Professor Kingsley Dixon, Director of Science at Kings Park and Botanic Garden in Perth, Western Australia, specialises in the ecology, restoration and conservation biology of Australian native plants and ecosystems. He has led the science group at Kings Park and Botanic Garden for the past 20 years in principles of integrated conservation science building a strong multi-disciplinary approach involving a number of key scientific disciplines. Research teams comprise scientists and postgraduate students specialising in seed ecology and biology, propagation science, germplasm conservation, conservation genetics and restoration ecology. This research group has contributed significantly to seed science in Australia, with major advances in understanding seed dormancy (pioneering work in smoke technology). Dr Dixon was instrumental over the past 12 years in leading and working with the research team that led to the discovery of a butenolide molecule responsible for eliciting smoke-like germination in seeds of Australian, agricultural and horticultural species. He is the inaugural Permanent Visiting Professor in the School of Plant Biology at The University of Western Australia.

SIBBALDIA GUEST ESSAY

THE SCIENCE-LIVING COLLECTIONS CONTINUUM IN BOTANIC GARDENS

Kingsley Dixon[1]

Botanic gardens represent a formidable force in conservation with almost 2500 botanic gardens located in 148 countries and housing 142 million herbarium specimens and over 6 million living plant accessions (www.bgci.org/botanic_gardens/). Dr Peter Wyse-Jackson, former Secretary General of Botanic Gardens Conservation International noted '… a new botanic garden is opened or announced each week somewhere in the world'.

Yet botanic gardens worldwide face an institutional dilemma. Mandated with conserving the world's flora (www.bgci.org/worldwide/gspc) they need to fast-track scientific approaches to address the urgent need for conservation solutions to the biodiversity crisis. Invariably, this call to arms requires a refreshed approach to utilising the resources across the garden – science, education, living collections. Whereas in the past there were direct links between the live plants in the collections and science, nowadays the links are more often than not tenuous, and at worst, non-existent. With the countdown to global biodiversity meltdown already underway and anticipated within the next 50 years, botanic gardens, as with other biological repository institutions are among the vanguard of institutions that need to demonstrate the ability of science to deliver operational actions.

Timely and effective conservation within the next decades will only deliver on the extinction crisis through integration – both at the intramural level where living collec-

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tions and science work hand-in-hand to deliver more effective, integrated conservation solutions, and at the institutional-community interface to deliver on-ground benefits. It behoves botanic gardens to seize the moment and ask the question, are they using their combined intellectual resources for conservation? Here, I examine the role of botanic gardens in conservation science and provide a road map for the development of more effective linkages between two significant resources, living collections and science.

Botanic gardens are well-placed to deliver global action for conservation of the world's plants. Botanic Gardens have a long-term perspective on maintenance of *ex situ* plant collections either as biodiversity banks (seed, DNA, living collections, cryogenic collections of mother tissue, symbionts) or herbaria. Indeed many major botanic gardens specifically support long-term conservation objectives underpinned by recurrent core-funding. A recent review by Dosmann (2006) views botanic garden collections as vibrant contributors to the scientific and cultural well-being of mankind. This same review, highlights that dwindling advocacy for collections-based research has placed a number of institutional collections at risk through lack of use.

The major *ex situ* germplasm banks of the world's agricultural and horticultural species maintained by government institutions represent major biological collections maintained outside of botanic gardens. Sadly there are examples of research institutions closing their botanical collections ostensibly because of lack of use or perceptions that the collections lack a sense of contemporary scientific or educational relevance.

In the modern research world of formula-driven funding particularly in universities, scientific activities will only exist if they directly or indirectly support revenue generation. Natural history collections are often the first casualties of this economic rationalist view. There are few examples outside botanic gardens where long-term curation of botanical collections remains as a core activity even with the best intention and endeavours of the research scientist. Gropp (2003) highlighted the plight of natural collections in universities showing that their living and herbarium collections where being closed or transferred to other institutions at an alarming rate. Dosmann (2006) attributes the apparent short-sightedness of institutions engaged in terminating natural history collections to a lack of institutional belief in a connection between these collections and their teaching and research mandates. What incredible research and teaching opportunities are being lost as collections are terminated or reassigned! Conversely who would argue that the 1.5 million specimens housed at the Royal Botanic Gardens Kew built up over 300 years of collection and curation is an institutional anomaly!

