo: Rebecca Cairns-Wick

Now extinct St Helena Olive, *Nesiota elliptica*.

Two decades of experience – partner anecdotes from the field

After 20 years of seed collecting by Millennium Seed Bank partners, a wealth of experiences and anecdotes have accumulated, demonstrating just how physically challenging plant conservation can be, but also revealing how organisations around the world face the many challenges of working towards their common goal: saving species. Here we share a handful of anecdotes submitted by members of the MSBP.

Salvation from an unseasonable blizzard

BLANKA RAVNJAK (University Botanic Gardens Ljubljana, Slovenia)

In the autumn of 2012, we collaborated at an MSBP workshop in Vienna, which included seed collecting in nearby hills. As we made our ascent the weather suddenly changed, and we were soon engulfed in a blizzard. Our only comfort was the thought of a warm cottage close by. We saw it, we were freezing, and we ran towards it, trying the door – it was locked! We had forgotten to check the opening hours. Luckily, half a kilometre away was another cottage where we had very welcome hot soup, and tea with a dash of rum.

Photo: Jože Bavcon

Workshop participants put into practice their seed-collecting skills on steep slopes not far from the Austrian capital, Vienna.

Hunting for Georgia's green gold

DAVID KIKODZE (Institute of Botany, Ilia State University, Georgia)

When seed collecting, we are frequently approached by farmers who can't believe we're collecting seeds. Sometimes we jokingly tell them we are searching for gold. Once, in a village in West Georgia, we saw a man ploughing – as usual, we told him we were searching for gold. Looking confused, he said he'd never heard about gold in the area, although he knew where to find endemic plant species. The man turned out to be a botanist from Kutaisi University, and he recognized us as his colleagues!

Photo: David Kikodze

Manana Khutsishvili, Head of National Herbarium of Georgia, Institute of Botany (right) and Tamar Kurdadze, Head of Bakuriani Alpine Botanical Garden, Institute of Botany, search for *Aegilops tauschii* as part of the Crop Wild Relatives Project in the Kakheti region of Georgia in June 2015.

By any means necessary on Indonesia's tallest volcano

DIAN LATIFAH (Bogor Botanic Gardens, Indonesian Institute of Sciences) & ANGGUN RATNA GUMILANG (Cibodas Botanic Gardens, Indonesian Institute of Sciences)

A memorable field trip was with colleagues to Lake Belibis at the foot of Mount Kerinci, Indonesia's highest active volcano. Surrounded by tropical forest, the area is very wet. We were riding motorcycles, known locally as 'ojeg' (meaning old motor). Unfortunately, the brakes were not good, so riding along the muddy tracks was very scary. Plus, the area by the lake is infested with leeches, and is very spooky due to the mist, so we collected the seeds as quickly as we could before it got dark.

Photo: Dian Latifah

Harto controls the motorbike up the slopes of Mt Labuh, Indonesia, and was heard to say that his smile gave his passenger, Agus Rustandi, confidence.

A rare case of 'always looking up disease' in Ghana

JOSEPH MIREKU ASOMANING (CSIR-FORIG National Tree Seed Centre, Ghana)

Most of the collections we have in Ghana come from tall trees. Thus, we have to look up into the trees to observe flowering, fruiting and maturity. The tendency to look up has become so strong in me that I am tempted to look up whenever I am outside. While with work colleagues, as they were chatting and laughing, I was looking into the trees. Amazed by my behaviour they asked for an explanation. My answer – I had caught a disease called 'always looking up'. My colleagues had a lot of sympathy for me, but I told them I enjoy the disease for two reasons: the seeds are being collected and conserved, plus I'll be the first to see Jesus when he comes back the second time.

Photo: Neville Walsh

The lure of Victoria's rare fire-followers

NEVILLE WALSH (Royal Botanic Gardens, Victoria, Australia)

On a warm sunny day in October 2007 the Victorian Conservation Seedbank team were out in north-west Victoria looking for the rare fire-follower Yellow Swainson-pea *(Swainsona pyrophila)*. After searching for some time through burnt mallee, I managed to find a patch, but as we began collecting, I realised I'd squashed one underfoot! Thankfully, *S. pyrophila* is an annual, so not too much damage done, but a lesson in the need to be forever watchful around rare plants.

Yellow Swainson-pea *(Swainsona pyrophila)*.

Walkie-talkies and snakes in Colombia

JENIFFER VIVIANA DÍAZ RODRIGUEZ (Alexander von Humboldt Biological Resources Research Institute)

Whilst sampling in Quinchas, a pretty region of Boyacá, I was with a colleague who had a walkie-talkie. Suddenly we spotted a large non-venomous boa constrictor; we were surprised, but took lots of photos. On finishing seed collecting, we returned to where we had seen the boa. My colleague was in front of me as we searched for the snake, but at that moment the expedition leader called us on the walkie-talkie and made us jump out of our skins. We laughed very much.

Photo: Jeniffer Viviana Díaz Rodríguez

The boa constrictor snake that Jeniffer encountered while out seed collecting.

Getting lost in translation in Nigeria

ALEXANDER GIWA (National Centre for Genetic Resources and Biotechnology, Ibadan, Nigeria)

Seed collecting in Nigeria throws up multiple challenges, as demonstrated on a 2017 trip to the Mambilla plateau in Taraba state. At the top of the list of challenges is difficult terrain – brought home to us on this trip when driving up steep mountain slopes and having to use canoes to reach rice crop wild relatives. Number two on the list of challenges is language barriers, with the group encountering several different tribal languages amongst the Mambillan people. And three is the task of building trust with local communities.

Photo: NACGRAB

A seasonally flooded road on the way to Dorofi, on the Mambilla Plateau close to the border with Cameroon.

Photo: Roberta Hope

Dr Kate Hardwick, Millennium Seed Bank Partnership Coordinator for Asia (centre), provides a demonstration of post-harvest handling to participants of a seed conservation techniques course in Chiang Mai, Thailand in 2015, including Dr Pramote Triboun (mauve shirt).

Forging seed conservation partnerships through culture, language and food

PRAMOTE TRIBOUN (National Biobank of Thailand, National Science and Technology Development Agency, Thailand)

One particularly special occasion in July 2018 was when Dr Kate Hardwick gave a presentation about seed conservation in Thailand and globally in the presence of HRH Princess Sirindhorn at the Lam Takhong Research Station. This coincided with the opening of new glasshouses at Lam Takhong. Dr Hardwick has participated in many activities in Thailand, plus she's a very good Thai speaker, so has been able to exchange ideas about the MSBP and her experiences in Thailand. We always have fun, particularly when introducing visitors to Thai food, culture and language.

Photo: Ziad Tahabsom

A wild Arabian fox spotted in Shoubak district, Jordan, on the way to Petra in 2005.

Arabian foxes and crop wild relatives

ZIAD TAHABSOM (National Agricultural Research Center, Jordan)

It was a hot summer's evening in June 2005, and we were returning from a long day in the desert searching for plants. We were exhausted but still had about 40 km to our hotel in the ancient city of Petra. As we began to feel the cool evening breeze we passed a canal blooming with wild plants, so we stopped to have a look, hoping to find new species. We managed to collect six species when we spotted an Arabian fox lying on cool rocks. We remained there until after dark collecting seeds and preparing herbarium samples and ultimately reached our hotel late in the evening.

Grazing in Finland's Åland

MARI MIRANTO (Finnish Museum of Natural History LUOMUS, University of Helsinki, Finland)

Maybe the most memorable seed-collecting trip was to the islands of Åland between Finland and Sweden in 2016. Åland hosts a wide array of threatened species occurring on the northern border of their distribution. The islands have plenty of traditional rural biotypes, and it was absolutely charming to collect seeds among grazing sheep and cows.

Photo: Mikael Lindholm

Biologist Mari Miranto collects *Sorbus hybrida* berries in Åland, Finland, as a part of the Global Tree Seed Bank Programme. *Sorbus hybrida* is endemic to Finland, Sweden, Norway and Denmark.

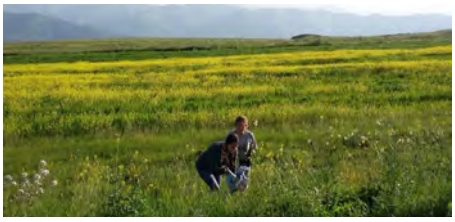


Photo: Sona Galstyan

Narine Hayrapetyan (left) and Anush Nersesyan collect seeds in Syunik province, Armenia, in June 2018.

Melting cars in Armenia

ANUSH NERSESYAN (Seed Bank of Armenian Flora)

On one occasion, seed collecting was planned in the Vayots Dzor region. Summer, open space, grasses and a very hot day. It was hard to work in such warm conditions, but we enjoyed our work. Suddenly the rear-view mirror in the car fell off because the glue had melted. We were silent for a few seconds, but then everyone burst out laughing. It's nice to realize that a human is more durable than a car, and it's particularly wonderful when you're doing the best job in the world.

