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**Seed science and banking networks for plant conservation:
the role of the Royal Botanic Gardens, Kew**

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SUMMARY

Addressing the grand challenges of providing adequate supplies of water, food and energy in the future to an ever growing human population without the decimation of biodiversity demands innovations in plant science and an accelerated effort in conservation. The scale of intervention necessary will be advanced most rapidly through collaborative networks. This paper highlights eight seed science and banking networks involving the Royal Botanic Gardens, Kew, UK since 2000. The networks, which span 66 countries including the UK, have: 1) provided understanding in the seed biology of tropical trees, orchids, halophytes and medicinal plants; 2) developed new cryo-storage methods for crops and horticultural species; and 3) helped to conserve the European and world's dryland flora.

Key words: seed biology, banking networks, biodiversity conservation

RIASSUNTO

**Reti per lo studio dei semi e di banche del germoplasma per la conservazione delle piante:
il ruolo del Royal Botanic Gardens, Kew**

Indirizzare le grandi sfide ad un adeguato approvvigionamento di acqua, cibo ed energia nel futuro per la popolazione umana sempre in continua crescita, senza che avvenga una decimazione di biodiversità, richiede delle innovazioni nello studio delle piante e un'accelerazione degli sforzi volti alla conservazione. La scala degli interventi procederà più rapidamente mediante la creazione di reti di collaborazione. In questo lavoro vengono presentate otto reti per lo studio dei semi e di banche del germoplasma, collegate sin dal 2000, comprendenti anche il Royal Botanic Garden, Kew, del Regno Unito. Le reti, che comprendono 66 Paesi, incluso il Regno Unito, hanno: 1) fornito conoscenze nella biologia dei semi di alberi tropicali, orchidee, alofite e piante medicinali; 2) sviluppato nuovi metodi di crio-conservazione per cereali e specie orticole; 3) dato un impulso alla conservazione della flora delle praterie d'Europa e del resto del mondo.

Parole chiave: studio dei semi, reti di banche del germoplasma, conservazione della biodiversità

Proceedings of the Meeting: "La conservazione in situ ed ex situ e il count-down 2010" (Catania, 11-13 ottobre 2009).

Introduction

According to the Millennium Ecosystem Assessment the current predicted rate of loss of species is approximately two- to three-fold faster than the geological record (Corvalan et al., 2005). Consequently, the need to conserve the world's ~300,000 higher plant species (Chapman, 2009) is urgent. Acknowledging that collective progress was required, a framework for action was developed about 10 years ago: the GSPC - Global Strategy for Plant Conservation (CBD 2002). The GSPC proposed targets on documenting, conserving and sustainably using plant diversity, and the sharing of knowledge. The targets support the broad conservation objectives of the Convention on Biological Diversity (CBD); that of ecosystems (*in situ*), species (*in situ* and *ex situ*) and genes (genetic and, more importantly, functional diversity).

Various approaches are available for the *ex situ* conservation of plants, although the most commonly used is that of seed storage [for review, see Linington and Pritchard (2001)].

The vast diversity of higher plants, and their varying seed physiological responses, means that effective seed conservation continues to be dependent on developments in fundamental understanding (science) and banking (technology). The purpose of this paper is to summarise the many collaborative projects in seed conservation and science that the Royal Botanic Gardens Kew has been involved in since 2000. The projects illustrate a rapid expansion in international collaboration within Kew's conservation programmes, which is a reflection of general changes in working practice of many plant science institutes and botanic gardens across the world (Crane et al., 2009).