The value of collections-based research can have far-reaching benefits for global conservation and for building knowledge to tackle the extinction crisis. For example, building upon a sound taxonomic base, Kew now actively supports capacity-building of conservation science capabilities elsewhere in the world including scientific training programmes with gardens in developing countries, through to repatriation of data derived from their herbarium collections. The Madagascan rare plant conservation programme operated by Kew has delivered broader in-country benefits for Madagascan icon plant groups that are the target of horticultural over-collection – orchids, succulents and palms. The Madagascan programme produced the first comprehensive field guide (in three languages), graduate level training of Malagasy students, building of laboratory and nursery facilities and repatriation of conservation data for the benefits of Madagascan conservation.

Botanic gardens are extending their botanical reach with collaborative partnerships that are providing outstanding new insights into conservation of the world's plants. A partnership between Kew, the South African National Biodiversity Institute (a consortium primarily of botanic gardens) and others has challenged traditional conservation approaches by re-evaluation of the phylogenetic relationships for 9,000 plant species from South Africa. These data showed that the traditional approach to conserve areas of high species richness should be balanced by an approach that recognises genetic differences between species. This study will provide important directions for prioritising conservation areas particularly in global biodiversity hotspots. Kew is now embarking upon a similar collaborative scientific partnership to define conservation in another of the world's temperate global biodiversity hotspots in the South West Australian Floristic Region.

The direct value of living collections in botanic gardens for global conservation is highlighted by the recent example of *Rhododendron tuhanensis* (Fig.1) being saved from extinction by the plant collection work of the Royal Botanic Garden Edinburgh (RBGE). The blood-red *R. tuhanensis* discovered in 1995 during an expedition to the slopes of Mt Kinabalu in Borneo and maintained as a living collection in the RBGE was deemed extinct when a subsequent expedition to the site in 2006 failed to locate specimens (Anon, 2007). This species among many

Fig. 1 *Rhododendron tuhanensis* collected from Mount Kinabalu in Borneo in 1995. Photo: Lynsey Muir.

others provides an example of the type of activities that can be provided through a botanic garden's living collection.

Governments are also realising the value of natural history collections – both directly to humankind as well as for protection of biodiversity in the face of global climate change. The United Nations Food and Agriculture Organization estimates that 75% of the genetic diversity of agricultural crops has been lost over the last century highlighting the critical importance of germplasm collections. Effective seed banking can provide genetic insurance for future generations with estimates of the seed longevity for scientifically maintained collections estimated to be the hundreds or thousands of years (Engels and Visser, 2003). The value of even small collections of seed is highlighted in an example where, following the invasion of Iraq, the discovery of a small shoe-box sized container of seed, the remnant of an Iraqi seedbank, contained important seed for locally adapted crops (Clarke 2003). These examples provide evidence of the capability of seedbanks, particularly those supported by a long-term institutional mandate.

Botanic gardens are at the vanguard in the development of *ex situ* seedbanks as a means for conservation of the world's plants. The Millennium Seed Bank Project of the Royal Botanic Gardens Kew will by 2010 collect and store in-country and duplicated at their major facility in the United Kingdom, 10% of the world's flora. The Project has grown to include development of seedbanks in botanic gardens around the world with collaborative research programmes developing expertise to collect, store and germinate a wide variety of species, including rare and ethnobotanically important species.

The science, education and collections capabilities of botanic gardens also share a role with non-government organisations (NGO's) in global conservation. International NGO's play a major role in global biodiversity conservation and several, such as Conservation International and WFF, have strong links to the botanic garden community such as the $50M eco-partnership of the HSBC 'Investing in Nature' programme (www.hsbc.com/investinginnature). The science and collections capabilities of botanic gardens can provide crucial underpinning knowledge and research capabilities to enhance the effective, science-based delivery of conservation actions.