A long day with Australia's itchy palm

TOM NORTH (Australian National Botanic Gardens, Australia)

The funniest collecting incident, in hindsight, was collecting *Arenga listeri,* a monocarpic palm that is endemic to Christmas Island. I was with a team of locals and we all jumped in to collect the fruits, except for one of the team. After a couple of minutes, she spoke up and said, 'Ah, I remember now, this is the itchy palm!' Sure enough, it was incredibly itchy, and not in a good way. The itch lasted for the rest of the day – and it was a long day.

Photo: Tom North

Arenga listeri fruits from Christmas Island.

MSBP collections – saving seeds to save the planet

Over the past 20 years, the Collections team at the MSB have seen many changes to *ex situ* seed conservation. We asked Nicola, Janet, Vicky, Frances, Ania, Udayangani and Rachael, who have collectively accumulated 124 years' work at the MSB, to share some of their memories.

What changes have you seen in the way collections are handled?

Janet: MSBP partners have shown us some novel seed-cleaning methods that we use now and share with other partners. Also, recognising in an increasingly changing world that as a partnership we can still drive conservation and seed-banking forward despite the challenges we face. Increasing use of technology has made the world smaller, which helps with communication. I think COVID-19 has brought us all closer in this way.

Vicky: The inception of the tree seed project meant an influx of wet fruits in the autumn. I really enjoyed getting my hands mucky squashing them, and the fantastic smell of fermenting fruit in the lab.

Nicola: There have been lots of changes – we now use tetrazolium testing to check viability of orchid seeds.

Frances: When I started, we used an x-ray machine with developing film. The introduction of the digital x-ray machine made a big difference to our processing speed!

Ania: With Vicky, I helped to develop Standard Operating Procedures for banking and cryopreserving fern spores and orchid seeds.

Vicky and Frances at the 2013 Seed Swap.

Rachael working with banana seeds in Vietnam.

Udayangani: Standardising seed germination data structure and integrating biostatistics to identify collections losing their viability. Introducing measures to identify short-lived and conservation priority taxa. Change in the expected seed germination standard from ≥75% to ≥85%.

Rachael: Greater use of viability data alongside germination data to assess the potential viability of collections. With many collections showing complex dormancy and germination requirements, we are not always able to crack these on the first round of germination tests. Working with limited seeds and staff time, use of viability data in the absence of germination data allows improved efficiency. We now duplicate more than 7,000 collections to cryo-storage, including some of our rarest and most short-lived species.

What is your best memory of working at the MSB?

Janet: Probably my early seed-collecting trips with partners in Rwanda, Burundi, Zaire and Botswana. Positives were seeing mountain gorillas, camping in the Kalahari, travelling for days and collecting in so many varied habitats. Less positive were the forest wasps, bed bugs and a flagellate! It was an adventure I will never forget.

Vicky: When I had to dress up as a pea pod for the 2013 seed swap!

Nicola: Seed-collecting and training trips to Kenya and Canada.

Frances: A seed-collecting trip to Italy in 2012.

Ania: Opening the Boyacá Seed Bank in Colombia and filming with Sir David Attenborough.

Udayangani: The day I noted that we exceeded the 10% target before the deadline. As the Seed Bank Data Resources Manager, I was in the privileged position to be the first person to see it. It was announced through the building tannoy. We all clapped with joy. It was a truly memorable day.

Rachael: Perhaps meeting some of my childhood inspirations like Jane Goodall. For me, visiting New Zealand was also particularly special as I lived there for a few years.

Any final comments?

Janet: The best thing about the partnership is the people; there are so many amazing people we have met, trained, been trained by and worked with.

Vicky: I feel privileged to work at the MSB – no two days are the same and I feel lucky to work with such a fabulous bunch of people for such an important cause. It's so amazing that I get up each day knowing that I'm doing my bit to save our planet and our biodiversity.

Frances: Perhaps it's unlikely I'll be here in 20 years' time, but I would love to continue working at the MSB saving the world's flora!

Udayangani: We must continue saving biodiversity through seed banking.

Rachael: I am proud to work for such an amazing organisation. I really feel like I am helping to save the planet.

Ania alongside frailejones *(genus Espeletia).*

Photos: RBG Kew / Rachael Davies / Alice Di Sacco

Significant species conserved across the globe

Every seed collection is important, bringing a wealth of information on the species (e.g. habitat, phenology and distribution) as well as the living seed itself. Below are just a few of the important plant species conserved by MSB partners in the last ten years.

Photo: Adelaide Clemente

Centaurea amblensis

Contributed by: Adelaide Clemente, Faculdade de Ciências da Universidade de Lisboa, Portugal

Endangered in Portugal. Seeds were collected in 2017, where new populations were recorded.

Photo: Michael Way

Caiophora deserticola

Contributed by: National Institute of Health, Peru

Local name 'Kisa'. This plant from the central Andes has powerful stinging hairs on the leaves and flowers and is locally used in medicinal infusions, such as for kidney disease, colds and fevers.

Photo: Herta Kolberg

Gladiolus diluvialis

Contributed by: Herta Kolberg, Namibia

An endemic and threatened species (EN) found in southern Namibia. This geophyte grows on extremely saline soil in seepage areas on the banks of an ephemeral river.

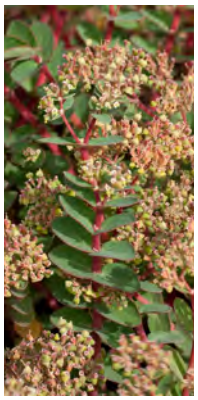
Photo: ukwildflowers.com

Teucrium chamaedrys

Contributed by: Steph Miles, RBG Kew

Listed as Critically Endangered in the UK, where only one population is thought to be native. A small number of seeds were collected in 2017 and *ex situ* plants have been established in the nursery at Wakehurst.

Photo: Tom Heller, RBG Kew



Euphorbia origanoides

Contributed by: Ascension Island Government, Conservation and Fisheries Directorate

A perennial dwarf shrub endemic to Ascension Island where it is Critically Endangered. Major threats are from climate change and introduced pests.

Photo: Iain Darbyshire

Daniellia alsteeniana

Contributed by: Mpande Sichamba, Ministry of Lands and Natural Resources, Zambia

A nationally endangered, rare tree species in Zambia, restricted to Northern and Luapula provinces. Threatened by over-exploitation, agriculture and settlement expansion.

Photo: Kezang Tobgay

Sorbus karchungii

Contributed by: Kezang Tobgay, National Biodiversity Centre, Ministry of Agriculture and Forests, Bhutan

Thought to be endemic to Bhutan and found in cool broad-leaved and mixed conifer forest. The leaves of this species are commonly used in making Bhutanese butter tea.

Photo: Jill Wagner

Erythrina sandwicensis

Contributed by: Jill Wagner, Hawaii Island Seed Bank, USA

A threatened (VU) and endemic Hawaiian tree that has very light and buoyant wood. It floats in water and was used by Hawaiians to make surfboards.

Photo: Gibson Sosanika

Papuodendron lepidotum

Contributed by: Gibson Sosanika, New Guinea Binatang Research Centre, Papua New Guinea

An endemic tree found in Papua New Guinea.

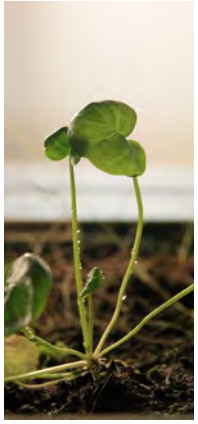
Photo: Dan Duval

Eucalyptus alatissima

Contributed by: Dan Duval, Botanic Gardens & State Herbarium, South Australia

A multi-stemmed mallee rare and endemic to the Great Victoria Desert region in Western and South Australia.

Photo: Katarzyna Topolska



Cochlearia polonica

Contributed by: Kostrzyca Forest Gene Bank, Poland

An endemic species, now extinct in the wild in Poland (EW) due to land drainage. Seeds were collected from one of the artificial sites, created in the 1970s by transplanting individuals from a natural population.

2010–2020 timeline

A selection of highlights, notable collections and successes across the MSBP from 2010 to 2020.

2010 The Australian Seed Bank Partnership was established. It has seen ten years as a formal partnership with more than 1,300 native species secured through collaborative projects, including more than 1,000 species new to the MSB. The Partnership has supported seed conservation training and development of critical germplasm guidelines, contributed to government policy on threatened species and bushfire recovery, and reported on progress towards the Global Strategy for Plant Conservation.

2010 During the 15 years of the joint Lebanese Agricultural Research Institute (LARI) and MSB project concluding in 2010, 1,376 seed collections of 877 species from 82 plant families were collected and banked at LARI. In February 2020, some were duplicated at the Svalbard Seed Vault, Norway. This represents 31.4% of Lebanon's flora now conserved *ex situ* in seed banks.

