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The Importance of Biological Collections for Biosecurity and Biodiversity

Joanne Daly & Megan Clark

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Megan Clark

The Importance of Biological Collections for Biosecurity and Biodiversity

JOANNE DALY AND MEGAN CLARK

CSIRO, PO Box 225, Dickson, ACT 2602, Australia

Sustainable food production depends on well functioning agro-biological ecosystems: a diversity of living organisms—the biodiversity—plays a critical role in the function of these ecosystems, particularly in the way in which biotic and abiotic processes shape agricultural productivity and sustainability. Biological collections are the repository for this biodiversity information and there is a strong track record of the knowledge generated from these collections improving sustainable food production and ultimately food security. However, the way these collections are used, and indeed what they are comprised of, is undergoing rapid change. The collections themselves are moving from repositories of our flora and fauna to warehouses of species data, spatial ecosystem models, digital images, tissues, genetic sequences and information. Furthermore, our tools include genomics and informatics which provide

an explosion of information that we now can mine in new ways we have never been able to do before. One example is the *Atlas of Living Australia* that will bring together all relevant biological knowledge of Australia's biota. But we need to do more, including using automation to harvest new knowledge and insights. It is critical that our science remains at the forefront with our collections being connected at a global level if we are to make a genuine difference. It will be a challenge to fund what is required, but we need to remember that what we are talking about is life on earth. There are exciting opportunities to more effectively manage and value our biodiversity as well as deliver biosecurity to maintain our productivity and prosperity as a nation. Our national efforts can also contribute to global solutions to challenges such as food security and environment degradation.

DR MEGAN CLARK is the Chief Executive of the CSIRO. She has a BSc with Honours in Economic Geology from the University of Western Australia, and a PhD in Economic Geology from Queen's University in Canada. She is a member of the Prime Minister's Science, Engineering and Innovation Council (PMSEIC); St Vincent's Hospital Foundation Board, National Research Innovation Committee Panel and the Automotive Industry Innovation Council. She began her career as a mine geologist and worked in mineral exploration, mine geology, R&D management, venture capital and technical strategy areas with Western Mining Corporation for fifteen years. More recently she was Vice President Technology and prior to that Vice President, Health, Safety, Environment, Community and Sustainability with BHP Billiton. In 2006 she was elected Fellow of the Australian Academy of Technology Science and Engineering and awarded an Honorary Doctor of Science Degree by the University of Western Australia.

The biological challenge

We live in times of unprecedented challenges (and opportunities) for humankind. During 2008, for the first time, we reached the point where more than 50% of the world's population was in urban environments and dependent on others for their food supply (UNFPA 2007). With projected population increases, we could see over 9 billion people on the planet by 2050 and over two-thirds of these in cities.

Others in these proceedings have discussed the global challenge of food security. To address this challenge we will require unprecedented amounts of data about the world in which we live. For living organisms, the core of this information has been organised around species with traditional identifications dependent on material held in natural history collections. These collections are more than just of historical interest—they remain

as important to our future as they have been in our past. Global challenges of the 21st century need 21st century collections. So collections of the future must go beyond pinned specimens in museum drawers. New technologies are expanding collections to include virtual as well as physical data—images, gene sequences and ecological data are part of the modern collection. Indeed, collections need to become ‘data factories’ that will build the knowledge base of life on earth.

A range of factors impinge on the relationship between food security and biodiversity, but we will highlight four: population growth, sustainable health of our land, biosecurity and climate change.

Population growth and its impact on food supply

More people need more food. Keating and Carberry (2010) modelled food demand for a global population of 9.1 billion. They found that food demand in 2050 could be 30–80% higher than in 2010. The variation in their estimates depended on assumptions about growth of food consumption in developing countries and the level of diversion of food to biofuels. For the higher levels of these, demand for food production for the period 2000 to 2050 was about the same as the accumulated food production estimated over the previous 400 years (1600–2000). It may come as a surprise that since the middle of the 20th century, global agricultural output has more than kept pace with a rapidly growing population. Between 1961 and 2008, the world’s population increased by 117% whereas food production (in calorific value) rose by 179% (Keating and Carberry 2010).