The plant collections (both living and dead) in botanic gardens represent a major global resource for biodiversity. Herbaria in botanic gardens and living collections representing 14 million accessions across with living collections representing nearly one quarter of the world's angiosperms. In addition, botanic gardens employ an estimated 1200 scientists in fields as diverse as the molecular and taxonomic sciences, conservation biology and restoration ecology. Graduate research programmes are a significant part of science initiatives in many botanic gardens with formal linkages with universities providing important botanical training. For example, Kings Park and Botanic Garden in Perth, Western Australia contributes a senior level programme in conservation biology and restoration ecology that is now the largest course of its type in Australia in the conservation sciences.

Scientists in botanic garden programmes are more often than not in tenured posts, providing the opportunity for long-term, strategic scientific programmes. Tenured posts provide the opportunity for the development of programmes that deliver on long term programmes such as major conservation initiatives (e.g. the Millennium Seed Bank programme) particularly when competitive funding programmes often only support research for moderately short periods, usually three years. An example of the success of botanic gardens' science is seen in The Angiosperm Phylogeny Group (APG), a consortium of phylogenists headed by scientists from the Joddrell Laboratory at Kew. The APG programmes (APG I and APG II) resulted in the most significant reassignment of angiosperm phylogenetic relationships and the greatest advance in classification of flowering plants since Linneaus. The Kew and associated DNA sequencing teams (including non-botanic garden scientists) achieved this milestone research through the use of the vast living collection resources and data repositories of the world's botanic gardens to obtain the critical samples for DNA analysis.

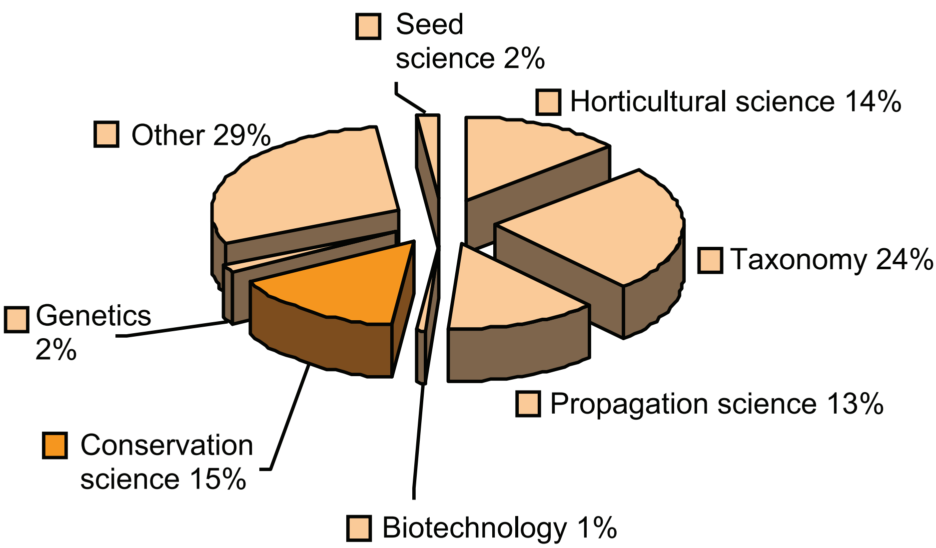

Fig. 2 Scientific activities in the world's botanic gardens sourced through BGCI and current as at 2002.

Natural history collections in botanic gardens by their very nature represent long-term historical cross-sections through a region's biota and present real opportunities for addressing some of the most pressing issues facing biodiversity. These collections provide data on location, habitat, life form and phenological attributes that can provide snapshots of past biogeographies, capabilities that are now proving to be invaluable for research into species and their dispersability over landscapes particularly those likely to be affected by global climate change. For example, Cambridge University Botanic Garden and Herbarium has the most extensive collections of British plants spanning almost 300 years of continuous records. These collections are now being used to map how species have modified distributions in response to climate change. Similar exercises are being undertaken through other herbaria in botanic garden to understand past distributions of plants and for estimating the likelihood of extinction events (see McInerny *et al.* 2006) and show the contemporary value of collections.