The Royal Botanic Gardens Kew

The Royal Botanic Gardens Kew (RBG Kew), which was established in 1759, has three science departments: (1) The Herbarium, Library, Art and Archive (HLAA), containing > 7 million preserved plant specimens, and serving as a vast 'reference library' for botanists from all over the world; (2) the Jodrell Laboratory, in which research is conducted on, *inter alia*, molecular systematics, biological interactions and micromorphology; and (3) Seed Conservation, home to the Millennium Seed Bank, with nearly 30,000 species of higher plants stored *ex situ* as seeds, and a seed conservation science programme. The Gardens at Kew and Wakehurst Place in Sussex, are home to > 30,000 taxa of living plants, including many species that are extinct in nature. RBG Kew has a mission to 'Inspire and delivery science-based plant conservation worldwide, enhancing the quality of life.' The mission is delivered through seven key strategies within the 'Breathing Planet Programme': 1) discovery and global access to plant and fungal diversity information; 2) mapping and prioritising species and regions of the world for conservation; 3) *in situ* conservation of what remains 4) successful use of locally-appropriate plant species; 5) *ex situ* conservation through seed banking; 6) restoration of damaged wild vegetation; 7) inspiring actions to counter environmental challenges.

Science and Banking Networks

The Millennium Seed Bank Project [1997-2010]

<http://www.kew.org/science-conservation/conservation-climate-change/millennium-seed-bank/index.htm>

Kew's Millennium Seed Bank Project (MSBP) is the largest *ex situ* plant conservation project in the world, focussing on global plant life faced with the threat of extinction and plants of most use for the future. The seeds are saved at low moisture content and cold temperature (-20°C). Working with a network of collecting partners across 50 countries, the MSBP has successfully banked 10% of the world's wild plant species, achieved with the banking of *Musa*

itinerans, a wild banana from China, in October 2009. Major partnerships include: Australia, Botswana, Burkina Faso, Chile, China, Jordan, Kenya, Lebanon, Madagascar, Malawi, Mali, Mexico, Namibia, Republic of South Africa, Tanzania and the USA. The future aim (under the Millennium Seed Bank Partnership) is to conserve another 45,000 species, reaching 25% of the world's flora in safe storage by 2020. Plants and regions most at risk from climate change and the ever-increasing impact of human activities are being targeted for conservation.

This project is led by Dr Paul Smith (Kew).

Tab. 1. Some MSB Project achievements, from 1997-2010, in numbers*

23	Countries that received assistance setting up a seed bank	450	The potential cold storage floor area (m ²) in the Millennium Seed Bank vault
43	Percentage of collections that are endemic, endangered or of local economic importance	>1500	People from around the world trained in seed conservation
54	Countries (and 123 organisations) constitute the global network	2500	Taxa (>10% of the native flora) conserved by September 2009 by the South African National Biodiversity Institute (SANBI)
73	MSc and PhD students co-supervised by departmental staff	9000	School children, on average, that visit the Wellcome Trust Millennium Building each year
250	Previously undescribed species collected	24,200	Species conserved and duplicated in the MSB vault
>300	Publications, of which >50% have appeared in peer-reviewed journals	1.6 x 10⁹	Estimated seeds held in the MSB vault

* Adapted from SAMARA 17 (2009) pp 6-7. ISSN 1475-8245.
http://www.kew.org/msbp/scitech/publications/samara/Samara17_english5.pdf

The Darwin Initiative Research Exercise on Community Tree Seeds (DIRECTS) [2003-8]

DIRECTS research in Africa investigated the seed physiology of > 70 identified priority tree species of known uses in dryland Africa, over 30% of which continue to be of conservation concern. Although the need for the conservation and sustainable use of these species was clear, appropriate protocols for seed handling were far from optimal. In generating and sharing data on the germination and storage of the species, the project partners contributed to the maintenance of forest biodiversity, especially the multipurpose trees that support the daily life of millions of people in sub-Saharan Africa. The African Tree Seed and Biodiversity Centres were key partners in the project and benefited through strengthened expertise. Forty nine staff were trained during workshops in Ethiopia, Burkina Faso and Ghana. Research contributed to the production of 23 seed leaflets on target species; for example *Azelia africana* (<http://en.sl.life.ku.dk/upload/118net.pdf>) and a handful of scientific papers.