We may be entering a period of enhanced volatility in food prices as the balance between food supply and demand gets tighter—if this is indeed the case it will have greatest impact on the world’s poor and vulnerable communities. In 2007–2009, global food stocks were at a record low; supply was constrained in some key grain-producing regions and diversion of food to biofuels increased rapidly. Not surprisingly, prices rose two- to three-fold (FAO 2010). Prices then stabilised and stocks of wheat have partly recovered, although in August 2010 wheat prices again climbed to a two-year high after the failure of the Russian wheat harvest (Polansek 2010). This is a grim reminder of how quickly we can move from a demand-constrained to a supply-constrained market. We have witnessed similar rapid market changes in the inelastic and regionally constrained

iron-ore markets in the last few years on the back of demand from China.

Despite some recovery, food markets remain volatile. A recent Australian example is the Indonesian beef market that constitutes 81% of the live cattle trade out of Australia. In June 2010 the Indonesian authorities enforced an upper limit of 350 kg live-weight on all live cattle imports. The market reacted and prices increased for animals less than this weight but exporters are now concerned about what to do with heavier animals. This in turn may upset market certainty and flow onto future supply and demand (Condon 2010).

Sustainable health of our land

More people need more land. Biodiversity is an integral part of the sustainable health of our land—the very resource that we rely on for food production. It is estimated that only about 9% of the projected growth in food production in the next 40 years is likely to come from expansion in the area of land under cultivation, and this will be in developing countries. The dominant source of growth in food production will need to come from intensification of agriculture, either through increased cropping intensity (14%) or more significantly, yield increases (77%) (Bruinsma 2009). The limited capacity to expand land under cultivation is illustrated by the current position in China. Estimates are only approximate, but Xie and colleagues (2005) reported a drop of about 7 million ha in arable land in China between 1996 and 2003 of a total of about 130 million ha. This was due to a range of factors and included the spread of urban environments, degradation of farmland, the return of land to forestry or set aside for conservation uses (see also Lohmar and Gale 2008).

Sustainable food production systems depend on healthy and functional agricultural ecosystems. These systems are dynamic, with the often unseen components of biodiversity keeping our ecosystems healthy. Their biodiversity provides for nutrient flows—through healthy soils, through new genetic traits for yield. Biodiversity also provides the pollinators and interdependencies that produce healthy plants and animals. A balance of organisms in soil and water systems is critical to their health.

Yet our land has issues of water security and a degrading ecosystem. This concern underpins one of the Millennium Development Goals—that of ensuring environmental sustainability. What is

required is a more fundamental understanding of the food systems, how they are governed and how to integrate the various research streams to address both conservation issues and food security challenges in a holistic way.

Biosecurity

This is a global issue and is one of the threats to food production and biodiversity. Lois Ransom [these proceedings page 22] has described the risks to Australia from incursion of unwanted organisms. These invasive species are a threat both to agricultural systems as well as native ecosystems. One estimate put the cost of invasive species in the US alone at over US\$120 billion per year (Pimentel *et al.* 2005).

Responding to climate change

The last issue relates to how environments are responding and adapting to climate change. Climate is not only changing, it is moving, and with it, move species, both foreign and native, as they respond to the changing climatic conditions and invade new areas. New associations between plants, and between plants and other species that depend on them, also will occur and new ecosystems will emerge.

So in summary, the challenge is that we need to grow more food, on landscapes already under pressure, and in the face of imminent climate change (FAO 2009) with increasing shortages of water and nutrients in many parts of the world; all this while we conserve and sustainably use our biodiversity. A study for the UN has estimated that the cost of failure to halt biodiversity loss on land alone, over the last 10 years, has been around \$500 billion (CBD 2009).

Collections as part of the solution

If we are to further develop and maintain sustainable agro-ecosystems, then we must achieve better management of our biodiversity resources. This involves knowing what organisms exist, how they interact, and how diversity changes and develops under environmental shocks. Biological collections provide the framework to define species level information—they are integral to that knowledge base, providing the key that links a wide range of biological knowledge to a defined species.