INTEGRATING SCIENCE WITH LIVING COLLECTIONS

Botanic garden's science has grown and developed from the earliest uses of living collections for training in medicinal properties in plants to the present, where teams of scientists embrace an impressive mandate of functions driven in part by the need for botanic gardens to deliver effective conservation of the world's flora. Initiatives such as the Global Strategy for Plant Conservation (GSPC), conceived through Botanic Gardens Conservation International (BGCI), provide a framework for progressing global conservation and provides a revitalised impetus for botanic gardens worldwide to deliver conservation particularly for rare and threatened species. For example, a survey of major European botanic gardens in 29 countries listed 105 gardens cultivating 308 of 573 threatened species listed under the Bern Convention (Maunder *et al.* 2001). Today, the breadth and complexity of research programmes in botanic gardens (Fig. 2) covers many areas of the botanical sciences and with the growing demand for conservation and restoration science services, now includes conservation biology and restoration ecology as foundation disciplines.

Annually botanic garden scientists represent a global research value estimated by me to be at least $100M p.a. (based on figures provided by BGCI in their review of botanic gardens – see www.bgci.org/botanic_gardens/) with global stand-outs including the Millennium Seed Bank Project and the Investing in Nature Programme coordinated by BGCI. Core science staff in botanic gardens are showing remarkable levels of innovation in developing botanic garden science through partnerships with academia, industry and the community (through volunteer science programmes). Reading annual reports from gardens such as the Chicago Botanic Garden and Royal Botanic Garden Sydney for example, show how scientific programmes have been leveraged with funding from competitive funding agencies and linkages with industry and academia. For example, the Kings Park Orchid Volunteers programme uses volunteers trained in sterile technique to assist the orchid conservation programme involving propagation of rare and endangered species for translocation programmes.

A trend in a number of botanic gardens is the research consortium approach. This concept aims to build and develop conservation and botanical science programmes through strategic partnerships with other institutions including botanic gardens, often involving integration across a number of disciplines. Take for example the 29 botanists of the first Angiosperm Phylogeny Group (APG I) representing the combined efforts of botanic garden botanists and research institution scientists from around the world. The research consortium approach is also reawakening scientists to the value of living collections held in botanic gardens whether this is by direct use of the collections for research and development (such as extraction of DNA from living specimens) or use of the horticultural expertise (for example, propagation knowledge for species in restoration programmes).

Botanic gardens by their small size, mandate and close links to practical horticulture have research and development programmes that can and do deliver outstanding community, industry and conservation benefits often involving links to their living collections capacity. The University of Wisconsin Arboretum developed one of the earliest restoration ecology programmes researching prairie ecology and restoration in the 1930's (Sachse 1965), programmes that continue today through other public gardens in the US. Singapore Botanic Garden was instrumental in the development of the rubber industry in SE Asia when the first seedlings arrived from Kew in 1877. Director of the gardens from 1878, Nicholas Ridley, spearheaded rubber cultivation techniques resulting in over seven million plants being sold out of the gardens and establishing Malaya as the world's leading producer and exporter of rubber. Singapore Botanic Garden also pioneered orchid hybridisation through Professor Eric Holttum, Director from 1925 to 1949. Holttum adapted the then newly developed asymbiotic propagation method for orchids discovered by Lewis Knudson (thereafter known as the Knudson C formulation) making Singapore Botanic Gardens the foremost centre for commercial orchid growing. In more recent times, Kings Park and Botanic Garden in Western Australia was responsible for developing the first molecular fingerprint for a rare plant species, the Corrigin Grevillea *Grevillea scapigera* and was the first institution to cryogenically store organised tissues of a same plant (Touchell *et al*, 1992; Rossetto et al. 1995).

One of the more significant innovations by a botanic garden in horticulture and ecology in recent times was the discovery in the 1990's by Kirstenbosch Botanic Gardens scientists Johannes de Lange, C Boucher and Neville Brown that smoke, rather than heat and ash from wild-fires was the agent most responsible for triggering germination after fire. Their discovery resulted in a revolution in seed propagation for rare and endangered species, restoration ecology and species for commercial horticulture. Importantly the discovery spawned smoke as a research tool for understanding the recruitment biology for many species from fire-prone habitats resulting in almost 200 scientific publications (see the following references for examples of the applications of smoke technology – Roche *et al*. 1994, Dixon *et al*. 1995, Roche *et al*. 1997, Roche *et al*. 1998, Lloyd *et al*. 2000, Flematti *et al*. 2004, Crosti *et al*. 2006).