2011 The UK Native Seed Hub was launched, aiming to enhance the resilience and coherence of the UK's ecological network by increasing the quality, quantity and diversity of native plants and seeds available for conservation and habitat restoration. Since then we have provided scientific expertise and research, technical advice, seed or native plants to 70 conservation projects, working with 41 partner or client organisations.

Photo: RBG Kew

Campanula rotundifolia in the Seed Hub production site.

2011 In collaboration with the Global Crop Diversity Trust, the Adapting Agriculture to Climate Change (Crop Wild Relatives) project launched. Twenty-five institutions across 24 countries were involved, making 4,644 seed collections from 26 genera and 371 taxa. This equated to over 12.8 million seeds.

Photo: A. Nersesyan

Aegilops neglecta, a CWR species.

2012 A European Native Seed Conservation Network (ENSCONET) Consortium joint seed-collecting trip took place in north-west Hungary. More than 15 seed collections were made, alongside sharing of experiences and knowledge within the Consortium. By 2017, collectively the ENSCONET Consortium had conserved 62.7% of European threatened species in seed banks.

Photo: T. Gil

Cirsium oleraceum, one of the species collected in Hungary.

2013 The Institute of Biotechnology and the Institute of Biology of the Kyrgyz National Academy of Sciences banked seeds of *Incarvillea olgae* (a beautiful sub-shrub with rose pink flowers) for the first time. *Incarvillea* is a highly endangered genus from Central Asia (Chen et al., 2010) and *I. olgae* is one of the top 35 most endangered plant species in Kyrgyzstan (USAID Biodiversity Assessment, 2001).

Photo: Georgii Lazkov

Incarvillea olgae.

2013 As part of the Kew Madagascar Conservation Centre (KMCC) Orchid Conservation Project, KMCC along with Kew's Conservation Biotechnology Unit undertook in vitro propagation experiments on the Endangered lithophyte orchid *Angraecum protensum* using seed and their associated fungi collected from the Itremo Massif Protected Area. Ten plants resulting from these experiments were reintroduced into the wild at the Itremo Massif to strengthen the population.

Photo: Stuart Cable

Angraecum protensum.

2014 The 'Ensuring the survival of endangered plants in the Mediterranean' project completed its first three-year phase. Seven conservation organisations collaborated to collect seed from over 900 endangered taxa across six Mediterranean islands (Sicily, Sardinia, Cyprus, Corsica, Crete and Mallorca). Through this project *Hypericum aegypticum* subsp. *webbii* was rediscovered in Crete having previously been thought extinct.

2015 From 2005 to 2015 the Department of Plant Conservation of the National Botanic Garden, Georgia, banked the seeds of over 33% of the country's flora. This included 252 species endemic to the Caucasus and 145 endemic to Georgia. By 2018, over 41% of Georgia's flora had been banked, including 151 endemics to Georgia, summarised in Mikatadze-Panstulaia et al., (2019) *European Journal of Sustainable Development*, 8: 37–42.

2015 The UK Flora Project launched, filling gaps and adding depth to our UK collections. Funded by the Esmée Fairbairn Foundation and working with a range of organisations, 892 collections were made, a third of which are nationally threatened, including 42 species new to the UK collections. The project delivered seed collection training and developed new germination and propagation protocols for priority species.

Photo: RBG Kew

Collecting *Veronica triphyllos*, a critically endangered arable archaeophtye.

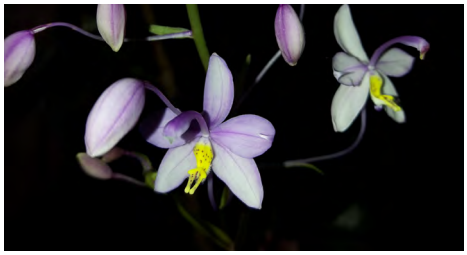
Photo: Greuk Pakkad

2016 Bangkok Forest Herbarium and Chiang Mai University's Forest Restoration Research Unit made Thailand's first ever seed bank collections. Overall, 61 tree species were collected, including four that are rare and endangered and six framework species, highly suitable for forest restoration. Framework species perform well in degraded conditions, shade out weeds, bear fruit quickly (attracting seed-dispersing wildlife) and are relatively easy to propagate.

One of the framework species collected, *Balakata baccata.*

2016 Whilst collecting tree seeds, staff from the National Biodiversity Centre, Ministry of Agriculture and Forests, Bhutan, found a strikingly attractive *Spathoglottis* species on limestone outcrops. This was later confirmed as a new species, *Spathoglottis jetsuniae.*

Photo: Kezang Tobgay



Spathoglottis jetsuniae.

2017 Ente di Gestione delle Aree Protette delle Alpi Marittime began germination studies on *Ptychotis saxifraga*, a species important not only for its rarity but also because it is intimately linked to the survival of a heavily threatened butterfly, *Papilio alexanor.* The species' ability to build a soil seed bank was evaluated, along with verifying the viability of the seeds stored in the bank and trying different germination tests to find a suitable protocol for the species' regeneration.

Photo: V. Carasso

Longitudinal section of the achene of *P. saxifraga.* In the circle the rudimentary embryo immersed in the endosperm is faintly visible.

2017 A joint Herbier National de Guinée and RBG Kew expedition to the Kounounkan Massif, Guinea, made a seed collection of then-undescribed *Gladiolus mariae* after finding a second population of the species first found in 2016. Since then, a third population has been found and in 2019 the species was officially described.

Photo: Xander van der Burgt

Gladiolus mariae.

2018 The Facultad de Estudios Superiores Iztacala, Universidad Nacional Autónoma de México, in collaboration with RBG Kew, accelerated work on cataloguing and databasing the native tree species of Mexico, uniting current knowledge on distribution, traditional use and conservation status as a resource for future conservation, forestry and livelihood programmes. They concluded Mexico has at least 2,885 native tree species, of which c. 44% are endemic and c. 33% have had a conservation assessment (Téllez et al., 2020. http://doi.org/10.7717/peerj.9898).

Photo: M. Way

Hesperocyparis arizonica, Sonora State, Mexico.

2018 The last year of the Alpine Plant Conservation and Research Network (APC & RN) project saw a joint collecting trip for project partners in the Swiss Alps. This was the occasion for discussions on the flora of the different regions of the Alps, their particularities and their conservation. Representatives from four countries attended, making 14 seed collections, as well as a film about the project. Over the APC & RN project, 685 seed collections of 595 species were made.

Photo: Jon Spaull

The Alpine Plant Conservation and Research Network group, Mouvoisin.

2019 North Carolina Botanical Garden established a Native Plant Materials Development programme with a gift from an anonymous donor to provide whole plants and bulk seed for use in ecosystem restoration. Since inception, 1.8 million seeds have been collected from 120 species, 50 taxa are now growing in seed increase plots for targeted restoration projects, and over 1,500 plugs of *Schizachyrium littorale* have been planted to help populations of an endemic butterfly.

Photo: Melissa McGaw / NC Wildlife Resources Commission

Planting *Schizachyrum littorale.*

2020 The South African Millennium Seed Bank Partnership, together with Custodians of Endangered Wild Flowers, targeted seeds of *Merremia malvifolia* (Critically Endangered Presumed Extinct). This plant was rediscovered in 2015 and the status will be updated to Critically Endangered as now one known population exists, but its locality is still under threat. The species was successfully collected by bagging of the seedheads prior to dispersal.

Photo: Nomama Mei

Covering fruit of *Merremia malvifolia* to capture seeds.

2020 MSB 20th anniversary! Over 260 organisations across 97 countries and territories have collaborated to conserve over 228,700 collections *ex situ*. We will be celebrating our joint achievements with a global 24-hour social media party on 19 November across Twitter and Facebook #MSBP20.

Research at the MSB

Research highlights from the Diversity and Livelihoods team at the MSB

The Diversity and Livelihoods team (Natural Capital and Plant Health Department) conducts research on the beneficial impact of plants and fungal diversity on human lives, by exploring the potential of this diversity and using seed collections to address fundamental global issues, such as food security, and helping toimprove people's livelihoods.

The Useful Plants Project (2007–2019) worked with local communities in Botswana, Kenya, Mali, South Africa and Mexico to build the capacity of local communities to successfully conserve and use native plants. Seed collections of 357 species were safeguarded *ex situ*, propagated and planted in rural communities and schools. Sustainable income-generating opportunities were created for 59 useful plants or their products locally, schools' programmes on useful plants were established and 33 undergraduate/postgraduate students were supervised. One major research output was the publication of the book *Wild Plants for a Sustainable Future: 110 Multipurpose Species*.

As part of the African Union's Great Green Wall (GGW) initiative and in collaboration with the Food and Agriculture Organization of the United Nations and country partners, Kew's pilot GGW project (2013–2020) developed a model based on the use of indigenous species to help inform larger restoration projects in the Sahara and Sahel region. Over 100 village technicians were trained in seed conservation and plant propagation techniques and the seeds of 55 species were propagated. The plants were used to restore 2,235 hectares of degraded land and sustainable income-generating opportunities were created based on 59 useful plant species to support people's livelihoods.