Collections and taxonomy

When we think of collections we usually think ‘taxonomy’. This is because taxonomists are the primary developers and users of collections as they organise life on earth into identifiable and distinct biological components. This allows us to integrate a range of different information around a common biological entity, such as a species.

Yet for collections to achieve their full potential, they need to deliver relevant information to a wide range of users. The Millennium Ecosystem Assessment (2005, p.14) said: *A major obstacle for knowing (and therefore valuing), preserving, sustainably using, and sharing benefits equitably from the biodiversity of a region is the human and institutional capacity to research a country’s biota.*

Taxonomy is at the core of this capacity. The impact of taxonomy on agricultural systems is clear. BioNET- INTERNATIONAL (2010) provides numerous cases showing a cost:benefit ratio of 1:50 to 1:700 for taxonomic intervention in pests. For example, Watts and colleagues (2008) have recently confirmed that the Australian invasive weed, *Lantana camara*, is a single species and not a hybrid swarm. They demonstrated that while the populations introduced into Australia did not come from a single location overseas there was a strong influence of material from Venezuela and the Caribbean. So it is unfortunate that earlier, unsuccessful, attempts at bicontrol of this invasive weed in Australia have sourced less than 10% of their 28 agents from this overseas region. A taxonomic approach will allow a better targeting of agents in the future.

Taxonomy also plays a vital role in border protection as it underpins our ability to diagnose problems. For example, in February 2004, a shipment of wheat destined for Pakistan was rejected because of alleged infestation by a serious fungal disease called Karnal bunt (ABC Rural 2004). Australian taxonomists were urgently called upon to assist in the resolution of the issue. They demonstrated that the infestation was a related and harmless native species of bunt (Pascoe *et al.* 2005; Taxonomy Australia 2008).

The application of collections and taxonomy to real problems, such as these, goes to the heart of CSIRO’s strategy for developing and sustaining biological collections. Our collections arose out of our early scientists’ work in applied ecology as they found they could not address the major

problems in agriculture in the 1930s and 1940s without dealing with the taxonomy of the pests. We believe this connection to applied biology will need to be a key driver in our collection strategy in the future.

Collections as living material

In addition to natural history collections, collections can also be of live material. Usually these types of collections are limited to a number of crops species and their close relatives, and are used as source material for breeding new varieties, for increasing yields, changing the characteristics of the crop or in response to biosecurity threats. For example, the spread of the wheat rust Ug99 throughout the world poses a major challenge to global wheat production (Stokstad 2007). Australian scientists are part of the Borlaug Global Rust Initiative that is looking across different races of wheat for diverse sources of resistance. Researchers at CSIRO have developed robust DNA markers to track several effective rust-resistance genes against Ug99 to speed up breeding applications (Ayliffe *et al.* 2008). Medium- to long-term strategies are aimed at uncovering new sources of broad-spectrum resistance in the wheat gene pool; using rust pathogen biology to identify new resistance genes; and exploring why rice is the only cereal crop with complete immunity to rust diseases (Ayliffe *et al.* 2010).

The use of living collections can go beyond the bounds of crop species. One example is the Australian National Algae Culture Collection (CSIRO Hobart) that has 1000 strains of more than 300 microalgae species—microscopic plants that inhabit the world's oceans and other aquatic environments. These algae are responsible for at least half of global primary productivity, converting solar energy to organic energy and fixing carbon dioxide in the process. Microalgae are rich in bioactive compounds and a source of genes for unique biosynthetic pathways, yet are a largely untapped resource, with only 10% of some 40 000 species isolated and cultured.

The CSIRO algal collection has been used as a resource for research on algal diversity, distribution, richness and taxonomic relationships, including those of economic importance and environmental concern (CSIRO 2010). In the last decade it has provided CSIRO researchers with a source of genes for the introduction of microalgal omega-3 LC-PUFA biosynthetic pathways into crop plants, thus opening up potential new path-

ways to ensure the supply of this essential oil for the future (Petrie *et al.* 2009). Exopolysaccharides from the micro-organisms are being investigated for new, bio-inspired adhesives as well as for medical, environmental and industrial use.