Innovation and adaptability have been the hallmarks of botanic gardens. But the outstanding success stories are those where the science and collections (horticulture) have worked hand-in-hand to take a discovery beyond the pure science. Whether the rubber programme of the Singapore Botanic Garden, rare plant conservation, ecological restoration programmes or the smoke story, the big advances have been made when scientists and horticulturists have collaborated to take a scientific finding to the broader community.

The task for botanic gardens is how to foster and maintain botanic gardens science and the collections connections so that the links are vital while respecting the unique capabilities of each partner in the collaboration. The challenges are formidable but not insurmountable. For each successful story of collaboration there are as many where collaborations between scientists and their living collections branches are weak, non-existent and, in rare cases I have witnessed almost open hostility between the science and living collections. Naturally, when you have highly qualified doctoral level professionals working with horticulturists, misunderstandings of the skills and abilities of the parties are possible. Indeed the widely accepted indicators of research performance in botanic gardens (publication record, grant success and student completions) on the surface appear very different from the performance indicators used in collections i.e. number of accessions. However both research and collections share a common purpose – the pursuit of excellence, whether this is perfecting a potting mix for a rare species or cracking the gene sequence for a rare species.

How can a botanic garden as a research and collections institution foster collaboration between scientists and horticulturists? I believe that there is no single solution but rather a continuum of opportunities that need to be encouraged and supported by collaborative successes that are institutionally acknowledged and celebrated. A key ingredient in starting collaborative linkages between collections and science is to look for the common ground. In a botanic garden this should be easy as most people work in a botanic garden because of a mutual interest in plants, their ecology, conservation and horticulture. In fact natural history collections are unique as research institutions as most staff have a strong personal interest in their study organisms. There are examples of genus-based collections in botanic gardens that have been built up over a lifetime of collecting and research effort by individual(s). Examples of horticultural excellence abound where horticulturists have devoted whole careers to mastering the horticulture of a particular plant group built upon a natural drive and enthusiasm for plants. With such potent foundations for building collaborations how can an institution move to capitalise on these benefits.

Closing the loop or bridge-building between science and living collections requires a multi-pronged approach. The following synopsis provides what I believe to be an approach that provides a useful template for developing and sustaining a science-living collections continuum that has real potential for invigorating and sustaining the scientific and horticultural abilities found in botanic gardens.

- Institutional advocacy for ('missionise') the science-living collection interface at all levels.
- The approach should be adaptable, flexible and responsive to contemporary issues such as global climate change.
- Actively engage all parties in building partnerships and collaborations including joint grants and publicity, shared student research programmes an education.
- Actively use and embrace each other's unique skills and attributes and corporately celebrate collaborative successes.
- Value-add the science-living collections continuum with external sponsors and stakeholders – for example, resource companies are more impressed and likely

to support programmes that show that science can lead to better plants in their restoration programmes.
- Ensure an open, free-flow of information between science and living collections.
- Administratively link organisational goals to collaborative successes through innovative use of performance indicators e.g. an indicator might be the number of collaborations between science and living collections that result in joint publications.
- Adoption of a science-based approach across the institution. For example, ensuring that horticultural developments are based on the outcomes of hypothesis driven experimentation.

Science (including herbaria) and living collections in botanic gardens provide unprecedented opportunities for research solutions to biodiversity loss in our contemporary world. To ignore the outcome multiplier effect that can result from a vibrant science-living collections continuum is to ignore the very origins of botanic gardens as scientifically-based living collections.

EPILOGUE

When asked recently what I saw as the key aspirations for the science team in Kings Park and Botanic Garden I thought for a moment and said, *pursuit of excellence, generation of knowledge, enjoyment of discovery*. Surely the same three concepts underpin horticulture in a botanic garden– what could be more satisfying in a botanic garden context than to have a vibrant culture where science and horticulture seamlessly intergrade. Whatever the value, intrinsic or otherwise of science in botanic gardens the challenge remains to integrate and value-add the two-way integration of science and collections.

From the earliest stirrings of botanic gardens to the present, botanic gardens have impressed their visiting public with their displays of botanical curiosities and as places of spiritual refreshment. However in a changing world where man's footprint threatens biodiversity and even the habitability of the planet, the time is ripe for botanic gardens to engage with their own staff to meet these new conservation and environmental challenges. Working together to enrich our knowledge to arrest the decline of the earth's natural resources should be the mantra for all botanic gardens.