In 2016, the Kew-Colombia Bio Programme launched, including ten funded projects. Although half the projects are still in progress, highlights to date include collaborations with more than 50 researchers from the UK and Colombia, partnerships with 25 Colombian institutions and, amongst other scientific publications, three books/booklets and two online portals (colplanta.org with 26,079 species profiles and usefulplantsofboyaca.org with 1,420 species profiles).

Through the Global Tree Seed Bank Programme, two conservation projects were established in 2015 in the Dominican Republic and Mexico. In the Dominican Republic, the aims were to preserve the threatened forests of Hispaniola by conserving seeds of native trees and building regional capacity in seed conservation. The project supported our collaborator, the Jardín Botánico Nacional in Santo Domingo, to become a key player in the restoration and recovery of natural, urban and semi-urban areas of the island through the establishment of a new seed bank in 2017 and conservation and propagation activities. The project enhanced research on seed desiccation tolerance of native trees and ensured the conservation and propagation of 250 tree species. Similarly, the project in Mexico helped implement a science-based conservation programme to support reforestation activities by working with our long-standing collaborators from the Facultad de Estudios Superiores Iztacala, UNAM, in México.

Wild Plants for a Sustainable Future: 110 Multipurpose Species was published in 2019. Aimed at practitioners, the book promotes the conservation and sustainable use of wild species in conservation, agriculture and forestry projects.

Useful plants from Mali.

Espeletia brachyaxiantha seen in 2017 against the backdrop of peaks of the Páramo de La Rusia, Boyacá, Colombia, during the first expedition as part of the PARAGUAS project.

Tim Peake with apple seeds from Newton's tree aboard the International Space Station in 2016.

Photos: Mauricio Diazgranados / Tiziana Ulian / ESA/NASA

Research highlights from the Comparative Seed Biology team at the MSB

The Comparative Seed Biology team focuses on key seed functional traits in wild plant species, especially traits related to germination, longevity and stress. Working in collaboration with partners in more than ten countries, research over the past ten years has included thermal time quantification in around 200 plant species (including crops, crop wild relatives and wild plants) from many habitats (arid lands to wet forest, coastal to inland). These findings have changed how seed companies select fit-for-purpose seeds to account for adaptation and resilience to climate change, both in agriculture and in seed farming for restoration.

We have also established that traits that affect seed viability (such as water loss in recalcitrant seeds, survival or persistence in the soil seed bank, or dry-seed-accelerated ageing) are dependent on cellular oxidative status, which is determined by a mechanism that is conserved across a broad phylogeny of plant and fungal orders.

In a slightly different collaboration, seeds of Sir Isaac Newton's apple tree at Woolsthorpe Manor, Lincolnshire, UK, were stored at the MSB before spending time in space with astronaut Tim Peake. Upon returning to earth, the seeds were germinated and grown into young trees at Wakehurst, after which they were sent to new homes around the UK and Europe to inspire future seed scientists.

Key research from across the Millennium Seed Bank Partnership

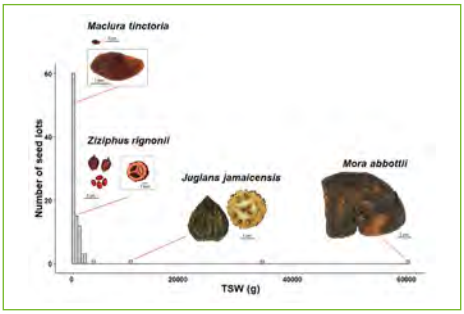


Figure 1 from Mattana et al. study in 2020 showing density distribution, expressed as number of seed lots, of the thousand seed weight (g) and morphological variability of the species investigated in the study. Mattana, E., Peguero, B., Di Sacco, A. et al., Assessing seed desiccation responses of native trees in the Caribbean. *New Forests* 51, 705–721 (2020).

Americas

Intensive seed physiology research has been undertaken with newly collected tree seed in the Mexican and Dominican Republic tree flora. For example, Sampayo-Maldonado and colleagues revealed the threshold temperatures for germination in an important Mexican timber tree, while Mattana and colleagues demonstrated the range of responses to desiccation in Caribbean tree seed. The first checklist of native trees of Mexico was published, with analysis of their distribution and *ex situ* conservation status. In the USA, collaborations with the Center for Plant Conservation have analysed usefulness of online collection data for seed collectors, and with Morton Arboretum have analysed the effectiveness of tree collection strategies.

Africa

Restoration projects have been a highlight for MSBP South Africa with research including pre-germination treatments and seed viability testing. Twenty-six threatened species are now in active collaborative restoration projects and a practical guide to growing indigenous plants for restoration has been developed. In addition, species population monitoring is contributing to Red List assessments for South Africa's flora. In Ethiopia, species collections through the Ethiopian Endemics and Afromontane Project will facilitate gene-flow research while databasing and georeferencing of herbarium specimens provides new data for species distribution analysis. In Madagascar over 1,000 Red List assessments have been published by the IUCN, supported by data from KMCC MSBP. Ongoing prioritisation work with SNGF targets the most threatened species for the MSB programme.

Photo: Paul Smith / RBG Kew

The endangered *Leucadendron remotum*.

Asia

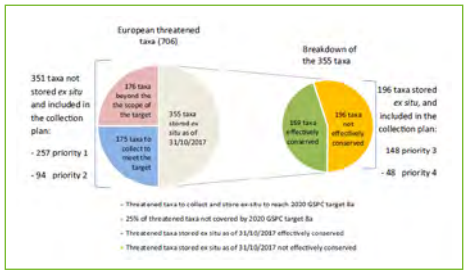
MSB partners in Asia have researched seed use for ecological restoration and sustainable development. In Bhutan, the National Biodiversity Centre has developed propagation protocols for tree species rescued from forest threatened by hydroelectric dam development. The Forest Restoration Research Centre, Chiang Mai University, Thailand studied seed storage behaviour and direct seeding for forest restoration, explored the use of drones in restoration planning and monitoring, and created an open access database of fruit, seed and seedling morphology of 310 native tree species. Bogor Botanic Gardens, Indonesia has studied the germination of the nutmeg relative, *Myristica fusiformis*, to enable its sustainable cultivation, while the University of the Ryukyus, Japan has also researched seed storage behaviour.

Photo: Khuanpirom (Aom)

Drones developed by Bird's Eye View (BEV), Chiang Mai.

Europe (including Caucasus)

One of the most significant publications was the European Native Seed Conservation Network (ENSCONET) Collecting Protocol (ENSCONET 2009), which enabled the standard of wild species collections to be maintained across different members of the network and beyond. By 2017 more than half of species (62.7%) had been conserved, with strategic recommendations provided on filling gaps to meet the 2020 Global Strategy for Plant Conservation (GSPC) target for Europe. Research focus across the European partnership is varied, from studying the geographic and phylogenetic patterns of seed germination to the pros and cons of standard germination protocols for alpine flora. In the Caucasus, there is a strong focus on understanding the distribution, diversity and traits of economically important plants, such as wheat and apples. Research has also provided evidence to determine non-detrimental levels of trade for wild-harvested flora (e.g. CITES for snowdrops) and contributed towards regional assessments of threatened species.



Representation of the breakdown of the 706 European threatened taxa. Figure taken from Rivière, S., Breman, E., Kiehn, M. et al., How to meet the 2020 GSPC target 8 in Europe: priority-setting for seed banking of native threatened plants. *Biodivers Conserv* 27, 1873–1890 (2018).

Oceania

In the recent decade, news from the Oceania region has been dominated by increased frequency and intensity of wildfires, as well as introductions of novel plant diseases, such as myrtle rust. Therefore, research has tended towards studying the implications of these threats on the native flora. In New South Wales, partners investigated the *ex situ* conservation options for two rainforest species (*Rhodamnia rubescens* and *Rhodomyrtus psidioides*) which are severely affected by myrtle rust. Differing seed storage behaviours for these species were found and recommendations made for conservation action. Researchers from Western Australia also highlighted the importance of altered fire seasonality for plant population recovery and proposed a conceptual demographic framework to understand its effects. This could be used to inform critical decisions for conservation, land management and fire management policy development globally. Further studies have looked at the relationship between specific traits and seed longevity for some iconic Australian flora (e.g. *Banksia*) and dormancy breaking (e.g. *Acronychia*).

Photos: Graeme Errington

Myrtle rust pustules on *Rhodamnia rubescens* fruit and foliage. From Sommerville, K. et al., (2019) Conservation in the wake of myrtle rust – a case study on two critically endangered Australian rainforest plants. *Pacific Conservation Biology*.

For further information on any of the research described here, please get in touch with the *Samara* team (**samara@kew.org**).