Collections as key knowledge

One of the great challenges for collections is their need to embrace the future and all the technological developments that are now available. The detailed and focused approach of traditional taxonomy will not deliver knowledge about our biodiversity at the rate needed to meet the challenges of landscape degradation and climate change impacts (Lane 2008).

In recent years, our views about taxonomy and species have been challenged by genomics projects that have turned the once cottage industry of taxonomy into an industrial-scale endeavour. Our estimate of the number of species on the planet has risen from just under 2 million to 10 million or more (Chapman 2009). The additional species are very small and are not readily amenable to traditional taxonomic treatment. Indeed in soil biology, and in the sea, many of these microbial species may never be named but merely known through fragments of their genetic code.

It is not possible, however, to ignore these very small species as curiosities, as they appear to be key components in the nutrient ebbs and flows in our ecosystems. Genomics can be used to determine what species are present and to look at their function. This is a new field of discovery called 'ecogenomics' that enables us to characterise an entire ecosystem. Venter and colleagues (2004) trawled the Sargasso Sea to sample and subsequently sequence whole communities of micro-organisms to yield new insights into oceanic carbon and energy cycles. Closer to home, Chanton and colleagues (2010) used next-generation sequencing technologies to characterise the health of ecosystems in contaminated estuarine sediments in eastern Australia.

This intersection between taxonomy, genomics and ecology is illustrated by Miller and colleagues from the Centre for Plant Biodiversity Research (Canberra). They are using DNA sequence data to study a range of Australian *Acacia* species to explore how they interact with other organisms—such as the nitrogen-fixing bacteria in their root nodules and the thrips that form abnormal growth (or galls) of plant tissue. This is the face of modern taxonomy, where the genetic code is analysed

by high-speed computers to understand co-evolutionary relationships at their most basic level. New fundamental insights will emerge that will be applicable for other domains of biodiversity research (Murphy *et al.* 2010).

To help us deal with the many new species revealed by these modern approaches, the biodiversity informatics community is developing a more contemporary way of naming species. These *Globally Unique Identifiers* in the form of Life Science Identifiers (2010) can be used for all biological names in current use as well as identifying new species. This is equivalent to ‘tagging’ them with a unique tax file number that identifies them and links to information about them.

One project that draws together the elements of genomics with unique identifiers is *The International Barcode of Life* project (iBOL 2010). This global initiative aims to construct a DNA reference library that can be used as an identification system for all multi-cellular life. It is the largest biodiversity genomics initiative ever undertaken and is an illustration of taxonomy on an industrial scale. Hundreds of biodiversity scientists, genomics specialists, technologists and ethicists from 25 nations are working together to construct the database. Their basic material is specimens from natural history museums, herbaria, zoos, aquaria, frozen tissue collections, seed banks, type culture collections and other repositories of biological materials that are treasure troves of identified specimens (iBOL 2010).

Images are also critical to collections of the future. The use of high-resolution images to assist with diagnosis of pests and diseases is at the forefront of modern biosecurity. The Pests and Disease Image Library (PaDIL 2010) is an Australian example. These images can be supported by remote microscopy tools that can assist distance identification of potential invasive species in real time. The Cooperative Research Centre for National Plant Biosecurity is working with its partners to support the use of remote microscopy not only in Australia but also in SE Asia (Kong and Thompson 2009).

These examples illustrate how physical collections are being drawn into the virtual world to become ‘data factories’. The challenges, though, are considerable as we will have to integrate and aggregate data that was never collected with this use in mind. The power of the internet and of computers will be needed to link and interrogate

large and complex datasets across institutional and international boundaries, including relating biological data with soil and climate information. Central to these achievements will be international programs like *The Global Biodiversity Information Facility* (2010) that provides the standards and tools to aggregate data globally. *The Encyclopedia of Life* (2010) and our own *Atlas of Living Australia* (2010) combine these accessible data to produce valuable end-products and provide new insights into our biodiversity.

The new types of knowledge to be generated will have wide application in areas as diverse as land-use planning, protection of threatened species, managing negative environmental impacts and restoring and preserving endangered habitats. No doubt they will also provide many reasons for us to simply delight in all the wonder of life on earth.