BIBLIOGRAPHY

ANON (2007). *Cuttings* 4(2). Botanic Gardens Conservation International.

CLARKE, T. (2003). Seed bank raises hope of Iraqi crop comeback *Nature*. 17;424(6946):242.

CROSTI, R., LADD, P.G., DIXON, K.W. AND PIOTTO, B. (2006). Post-fire germination: The effect of smoke on seeds of selected species from the central Mediterranean basin. *Forest Ecology and Management* 221: 306–312.

DOSMANN, M.S. (2006). Research in the Garden: Averting the Collections Crisis. *The Botanical Review*. 72 (3): 207–234.

DIXON, K.W., ROCHE, S. AND PATE, J.S. (1995). The promotive effect of smoke derived from burnt native vegetation on seed germination of Western Australian plants. *Oecologia* 101: 185–192.

ENGELS, J.M.M., VISSER, L. (2003). Genebank management procedures. Pp.60–79 in Engels and Visser (Eds) *A Guide to efective management of germplasm collections. IPGRI Handbook for Genebanks No.6*. International Plant Genetic Resources Institute, Rome.

FLEMATTI, G.R., GHISALBERTI, E.L., DIXON, K.W. AND TRENGOVE, R.D. (2004). A compound from smoke that promotes seed germination. *Science* 305: 977 (13 August 2004). Published online 8 July 2004; DOI: 10.1126/science.1099944.

FOREST, F., GRENYER, R., ROUGE, M., DAVIES, T.J., COWLING, R.M., FAITH, D.P., BALMFORD, A., MANNING, J.C., PROCHES, S., VAN DER BANK, M., REEVES, G., HEDDERSON, T.A. AND SAVOLAINEN, V. (2007). Preserving the evolutionary potential in biodiversity hotspots. *Nature*, 445, 457–460.

GROPP, R.E. (2003). Are University Natural Science Collections Going Extinct? *Bioscience* 53 (6): 550.

LLOYD, M., DIXON, K.W. AND SIVASITHAMPARAM, K. (2000). Broadscale application of smoke for restoration of remnant vegetation and mined lands. In C.J. Asher & L.C. Bell (Eds) *Proceedings of the third Australian workshop on native seed biology for revegetation*. 17–18 May 1999, Perth, Western Australia. pp. 237–241. Australian Centre for Mining Environmental Research, Brisbane.

MAUNDER M., HIGGENS, S. & CULHAM, A. (2001). The effectiveness of botanic garden collections in supporting plant conservation: A European case study. (19)383–401.

MCINERNY, G.J., ROBERTS, D.L., DAVY, A.J. and CRIBB, P.J. (2006) Significance of sighting rate in inferring extinction and threat. *Conservation Biology* 20 (2), 562–567.

ROCHE, S., DIXON, K.W. AND PATE, J.S. (1994). Smoke – a new process for germinating Australian plants. *Australian Horticulture* 91: 46–48.

ROCHE, S., DIXON, K.W. AND PATE, J.S. (1997). Seed Ageing and Smoke: Partner Cues in the Amelioration of Seed Dormancy in Selected Australian Native Species. *Australian Journal of Botany* 45: 783–815.

ROCHE, S., DIXON, K.W. AND PATE, J.S. (1998). For everything a season: Smoke-induced seed germination and seedling recruitment in a Western Australian *Banksia* woodland. *Australian Journal of Ecology* 23: 111–120.

ROSSETTO, M., WEAVER, P.K. AND DIXON, K.W. (1995). Use of RAPD analysis in devising conservation strategies for the rare and endangered *Grevillea scapigera* (Proteaceae). *Molecular Ecology* 4: 321–329.

SACHSE, N.D. (1965). A thousand Ages: The History of the University of Wisconsin Arboretum. Univ. Wisconsin Arboretum, Madison.

TOUCHELL, D.H., DIXON K.W. AND TAN B. (1992). Cryopreservation of shoot-tips of *Grevillea scapigera* (Proteaceae): a rare and endangered plant from Western Australia. *Australian Journal of Botany* 40: 305–10.