Seed utilisation projects around the globe

Across the MSBP, seeds stored locally or at the MSB are being used for projects to restore locally lost species after urban development or environmental damage, participate in multi-national replanting projects or work with pre-breeding partners on crops of the future.

Joseba Garmendia Altuna, Aranzadi Science Society, Spain

In 2014, a sea storm destroyed a large part of the Iñurritza dunes in the province of Gipuzkoa. These dunes are home to around 20 species catalogued at the regional level, several of them included in the red list of Spanish vascular flora. Among them is *Galium arenarium*, a species whose only peninsular locality is in Iñurritza. After the storm, only two specimens survived (19 were counted in 2013). Fortunately, in 2013, numerous seeds of this endemic were collected from the Bay of Biscay, which made it possible to strengthen the population and save it from extinction.

Photo: Aranzadi Science Society

Galium arenarium.

Elke Zippel, Botanischer Garten und Botanisches Museum Berlin, Germany

Populations of *Dianthus gratianopolitanus* in the lowlands of Germany have been lost or are threatened. This attractive flower was identified as a target species for a national project. Based on seed collections from remaining populations stored at the seed bank in Dahlem, over the course of three years more than 2,000 plants were grown and planted in ten different areas, with close monitoring to investigate the success in different habitats in terms of survival and flowering.

The critical importance of sufficient water during and following planting was identified, but we still achieved an average of 25% survival over five years. Direct seed planting showed much lower survival rates of 1.6% over the same period. Populations are thriving and continue to be monitored, but the presence of the species in the region has stabilised.

Photo: Elke Zippel

Dianthus gratianopolitanus.

Photo: Andrew Crawford

Showy everlastings retain their colour long after they are picked and dried.

Andrew Crawford, Department of Biodiversity, Conservation and Attractions, Australia

Mingenew everlasting, *Schoenia filifolia* subsp. *subulifolia*, is an endangered species endemic to Western Australia. This species is currently only known from three extant populations (two of which have been collected from) and is in decline. In 2015 a translocation commenced to establish a new, secure population of the species. Initially seedlings were used which flowered, set seed and became established in small numbers. Considering the annual nature of the species it was thought that direct seeding would be a good way to establish more plants; however, this would likely be less successful on a per seed basis than using seedlings.

Due to the dramatic decline in numbers in one of the populations it was not considered prudent to use the collections for direct seeding, despite reasonable quantities of seed available *ex situ*. In 2019 a seed production area was established at a primary school to bulk seed of the species. Seed was successfully harvested later that year, which has now been used in a direct seeding trial to boost plant numbers in the translocated population.

Helminger Thierry, Botany Section, National Museum of Natural History, Luxembourg

Two decades ago, only few tiny *Arnica montana* populations of mostly overaged individuals subsisted, due to the disappearance of its habitat in heathlands and *Nardus* meadows. In 2000, the research center of the museum initiated a restoration project for this species, with experimental demography and a study of its population genetics. The two objectives were: i) maintain viable populations by reinforcement of extant populations and reintroduction to former locations, and ii) restore its habitat through sheep grazing and mowing.

For grassland renaturation in Luxembourg the SICONA intercommunal syndicate plays an important role. They primarily choose species that are typical for extremely rare grassland communities or that are regressing. Young plants are planted in groups of 50 plants. Since 2013, some 20,000 plants from 30 species have been reintroduced on 100 different sites. Together with the National Museum of Natural History, the SICONA intercommunal syndicate has initiated a project to start the production of autochthonous seeds of grassland species in order to provide seed mixtures for restoration measures. Young plants of known native provenance are grown by farmers on single-species fields in order to collect the seeds that are then available for native seed mixtures.

Photos: Helminger Thierry

Arnica montana seeds.

Clonal propagation of planted *Arnica montana* individuals.

Einav Mayzlish Gati, Sivan Golan, Dikla Lifshitz, Tomer Faraj, Ofer Cohen, Alon Zinger, Yehudit Lazar, Alina Hezroni and Ellen Graber, Israel Plant Gene Bank

In 1975 there was a large oil leak into the Evrona Nature Reserve, a unique, extreme saline sandy desert ecosystem. In 2014 a second spill occurred further north near Be'er Ora, causing extensive ecological damage across approximately 144 km^2 of the Evrona Nature Reserve.

As we conserve seeds collected from the Evrona reserve over the last decade and have extensive experience in the germination of wild plants, we examined the ability of three native plants from the reserve to germinate and develop under the extreme pollution conditions of both leaks. Furthermore, we set up a controlled experiment to determine the pollution thresholds that limit plant growth.

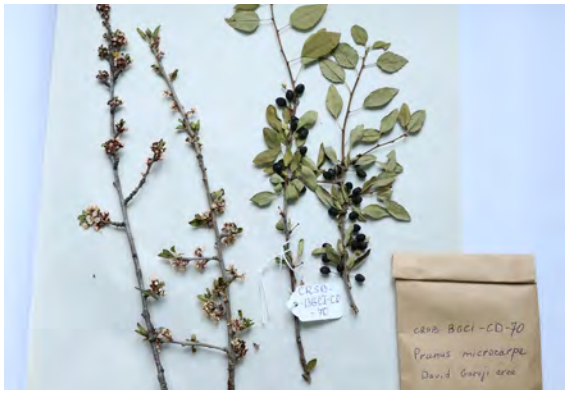
The survival and morphology of the seedlings were strongly affected by the contamination in both spills, leading to dwarf plants with few leaves and a high mortality rate. However, dilution of the contamination levels to 10% and below allowed almost normal germination and seedling development. This research, as well as other questions we are examining, will allow the authorities to better understand the requirements for rehabilitation of the reserve.

Photos: Israel Gene Bank

A subchannel of oil pollution after the 2014 oil spill in the Evrona reserve.

Soil sampling.

Photos: Tsira Mikatadze-Pantsulaia



Prunus microcarpa herbarium specimen.

Amygdalus georgica seedlings.

Tsira Mikatadze-Pantsulaia, National Botanical Garden of Georgia

The National Seed Bank (NSB) of the National Botanical Garden of Georgia has been working in conjunction with the Botanic Gardens Conservation International (BGCI) to develop and implement *ex situ* and *in situ* conservation activities for the IUCN Red List species Georgian almond (*Amygdalus georgica*) and small-fruited cherry (*Prunus microcarpa*).

Within the framework of the implemented projects, seeds were placed in the NSB and duplicated at the MSB, a bank of live specimens was created from collected seeds, and reintroduction works were carried out within the natural distribution areas of the species where the populations were reduced or destroyed. This work was very important for our country, and we thank BGCI and the Fondation Franklinia for their financial support.

Asif Javaid, National Agricultural Research Center, Pakistan

There are 41,000 germplasm accessions in the National Genebank of Pakistan, including 3,250 of rice, 1,600 of peas and 800 of tomato. Through characterisation and evaluation of these germplasm accessions we can study their genetic diversity and make selections of elite germplasm lines.

Elite germplasm lines of rice are selected for early maturity, yield components and grain length. For peas, selection is made for powdery mildew resistance and grain yield. Preferred characters for selection of elite germplasm lines in tomato are earliness, fruit colour, shape and yield. Elite germplasm lines are shared with plant breeders for crop improvement.

Photo: Asif Javaid

Rice field.

Joêlle Breidy, Lebanese Agricultural Research Institute (LARI), Lebanon

LARI's seed bank conserves collections from 950 different wild species. These collections are a resource for habitat restoration, by enabling them to be put back where lost, and a resource for research and new technology. Crop wild relatives possess valuable characteristics that can be transferred by breeding to cultivated varieties.

Aubrieta libanotica is a species of Brassicaceae endemic to Lebanon and Syria. It is a perennial evergreen plant with small lilac flowers that inhabits rocks and banks. This showy flowering plant used to grow in Zahle in three different rocky locations. The third population was lost due to road construction. Seeds from the first and second location were collected and conserved at LARI's seed bank and were put back in the third location.

Photo: Joêlle Breidy

Purple rock cress *Aubrieta libanotica*.

Training, public engagement and dissemination

To achieve its global ambition to protect plant biodiversity, the MSB Partnership has focused on training and the exchange of knowledge with our partners. Training programmes started in 2000 and have taken place both at the MSB and at partner institutions around the world. The training has taken different forms: short courses (including Seed Conservation Techniques), technical attachments, joint collecting trips and student placements and visits. With all training, the aim is to help individuals and institutions collect, process and store seeds for long term conservation, following the Seed Conservation Standards.