Conclusion: the way forward

Food security is a key challenge for humanity. Sustaining the world’s food systems implies sustaining the biodiversity that underpins healthy, functional ecosystems. Collections play a key role in providing the underpinning knowledge about our biodiversity to help in its management. Finally, these collections must embrace the future and evolve to include a much wider set of tools and methods that will revolutionise our collection-based work. Maintaining well-resourced and well-connected biodiversity collections is absolutely fundamental to help us in addressing the food security challenge. We can, and must, connect and integrate across the molecular scale right up to ecosystem level. Collections can be at the heart of this knowledge. They can be leaders into the future as well as reminders of the past.

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References

- ABC Rural 2004. Further tests for Karnal bunt on wheat shipments. Reported on 27 February 2004.
<http://www.abc.net.au/rural/news/stories/s1054766.htm>
- Atlas of Living Australia*. Viewed August 2010.
<http://www.ala.org.au/>

- Ayliffe, M., Singh, R. and Lagudah, E. 2008. Durable resistance to stem rust needed. *Current Opinions in Plant Biology* **11**, 187–192.
- Ayliffe, M., Jin, Y., Steffenson, B., Kang, Z., Wang, S. and Leung, H. 2010. Molecular-genetic dissection of rice nonhost resistance to wheat stem rust. In: McIntosh, R.A. (ed.) *Borlaug Global Rust Initiative 2009. Proceedings of a Technical Workshop held at Obregon, Mexico 17–20 March 2009*. Cd. Obregon, Mexico, BGRI, 268 pp; pp. 103–109.
- BioNET-INTERNATIONAL 2010. *Why Taxonomy Matters—Case Studies*. Viewed September 2010.
<http://www.bionet-intl.org/opencms/opencms/caseStudies/caseStudies/list.jsp>
- Bruinsma, J. 2009. The resource outlook for 2050: by how much do land, water, and crop yields need to increase by 2050? *Background paper for High-Level Expert Forum 'How to Feed the World in 2050'*. FAO, Rome, 24–26 June 2009. 33 pp. Viewed October 2009.
<http://www.fao.org/wsfs/forum2050/wsfs-background-documents/wsfs-expert-papers/en>
- CBD (Secretariat of the Convention on Biological Diversity) 2009. *Biodiversity, Development and Poverty Alleviation. Recognising the Role of Biodiversity for Human Well-Being*. Montreal, Secretariat of the Convention on Biological Diversity, 52 pp.
- Chapman, A. 2009. Numbers of living species in Australia and the world. Report for the Department of the Environment and Heritage, Canberra, Department of the Environment and Heritage, 60 pp.
- Chariton, A.A., Court, L.N., Hartley, D.M., Colloff, M.J. and Hardy, C.M. 2010. Ecological assessment of estuarine sediments by pyrosequencing eukaryotic ribosomal DNA. *Frontiers in Ecology and the Environment* **8**, 233–238.
- Condon, J. 2010. Top End cattle prices 'polarised', 15 July 2010 *North Queensland Register*. Viewed August 2010.
<http://nqr.farmonline.com.au/news/state/livestock/cattle/top-end-cattle-prices-polarised/1886499.aspx>
- CSIRO 2010. *Australian National Algae Culture Collection*. Viewed September 2010.
<http://www.csiro.au/places/Australian-National-Algae-Culture-Collection.html>
- Encyclopedia of Life*. Viewed August 2010.
<http://www.eol.org/>
- FAO 2009. Global agriculture towards 2050. *High Level Expert Forum 'How to Feed the World 2050'*. Rome, 12–13 October 2009. Food and Agriculture Organisation of the United Nations, Rome, 4 pp.
- FAO 2010. *Crop Prospects and Food Situation*. Viewed August 2010.
<http://www.fao.org/docrep/012/ak347e/ak347e00.pdf>
- Global Biodiversity Information Facility*. Viewed August 2010. <http://www.gbif.org/>
- iBOL 2010. Barcode of life—identifying species with DNA barcoding. *International Barcode of Life*. Viewed September 2010.
<http://www.barcodeoflife.org/what-is-ibol/>
- Keating, B.A. and Carberry, P.S. 2010. Sustainable production, food security and supply chain implications. *Aspects of Applied Biology* **102**, 7–19.
- Kong, G. and Thompson, M. 2009. Remote microscopy has landed in south east Asia. Viewed September 2010.
<http://www.crcplantbiosecurity.com.au/content/remote-microscopy-has-landed-south-east-asia>
- Lane R. (Chair) 2008. *Taxonomy in Europe in the 21st Century. Report to the Board of Directors European Distributed Institute of Taxonomy*. 7 pp. Viewed April 2010.
<http://ww2.bgbm.org/EditDocumentRepository/Taxonomy21report.pdf>
- Life Sciences Identifier Resolution Project*. Viewed August 2010. <http://lsids.sourceforge.net/>
- Lomar, B. and Gale, F. 2008. Who will feed China? *Amber Waves* **6**(3), 10–15. Economic Research Service, USDA. Viewed 20 September 2010.
<http://www.ers.usda.gov/AmberWaves/June08/PDF/ChinaFeed.pdf>
- Millennium Ecosystem Assessment 2005. *Ecosystems and Human Well-being: Biodiversity Synthesis*. World Resources Institute, Washington, DC, 100 pp.
- Murphy, D.J., Brown, G.K., Miller, J.T. and Ladiges, P.Y. 2010. Molecular phylogeny of *Acacia* s.s. (Mimosoideae: Leguminosae)—evidence for major clades and informal classification. *Taxon* **59**, 7–19.
- PaDIL 2010. *Pests and Disease Image Library*. Viewed September 2010.
<http://www.padil.gov.au/>
- Pascoe, I.G., Priest, M.J., Shivas, R.G. and Cunningham, J.H. 2005. Ustilosporous of *Tilletia*