Research initiated by DIRECTS continues in the various collaborating institutes: Benin - Institut National de Recherche Agronomiques (INRA); Botswana - National Tree Seed Centre (NTSC); Burkina Faso - Centre National de Semences Forestières (CNSF); Cape Verde - Institut Nacional de Investigacac Agraria (INIDA); Cote d'Ivoire - Centre National de Recherche Agronomique (CNRA); Ethiopia - Forestry Research Center (FRC); Ghana - Forestry Research Institute of Ghana (FORIG); Kenya - Kenya Forestry Research Institute (KEFRI); Madagascar - Silo National des Graines Forestières (SNGF); Malawi - National Tree Seed Centre, Forestry Research Institute of Malawi (FRIM); Mali - Centre Régional de Recherche Agronomique (CRRA); Niger - Institut National de Recherches Agronomiques du Niger (INRAN); Nigeria -

Owolowo University; Tanzania - Tanzania Tree Seed Agency (TTSA); Togo - National Tree Seed Centre (NTSC); Uganda - National Tree Seed Centre (NTSC). Some of this follow-up work is being progressed through the triennial work programme of the Forest Tree and Shrub Seed Committee of the International Seed Testing Association (www.seedtest.org/en/tcom-fts.html)

This project was led by Dr Moctar Sacandé and Prof Hugh W Pritchard (Kew) and supported by the UK Darwin Initiative (<http://darwin.defra.gov.uk/>), with gift-in-kind from Bioversity International (<http://www.bioversityinternational.org/>).

Cryo-conservation Center of Excellence for sub-Saharan Africa (CCESSA) [2005-8]

Biodiversity is under considerable threat, largely as a consequence of human activities, to the extent that some scientists consider us to be in the '6th extinction'. In response, Target 8 of the Global Strategy for Plant Conservation of the Convention on Biological Diversity (CBD, 2002) recommends that 60% of threatened plant species should be available in *ex situ* collections by 2010. The most cost-effective way of conserving plant genetic resources is as seed collections in seed banks, where the seeds are stored in dry state, and at low temperature and relative humidity (RH). Seeds that can be stored under these conditions are referred to as 'orthodox', and under the correct conditions can be stored, possibly, for centuries. However, seeds of a significant number of species cannot be stored in this manner, including many from the rainforest and numerous socio-economically important trees and palms and other horticultural species. For these species, alternative storage methods need to be developed. This project screened > 50 species for seed desiccation tolerance and cryopreservation (storage at ultra-low temperature, usually in liquid nitrogen vapour). The cryo-storage protocol often involves the isolation and storage of the embryonic axes and the findings are being used to facilitate generalised guidelines for the various axis types.

The project, which produced >10 scientific papers and trained numerous staff and students, is evolving into a national integrated programme for the cryo-conservation of South African plants and animals, with network opportunities to research groups elsewhere in the world. The project was supported by the UK Darwin Initiative (<http://darwin.defra.gov.uk/>) and led by Prof Pat Berjak (RSA; <http://www.ukzn.ac.za/plantgermcons/researchers2.htm>), Dr Chris Wood and Prof. Hugh W Pritchard (Kew). Significant research continues in this area within the institutes and through their membership of the International Seed Testing Association's Seed Storage Committee (<http://www.seedtest.org/en/tcom-sto.html>).

European Native Seed Conservation Network (ENSCONET) [2005-09]

<http://www.ensconet.eu/partners.htm>.

ENSCONET ran for 5 years from 2005 under the EU 6th Research Framework Programme. The objective was to optimise seed conservation practices and avoid the extinction of native species from Europe. Co-ordinated by staff of the Seed Conservation Department, ENSCONET consisted 24 different institutions in 18 European countries: UK, Greece, Slovakia, Hungary, Crete, Spain, Ireland, Cyprus, Belgium, France, Italy, Austria, Poland, Portugal, Germany, Finland, Norway, Bulgaria. Associate membership was extended to seven more institutes including in Luxembourg and Switzerland. Partners included European seed banks, botanical gardens and other institutes interested in seed conservation.

The European network aimed to make best use of time and resources by reducing duplication of effort. Collaboration improved the quality, co-ordination and integration of European seed conservation practice, policy and research for native plant species. ENSCONET also assisted EU conservation policy and its obligations to the CBD and its GSPC (CBD 2002).