In-country courses have been arranged in collaboration with partner institutions and are often geared towards specific project needs, bringing together skills and knowledge from different institutions. For example, in December 2017, Kew and Te Tira Whakamataki (the Maori Biosecurity Network) delivered two five-day courses on wild species seed conservation at Auckland Botanic Gardens and Otari-Wilton's Bush Reserve (Wellington). Due to the recent discovery of myrtle rust in New Zealand earlier that year, staff from the Australian Seed Bank Partnership also contributed their considerable experience and first-hand knowledge of the effects of myrtle rust. Myrtaceae identification advice was provided by colleagues at the gardens and the Department of Conservation (DoC). In addition to botanic gardens and DoC staff, representatives from 11 Iwi (tribes), Hapu (sub-tribes) and Maori organisations attended and participated in the courses. In April 2018, the Global Tree Seed Bank Programme in Japan kicked off with a five-day training course delivered by Kew and the University of the Ryukyus, Okinawa, which was attended by participants from the University of the Ryukyus, Kyushu University and representatives from six other organizations. As well as seed conservation training, seed desiccation tolerance testing methodologies were included.

Photo: RBG Kew

The Seed Conservation Techniques course brings together scientists from across the Partnership to learn about the practical and theoretical aspects of *ex situ* seed conservation.

Photo: Sharon Balding

A presentation on seed desiccation tolerance testing methodology.

The impact of capacity building in Colombia

AMALIA DÍAZ & JENIFFER DÍAZ
(Humboldt Institute, Colombia)

Beyond helping to increase our seed collections and allowing us to contribute to the conservation of the tropical dry forest (the most threatened ecosystem in Colombia), the Global Tree Seed Bank Programme left another important legacy. This was an increase in local capacity in terms of personnel, interns and collaborators, who are key to the management and enrichment of the collections.

Throughout the project, three important elements of our capacity were boosted:

1. Educating: To have students as interns was an enriching opportunity. We learned how to share our knowledge and allowed space for the students' dissertations, doubt, analysis and solutions. Education is one of our best tools as scientists, and knowledge is useless unless it is shared.

2. Leading: We organised the first symposium on 'the role of seed banks in plant conservation'. Taking place during the 10th Colombian Botany Conference in August 2019, it brought together seed banks from five institutions to share experiences, focusing the discussion on conservation and not just food security. Our capacity was strengthened by leading an event of national interest and bringing interested parties together, allowing space to start discussions.

3. Collaborating: As a direct result of the symposium, four local seed banks formed the 'Colombian Network of Seed Conservation' to create a national focus point for those interested in seed banks and their use in seed conservation. The network seeks to unify seed banks concerned with food security and those concerned with conservation. From this experience we have learned to collaborate with other institutions, going beyond our own comfort zone in the search of a common objective.

The Spanish language seed manual jointly published by the Humboldt Institute Colombia and RBG Kew sets out protocols & best practices for effective seed conservation. Available from the Humboldt & Kew Repositories and the MSB Data Warehouse.

Our partners around the globe have their own ways of working with their communities to achieve local progress in preserving or restoring species and ecosystems, adding up to a network of success stories. A couple of examples are provided below.

Photos: G. Malambane

A parent who is also a traditional doctor imparts skills on how to sustainably harvest *Harpagophytum procumbems* (Pilikwe) leaving the important root stock to sprout again in the rainy season.

Community engagement and training in Botswana

ALBERTINAH MATSIKA (Botswana University of Agriculture & Natural Resources (BUAN))

We have worked hard to promote sustainable harvesting and the use of indigenous plant resources locally in Botswana. Seeds from many important species were not only banked, but some were germinated and propagated at BUAN nursery alongside smaller nurseries in partner villages. The propagated species were given back to the communities and we encouraged and promoted the participation of women and primary school children in many of the project activities.

The MSB and Useful Plant Project (UPP) teams also conducted workshops and information-sharing sessions with relevant stakeholders on the prevention and minimization of adverse impacts on many species of local ethnobotanical importance. The involvement of children and women at an early stage certainly ensured that the knowledge learnt has a lasting impact in the community.

For example, primary school students learnt how to properly cut and collect species of traditional importance, in a way that will allow them to fully grow back when the rains come, and how to preserve herbarium specimens for future reference.

UPP coordinator Sam Ngwako near the low-cost net shading, serving as a greenhouse in a school where children monitored the growth of the propagated indigenous trees. Seedlings were replanted in the wild and local spaces such as schools and village areas.

Photo: Jerry Kahlo

Kenilworth Racecourse Conservation Area.

Photo: Fayruz Prins

Erica turgida, a member of the heather family extinct in the wild and reintroduced at KRCA.

Kenilworth Racecourse Conservation Area was featured in the 10th anniversary edition of *Samara*. Jerry Khalo provides an update on its progress and describes the public engagement which helps to sustain it.

Kenilworth Racecourse Conservation Area – Ten years on

JERRY KHALO (Site Manager of Kenilworth Racecourse Conservation Area, Cape Town, South Africa)

Kenilworth Racecourse Conservation Area (KRCA) is renowned for being the most valuable piece of Cape Flats Sand Fynbos remaining and houses the last population of micro frogs, *Microbatrachella capensis*, on the Cape Flats. Had it not been for the collective efforts of various nature conservation organisations (including the Millennium Seed Bank, Kirstenbosch National Botanical Garden, and City of Cape Town: Biodiversity Management Branch) and the willingness from the owners (now Kenilworth Racing (Pty) Ltd), this priceless remnant would have been lost.

Following the implementation of the first ecological fire in 2005, the entire conservation area has been subjected to planned fires, leading to the discovery of new floral species that had been dormant under the 100-year-old veld. This has also boosted the population of *Erica margaritacea*, Critically Endangered plants occurring only at KRCA. Regardless of its ecological status, management interventions – guided by collections of monitoring data – to sustain its functions remain necessary. Now that the project has matured, it has become a great learning platform for school children and university students and attracts various public groups on guided walks, such as Spring Walk, where flora found in the area is showcased to the public.

The conservation team continues to closely monitor the ecological characteristics of the site for better-informed management decisions. Currently, according to the most recent Vegetation Condition Assessment, KRCA is thought to be in a natural condition, with the occasional occurrence of invasive alien plants that are regularly eradicated. The project is currently under the collaborative management of Cape Town Environmental Education Trust (CTEET), the City of Cape Town and Kenilworth Racing (Pty) Ltd, with great support from the Friends of Kenilworth Racecourse Conservation Area.

Can you conserve it in a seed bank?

JOHN DICKIE (Senior Research Leader and Assistant Head of Collections, RBG Kew), SARAH WYSE (Lincoln University in New Zealand, formerly Kew Early Career Research Fellow) & ALICE DI SACCO (Research Officer – Forestation, RBG Kew)

In planning *ex situ* seed conservation projects, it's essential to know if target species bear seeds that do not survive drying and freezing; in other words, if they are 'recalcitrant' and cannot be stored in a conventional seed bank. *The Compendium of Information on Seed Storage Behaviour* (Hong et al., 1996) was the first attempt to compile an evidence-based list which then provided the basis for the first trait dataset in the Seed Information Database (SID), developed as part of the MSBP. The original *Compendium* contained information on around 7,000 species, growing to 24,784 taxa currently in SID (data.kew.org/sid/sidsearch.html). This has been used to estimate the likely proportion of species bearing recalcitrant seeds globally. While the global average may be around 10% (Wyse & Dickie, 2017), there is considerable variation across vegetation types, with the estimated proportion of woody species in tropical forests having recalcitrant seeds being at least 20% and possibly more than 40% (Tweddle et al., 2003).

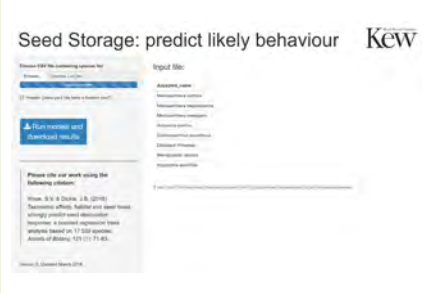


Figure 1: Screenshot of Seed Storage predictor tool with species names added.

Aesculus hippocastanum, a recalcitrant species.

Photo: RBG Kew / William Milliken

	A	B	C	D	E	F	G
1	Accepted_name	Genus	Family	Order	tax.level	probability.of.recalcitrance	storBehav
2	Medusanthera laxiflora	Medusanthera	STEMONURACEAE	Aquifoliales	Order	0.788149709	Recalcitrant
3	Medusanthera megistocarpa	Medusanthera	STEMONURACEAE	Aquifoliales	Order	NA	InsufficientInfo
4	Medusanthera inaequalis	Medusanthera	STEMONURACEAE	Aquifoliales	Order	NA	InsufficientInfo
5	Avicennia marina	Avicennia	ACANTHACEAE	Lamiales	Species	1	Recalcitrant
6	Codonacanthus pauciflorus	Codonacanthus	ACANTHACEAE	Lamiales	Family	0.033195204	Orthodox
7	Dicliptera chinensis	Dicliptera	ACANTHACEAE	Lamiales	Family	0.045703388	Orthodox
8	Hemigraphis reptans	Hemigraphis	ACANTHACEAE	Lamiales	Family	0.063615378	Orthodox
9	Hygrophila salicifolia	NA	NA	NA	NA	NA	NA
10							

Figure 2: Screenshot of resulting spreadsheet with probability of recalcitrance provided.