- ehrhartae*, a smut of *Ehrharta calycina*, are common contaminants of Australian wheat grain, and a potential source of confusion with *Tilletia indica*, the cause of Karnal bunt of wheat. *Plant Pathology* **54**, 161–168.
- Petrie, J.R., Shrestha, P., Mansour, M.P., Nichols, P.D., Liu, Q. and Singh, S.P. 2009. Metabolic engineering of omega-3 long-chain polyunsaturated fatty acids in plants using an acyl-CoA $\Delta 6$ -desaturase with $\omega 3$ -preference from the marine microalga *Micromonas pusilla*. *Metabolic Engineering* **12**, 233–240.
- Pimentel, D., Zuniga, R. and Morrison, D. 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. *Ecological Economics* **52**, 273–288.
- Polansek, T. 2010. Wheat prices surge to two-year high as Russia bans grain exports. *The Wall Street Journal*, August 06, 2010 8:38 am, Viewed August 2010.
<http://www.theaustralian.com.au/business/news/wheat-prices-hit-two-year-high-as-russia-bans-grain-exports/story-e6frg90x-1225901936007>
- Stokstad, E. 2007. Deadly wheat fungus threatens world's breadbaskets. *Science* **315**, 1786–1787.
- Taxonomy Australia 2008. *Australia's Biological and Genetic Revolution—A plan for Future Innovation in Australia's Biological Resources. Response to the Review of Innovation*. Viewed September 2010.
http://www.innovation.gov.au/innovationreview/Documents/129-Taxonomy_Australia.pdf
- UNFPA (United Nations Population Fund) 2007. *State of the World Population 2007—Unleashing the Potential of Urban Growth*. Viewed September 2010.
<http://www.unfpa.org/swp/2007/english/introduction.html>
- Venter, J.C., Remington, K., Heidelberg, J.F., Halpern, A.L. et al. 2004. Environmental genome shotgun sequencing of the Sargasso Sea. *Science* **304**, 66–74.
- Watts, R., Wang, X., Connors, J. and Lepschi, B. 2008. *Systematics of Environmental Weeds 5.1: Assessing the Origins and Diversity of Lantana in Australia*. Viewed September 2010.
http://www.taxonomy.org.au/weeds_5.1.html
- Xie, Y., Yu, M., Tian, G. and Xing, X. 2005. Socio-economic driving forces of arable land conversion: a case study of Wuxian City, China. *Global Environmental Change* **15**, 238–252.