ENSCONET worked on four activity areas: collecting, curation, data management and dissemination. ENSCONET has also produced: (1) ENSCOBASE – 'Virtual Seed Bank' –

online access to European native seed collection data including germination tests; (2) a seed collection manual – a guide to making quality, long-lasting seed collections from wild species; (3) curation protocols and recommendations – best practice seed curation practices.

The project was managed by Simon Linington and Dr Jonas Mueller (Kew).

EU COST Action 871 - Crop plant cryopreservation [2006/7 – 2010/11]

http://w3.cost.eu/index.php?id=181&action_number=871;

<http://www.biw.kuleuven.be/dtp/tro/cost871/STSM.htm>.

The Action has improved and applied technologically advanced techniques for plant genetic resources conservation of crops that are grown and/or conserved in Europe with the main emphasis on long-term conservation through cryopreservation. The Action has also deepened cooperation in Europe, by regular meetings, scientific contribution to international conferences and collaboration with industries, in order to comply with the secondary objectives: (1) to screen in detail the current utilisation of plant cryopreservation in Europe.; (2) to screen and compare the efficiency of existing plant cryopreservation protocols; (3) to improve fundamental knowledge about cryoprotection through the determination of physico-biochemical changes associated with tolerance towards cryopreservation; (4) to develop new plant cryopreservation protocols. These have been based on existing protocols (objectives 1 and 2) and new findings (objective 3): (5) to assure the genetic stability and true-to-typeness of plants after cryopreservation; (6) to apply cryopreservation to European plant germplasm collections; (7) to establish the environmental, social and economic impact of plant cryopreservation.

The project has involved scientists from 19 countries: Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Greece, Italy, Luxembourg, Netherlands, Poland, Portugal, Serbia, Slovak Republic, Slovenia, Spain, Switzerland, UK The project has been led by Dr Bart Panis (University of Leuven, Belgium) and involved Prof Hugh W. Pritchard (Kew) on the UK Management Board. Additional capacity building in this area is delivered through the MSc Biotechnology Course at the University of Bedfordshire, UK (<http://www.beds.ac.uk/courses/bysubject/biobiosci/msc-biotech>) and relevant conferences are staged by the Society for Low Temperature Biology (<http://www.sltb.info/>).

The Useful Plants Project (UPP) [2007-2010]

Project MGU - the Useful Plants Project (<http://www.kew.org/science-conservation/conservation-climate-change/millennium-seed-bank/using-our-seeds/helping-communities-worldwide/>) aims to increase the capacity of local communities to store and propagate plant species that are most useful to their wellbeing.

The Useful Plants Project began in June 2007, supported by a philanthropist based in Spain. The name MGU reflects the generous support provided by this philanthropist. The project works with collaborators in Botswana, Kenya, Mali, Mexico and South Africa. Many inhabitants in these countries depend directly on natural vegetation for everyday needs such as food, medicine, fuel and building materials. Plants are faced with a range of threats that include climate change, over-exploitation, shortage of water, habitat loss and invasion of exotic species. The Useful Plants Project will help communities to be better equipped to face such challenges by improving their livelihoods and using the surrounding resources in a more sustainable way; for example, the African baobab (*Adansonia digitata*), widely used by local communities in Africa as a source of water, food and medicine. In the participating countries, the main activities of the project include: (1) to identifying target species, through research and by engaging with local communities, that are most useful to people; (2) collecting and conserving seed in the countries where they are collected with duplicates stored at Kew's Millennium Seed Bank. This means that there is always a reserve of seeds available to

regenerate these plants in the future; (3) propagating plants and supporting *in-situ* conservation by working with local communities, through training and improvement of local facilities; (4) carrying out phytochemical studies on the most important medicinal plants to ensure sustainable harvesting; (5) progressing the ecophysiology of germination and development of tissue culture protocols when rare and threatened species are difficult to propagate by seed.

This project is managed by Dr Tiziana Ulian and Dr Paul Smith (Kew).