As the seed storage behaviour dataset in SID became increasingly populated by data from successful storage of species' seeds under seed bank conditions, concerns about bias in estimates based on SID grew. So, work began on identifying global predictive patterns that might inform seed collection management decisions. Specifically, the challenge was to use analytical and modelling approaches on large but incomplete and potentially biased datasets, to get reliable and usable predictions in species not yet subjected to experimental studies.

The models for predicting species' seed desiccation tolerance or sensitivity rely on three boosted regression tree models, based on habitat and trait information for the species, and the seed desiccation responses of close relatives (either members of the same genus, family or order, depending on the model) (Wyse & Dickie, 2018). Model predictive success was tested by ten-fold cross-validation, and the utility of the models demonstrated by predicting seed desiccation response for two floras: Ecuador, and Britain and Ireland. The most important predictor variables were the seed desiccation responses of a species' relatives, seed mass and annual precipitation. The three models had varying success rates for identifying the desiccation-sensitive species.

For example, due to data availability, prediction accuracy was higher for the relatively poor, but well known British and Irish flora, where it was estimated that a desiccation-sensitive species had a 96.7% chance of being correctly identified, compared with 80.8% in the much richer but less studied flora of Ecuador. Importantly, this work showed that conventional seed banking may not be a viable *ex situ* conservation option for many threatened plants (Wyse et al., 2018). The great news for practitioners is that the models are now available as an online tool for estimating the probability that any species has orthodox or recalcitrant seeds, using Shiny App (seedcollections.shinyapps.io/seed_storage_predictor/).

After name-checking through the Taxonomic Names Resolution Service, species names are entered as binomials, either singly or in a list (up to 500 or so for the online app, as a .csv file). The output confirms the name, the model used to make the prediction (genus, family or order) and the probability that the species has desiccation-sensitive seeds.

In general, probabilities closer to zero or closer to one suggest increased likelihood of orthodox or recalcitrant seed behaviour, respectively. Probabilities close to 0.5 indicate maximum uncertainty, not 'intermediate' storage behaviour, supporting the need for more research on those species. Furthermore, despite the modelling approach minimising the effect of bias in the dataset, there is still a lack of data on recalcitrant species, especially from tropical moist forests, and we encourage our partners to research them and publish the results, so they can contribute to continuous improvement of model predictions. Partners already contributing to this research include those in Australia, Bhutan, Colombia, Dominican Republic, Japan, Mexico and Thailand.

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Visiting researchers: a catch-up and a farewell

Since its start, the Millennium Seed Bank Partnership has supported numerous postgraduate students and researchers from around the world. Here we catch up with two featured in the 10th anniversary edition of *Samara*, Hongying Chen and Andrew Crawford, and say farewell to Fui Ying Tsan, the latest researcher leaving the Millennium Seed Bank after finishing her work this September.

Andrew Crawford

Fui Ying Tsan

Hongying Chen

Photos: RBG Kew / Hongying Chen / Fui Ying Tsan

What position are you working in today?

Andrew: I'm now a Research Scientist with the Department of Biodiversity, Conservation and Attractions (the same department as ten years ago, just a different name) managing the Western Australian Seed Centre, Kensington (previously known as the Threatened Flora Seed Centre).

Fui Ying: I'm an associate professor from the Faculty of Plantation and Agrotechnology, Universiti Teknologi MARA in Malaysia.

Hongying: I'm working in the Germplasm Bank of Wild Species of China as a seed scientist.

Can you tell us about a project you are currently working on?

Andrew: I am working on a number of seed conservation projects. One focuses on conserving seed of conservation-significant plant species that may be impacted by myrtle rust (*Puccinia psidii*) were it to be introduced into Western Australia. Other projects are focused on collecting seed and helping recover threatened plant species that were affected by the bushfires that occurred in the summer of 2019/20.

Hongying: I'm working on several projects concerning molecular mechanisms during seed longevity, of desiccation tolerance and of cryopreservation. We found that lipid changes are a key determinant of desiccation-induced viability loss in seeds and the lipids also remodel during seed cryopreservation.

Fui Ying: My research field includes seed science and plant physiology. I've just finished a sabbatical at Wakehurst, where I worked on regenerative biology of tropical recalcitrant seeds with a special interest in those that have the capability to sprout even when fragmented.

How has your association with the MSBP helped in terms of your career development? For example, are you still in contact with partners?

Andrew: The opportunity to undertake and complete my PhD as part of the MSBP helped strengthen my research skills. These skills, combined with my practical experience with seed collecting, placed me in a strong position to take over management of the seed centre upon the retirement of the previous manager. In Australia, there are strong links between the states and territories that have been involved with the MSBP and this has led to the formation of the Australian Seed Bank Partnership.

I have also formed lasting friendships with MSB staff and students whom I met on training visits to the MSB. This has resulted in a number of them visiting when they have travelled to Western Australia.

Hongying: During my career development over the last ten years, I have had lots of good suggestions from Professor Hugh Pritchard during discussions on experimental design and results. Last year, I went back to the MSB as visiting researcher for one year and caught up with colleagues. I hope in the future we can still keep the relationships we have founded and build up more collaborations in various seed research areas.

Fui Ying: Both Professor Hugh W Pritchard and Dr Louise Colville as my line managers have inspired me with more thoughts on this work and I appreciate it very much. I enjoyed my stay here despite having difficulties during lockdown as it has delayed my work.

Supporting the Global Strategy for Plant Conservation

CHINA WILLIAMS (Senior Science Officer, Science Policy, RBG Kew) & CARLY COWELL (Senior Science Officer, Conservation Policy, RBG Kew)

Plants and fungi are essential for life on Earth and provide natural resources such as food, medicine and clean water. They sustain life through oxygen, carbon and nutrient cycling, and support human wellbeing. The Millennium Seed Bank Partnership (MSBP) is helping to address three of the greatest global challenges facing humanity today: biodiversity loss, sustainable development and climate change. The MSBP has a vital role to play in implementing international conventions that protect biodiversity.

The Global Strategy for Plant Conservation (GSPC) was adopted by the Convention on Biological Diversity in 2002 and consists of three objectives encompassing 16 targets. It provides a framework for the policies and actions required to prevent the loss of plant diversity and promote plant conservation.

The GSPC promotes knowledge transfer and capacity sharing to support plant conservation. In its 20 years the MSB has contributed to nine of the targets. It has promoted and shared new science and best practice (Targets 14, 15 and 16) through training programmes, the MSBP Seed Conservation Standards and review process, the MSBP Data Warehouse, and the *Samara* newsletter. The accumulated knowledge and experience relating to conservation seed banking has enabled the Partnership to advise in a range of areas vital to seed conservation techniques, including species prioritisation and targeting, design of seed banks and collection programmes, data management, viability testing and seed longevity and environmental and taxonomic diversity in seed desiccation tolerance.

Photo: Aisyah Faruk

Anush Nersesyan taking a photo of *Astragalus compactus* in the Vayots Dzor province of Armenia.

The GSPC encourages conservation in *ex situ* facilities to support *in situ* conservation measures, and Kew's Millennium Seed Bank has been a global example of best practice for Target 8. It is the largest *ex situ* plant conservation contribution to the GSPC targets, currently storing more than 96,500 collections representing 39,681 species. These have been collected through the Partnership from 190 countries and territories and undergo regular curation to align with taxonomic revisions. MSBP collections contain substantial taxonomic diversity, representing 349 plant families and over 6,100 genera. 78% of the collections represent endangered, endemic or economically important taxa. The GSPC highlights the importance of crop and tree seed conservation (Target 9). The MSB holds 3,800 collections of 237 taxa representing 25 of the most important crops for global food security made through the Adapting Agriculture to Climate Change (Crop Wild Relatives) project, while the Global Tree Seed Bank Programme focuses on rare, threatened and useful species, conducting world-leading research on tree conservation, including seed biology, behaviour, cryopreservation protocols and reforestation.

Through its work and contributions to the GSPC targets, the MSBP has made significant impacts in the achievement of the UN Sustainable Development Goals, in particular SDG 1: No Poverty and SDG 2: Zero Hunger, by finding and banking crop wild relatives and useful plants. Work on crop and seed conservation, looking at livelihoods through fruit and nut conservation, aids contributions towards SDG 12: Responsible Consumption and SDG13: Climate Action. Lastly, through the MSBP's collections of banked seed, SDG 15: Life on Land can be achieved.

The GSPC and SDGs have brought together a global community dedicated to conservation and the sustainable use of plant diversity and provided a focus for international action. The MSBP continues to play an essential role and moving forward needs to look towards engaging a cross-sectoral range of stakeholders to successfully achieve the aim of mainstreaming biodiversity.

Photo: Orla Elliston

Conservation Partnership Coordinator, Dr Aisyah Faruk, collecting wild pears *(Pyrus salicifolia)* in Georgia for the 'Enhancing rural Caucasian livelihoods through fruit and nut conservation' project.

Managing seed bank data – application of biodiversity informatics to the mobilisation of collection data

UDAYANGANI LIU (Seed Bank Data Resources Manager, RBG Kew)

It has been an honour and a privilege to be involved with the world's largest *ex situ* seed conservation project, the Millennium Seed Bank Partnership (MSBP), managing data for collections conserved at the MSB.

A wide range of databases and tools have been developed to enable the efficient conservation of seeds. Our collection data management system (SBD), built in Sybase ASE, has evolved during the past 20 years. SBD contains in-depth data on collections and plays a significant role in collection prioritisation, curation, management, monitoring and reporting.

The Taxon Database standardises plant naming across collections, enabling curators to select the correct taxon which then identifies the correct curation protocol. The MSBP has a unique opportunity to capture large amounts of taxon-based information on a range of seed biological characteristics, both from the collections and published sources (Liu et al., 2019a). This led to the development of the Seed Information Database (described on page 16) which disseminates a range of trait data and various online tools useful for *ex situ* seed conservation.

Integrating biodiversity informatics with collection, taxon, climatic and biodiversity data (Liu and Dickie, 2017) enabled us to develop tools to predict seed storage behaviour (page 16) and seed germination conditions, as well as to prioritise vascular plants for species-based conservation (Liu et al., 2019b). The depth and breadth of information, knowledge and research outputs underpinning plant conservation being generated by MSBP collections and associated data across the world is unparalleled. It is shared with policy makers and disseminated to the wider scientific community and the public. Our future aim is to further apply biodiversity informatics concepts to the mobilisation of collection data.

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MSBP Data Warehouse

TIZIANA COSSU, TIM PEARCE & NAOMI CARVEY (Data Warehouse Team, RBG Kew)

In 2012, the Millennium Seed Bank Partnership (MSBP) Data Warehouse was launched to provide an online resource for partners of the MSBP. It is essentially a database of most of the seed accession records held at RBG Kew's Millennium Seed Bank, as well as complementary accession datasets from selected partners across the MSBP. The data are compiled offline into a BRAHMS7 database and, depending on the agreement with the data provider (and some other filters around the completeness of species identification), are subsequently delivered to the MSBP Data Warehouse website (http://brahmsonline.kew.org/msbp/SeedData/DW).

Figure 1: Map of seed collections in the MSBP Data Warehouse.

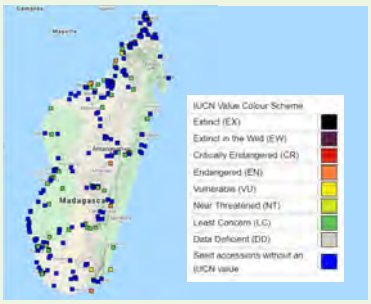

Figure 2: Example of mapping capabilities – a map of collections in Madagascar with their relative IUCN status.

Currently, the offline BRAHMS7 database holds records of over 228,000 seed collections made across the partnership from 204 countries and territories and 96 different seed banks. This provides information on over 48,800 different species. The database also holds data on some 215,700 germination tests and over 9,870 x-ray images. The online data currently displays records of 151,470 seed collections (Fig. 1) with their associated botanical records, 180,601 germination tests and 2,156 x-ray images. Filtering and mapping tools are available to create maps displaying the collection points according to collections, family, genera and IUCN status (Fig. 2), but not all the coordinates are shown. Fuzzy mapping is applied to some of the collections belonging to threatened species or as requested by the data providers. A growing list of useful links to online resources are also available (IPNI, Plants of the World Online, The Plant List, JSTOR, Biodiversity Heritage Library, RBG Kew Seed Information Database). Currently, access to the data is restricted to MSB partners and their collaborators, but plans are in place to engage with partners to move towards opening this valuable resource to a wider conservation community.

The development of database technologies and website functions is changing rapidly. A radical new version of BRAHMS (dps007.plants.ox.ac.uk/bol/brahms/software/v8) and a planned re-write of the BRAHMS online software will add significant functionality to the MSBP Data Warehouse over the coming year. Improvements to delivering collections data, germination protocols, access to herbarium vouchers and more imagery are in the pipeline. The increase in the use of the MSBP Data Warehouse has been steady and we aim to continue to improve the offering so that a much wider audience will have this useful resource available to them.

New MSB partnerships

Country/ territory	Counterpart name/partnership	Start	Duration (years)
Korea	Korea Institute of Aboretum Management	June 19	5
Peru	National Institute of Health*	July 19	2.5
Taiwan	Taiwan Forestry Research Institute*	September 19	5
Armenia	Nature Heritage NGO	January 20	3
Oman	Oman Botanic Gardens*	April 20	3
South Africa	South African National Biodiversity Institute (SANBI)	May 20	3
USA	The Center for Plant Conservation, California	May 20	5
Vietnam	Plant Resource Centre, Vietnam Academy of Agricultural Sciences	July 20	5
India	Jawaharlal Nehru Tropical Botanic Garden & Research Institute (JNTBGRI)*	August 20	5
Mozambique	Instituto de Investigação Agrária de Moçambique (IIAM)	October 20	5

* Denotes new MSB Partner

Recent seed science publications from across the Partnership

Anon. (2019). Global Strategy for Plant Conservation (target 8). University Botanic Gardens Ljubljana. Available online.

Ballesteros, D., Pritchard, H.W., & Walters, C. (2020). Dry architecture: towards the understanding of the variation of longevity in desiccation-tolerant germplasm. *Seed Science Research,* 30: 142–155. Available online.

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Colville, L., & Pritchard, H.W. (2019). Seed life span and food security. *New Phytologist,* 224(2): 557–562. Available online.

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Hitchcock, A., Williams, J. & Cowell, C. (2020) Lessons learned as *Erica turgida* is returned. *Journal for Nature Conservation,* 56. Available online.

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Zuhri, M., Latifah, D., Ariati, S.R., Rahdiana, S., Emus, & Cahyadi (2020). Seed Availability Assessment and Seed Collection of Wild Plants in Selabintana Forest, Mountain Gede Pangrango National Park, West Java for Long-term Seed Banking. *Journal of Kebun Raya,* 23(1): 37–46. Available online.

MSB Dashboard	1 October 2020
Total collections	96,637
Total countries (including overseas territories)	190
Total families	349
Total genera	6,138
Total species	39,681
# of good seeds	2,362,661,364

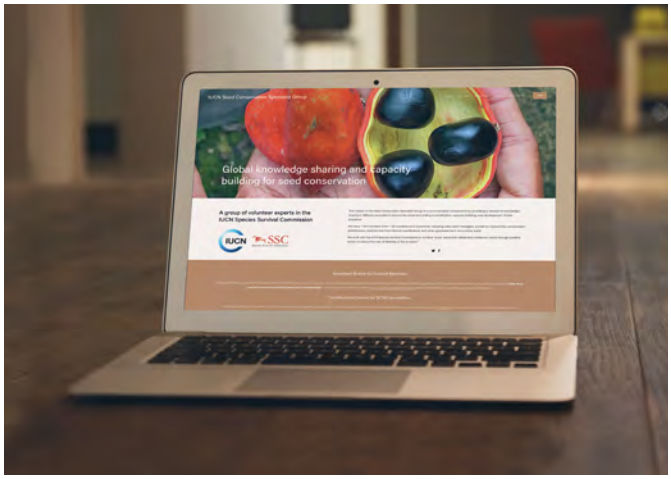
***Samara* Editors**
Sharon Balding, Elinor Breman, Chris Cockel, Aisyah Faruk, Alice Hudson and Hanna Oldfield.

Royal Botanic Gardens, Kew
Millennium Seed Bank, Wakehurst Place, Ardingly, Haywards Heath, West Sussex, RH17 6TN, United Kingdom

Email samara@kew.org

Samara provides information and inspiration for MSBP partners and a flavour of the successes of the Partnership. It is available as a PDF from the Kew website at **https://www.kew.org/science/our-science/publications-and-reports/publications/samara**.

Seed Conservation Specialist Group



The IUCN Seed Conservation Specialist Group new website is now live! The mission of the Seed Conservation Specialist Group is to promote seed conservation by providing a network for knowledge-sharing in different ecosystems around the world, and aiding in prioritisation, capacity-building and development of best practice.

We work with the IUCN Species Survival Commission to achieve 'a just world that values and conserves nature through positive action to reduce the loss of diversity of life on earth'.

Our Seed Conservation Directory of Expertise contains information on individuals, facilities and expertise related to seed conservation, focused on plant species of wild origin.

If you would like to be a member of the specialist group, or have any feedback about your experience with the website, please contact us via seedconservationsg.org/contact. You can also follow us on Twitter @IUCN_Seeds or join the IUCN Seed Conservation Specialist Group on Facebook.