Orchid Seed Stores for Sustainable Use (OSSSU) [2007-12]

With around 25,000 species currently known to science, the orchid family is perhaps the largest and most diverse. Under current circumstances it is predicted that large numbers of orchids will become extinct in the wild within the next 50 years, making conservation an ever more urgent task (Seaton et al., 2010). This Darwin Initiative project is designed to establish orchid seed banking and biotechnology around the globe, through innovative research and sharing of data and knowledge.

The original aim of OSSSU was to collect and store seed of at least 250 species, focusing on orchid hot spots in the Asian and the Central and South American regions, representing the orchid floras of 15 participating countries: Bolivia, Brazil, Chile, China, Colombia, Costa Rica, Cuba, Ecuador, Guatemala, Indonesia, Mexico, Philippines, Singapore, Thailand and Vietnam. With associates joining from Italy, Spain and Estonia, and with many more interested parties, including India, the objective now is for OSSSU to evolve into the Global Orchid Facility (GOF). GOF will link about 40 institutes from 30 countries with the objective of conserving about 1000 orchid species and serving as an educational resource for scientists, the public and policy makers.

Regional workshops have been held in China, Ecuador and Costa Rica. Including cascade training, > 100 staff and students have received guidance in orchid biotechnology, supported by the publication of a technical volume on growing orchids from seeds in English, Spanish and Chinese.

The project (<http://ossu.org/>) is managed by Phil Seaton (p.seaton@kew.org) and led by Prof Hugh W Pritchard (Kew).

EU COST Action FA0901 - Putting halophytes to work: from genes to ecosystems. [2009-13]

The growing human population will present an increasing challenge to world agriculture that can only be met through the sustainable use of a broad range of habitats, including saline lands. Halophytes have evolved in saline habitats and are an untapped source of food, fibre and bioenergy. Deepening understanding of halophytes and saline ecosystems will help combat salinisation, soil erosion, loss of biodiversity and bioproductivity. The main objective of the Action is to collate existing knowledge of halophytes from gene function to ecosystems that will impact on conservation and management of saline environments and agricultural productions.

The Action has created an interdisciplinary group of scientists to bridge gaps between disciplines by jointly exploring the biodiversity of halophytes, re-evaluating their uses as crops, including bioenergy, as sources of salt-resistance genes and for use in the restoration and rehabilitation of salinized or contaminated land. The Action is tackling the problems of salt-affected agricultural land and supports the timely development of a saline agriculture using brackish water as a replacement or a supplement for diminishing freshwater. Twenty two countries are involved in the Action: Belgium, Bulgaria, Cyprus, Denmark, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Israel, Italy, Netherlands, Norway, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain, Sweden and the UK. (http://w3.cost.eu/index.php?id=181&action_number=FA0901)

The project is co-led by Prof Tim Flowers (University of Sussex, UK) and Dr Ilse Kranner (Kew) is on the UK Management Board.

Conclusion

The seed science and banking work of the Royal Botanic Gardens Kew has exponentially increased in the last decade through the development of strategic partnerships for plant science and conservation. In the eight network programmes covered here, main collaborations have extended to 65 countries (Table 2). Only through such international collaborations can global knowledge and conservation be progressed effectively and efficiently.

Tab. 2. Kew's main country collaborators in seed science and banking networks for plant conservation since 2000

Australia	Cyprus	Jordan	Romania
Austria	Denmark	Kenya	Serbia
Belgium	Ecuador	Lebanon	Singapore
Benin	Estonia	Luxembourg	Slovak Republic
Bolivia	Ethiopia	Madagascar	Slovenia
Botswana	Finland	Malawi	Spain
Brazil	Former Yugoslav Republic of Macedonia	Mali	Sweden
Bulgaria	France	Mexico	Switzerland
Burkina Faso	Germany	Namibia	Tanzania
Cape Verde	Ghana	Netherlands	Thailand
Chile	Greece	Niger	Togo
China	Guatemala	Nigeria	Uganda
Colombia	Hungary	Norway	
Costa Rica	Israel	Republic of South Africa	USA
Cote d'Ivoire	Indonesia	Philippines	Vietnam
Cuba	Italy	Poland	
Czech Republic	Ireland	Portugal	

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