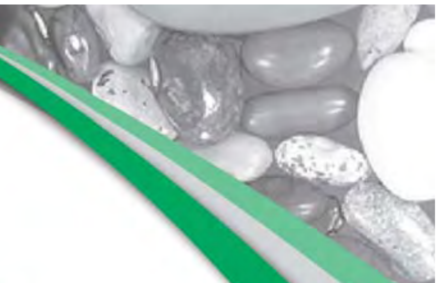

THE CRAWFORD FUND
For a Food Secure World

BIODIVERSITY AND WORLD FOOD SECURITY:

NOURISHING THE PLANET AND ITS PEOPLE

The Crawford Fund
Sixteenth Annual Development Conference
Parliament House, Canberra
30 August – 1 September 2010

Editor A.G. Brown

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The Crawford Fund

An initiative of the Australian Academy of Technological Sciences and Engineering

Mission

To increase Australia's engagement in international agricultural research, development and education for the benefit of developing countries and Australia

The Fund

The Australian Academy of Technological Sciences and Engineering established The Crawford Fund in June 1987. It was named in honour of Sir John Crawford, AC, CBE, and commemorates his outstanding services to international agricultural research. The Fund depends on grants and donations from governments, private companies, corporations, charitable trusts and individual Australians. It also welcomes partnerships with agencies and organisations in Australia and overseas. In all its activities the Fund seeks to support international R&D activities in which Australian companies and agencies are participants, including research centres sponsored by, or associated with, the Consultative Group on International Agricultural Research (CGIAR) and the Australian Centre for International Agricultural Research (ACIAR).

Good news is worth sharing, and the Fund's Public Awareness Campaign — of which its annual Parliamentary Conference is a key feature — increases understanding of the importance and potential of international agricultural research, its achievements and needs.

And the results of research should be extended to as wide a set of users as is possible. With this objective, the Fund's Training Program and Master Classes fill a niche by offering practical, highly focused non-degree instruction to men and women engaged in the discovery and delivery of new agricultural technologies, farming practices and policies in developing countries.

The office of the Fund was transferred from Parkville in Melbourne to Deakin in Canberra at the beginning of 2009.

More detail is available at http://www.crawfordfund.org

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Contents

Acknowledgements

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ACIAR—the Australian Centre for International Agricultural Research

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World Vegetable Centre

Foreword

THE HON. NEIL ANDREW

The Crawford Fund's sixteenth annual Parliamentary Conference in 2010 focussed on the relationship between biological diversity and food security. These proceedings are a record of presentations and discussions over three days at the premier event in Australia marking the UN International Year of Biodiversity, and presaging the UN 2011–2020 Decade of Biodiversity.

Agriculture—the planned sowing and harvesting of plants that had previously been gathered in the wild, and the parallel domestication of animals—probably first dawned in the Fertile Crescent of the Middle East around 10 000 years ago, and independently in northern and southern China, Africa's Sahel, New Guinea and several regions of the Americas. Some of these sites had access to only a few species of productive and nutritious plants, and the limited range and quantity of food remained a major constraint on population health and size for thousands of years, despite recognition long ago of the potential value of irrigation, crop rotation, fertilisers and pesticides. Expanded global travel over the last 500 years has greatly broadened the range of species available to agriculture worldwide, while the rise of the chemical industry in the last century has transformed the availability of fertilisers, pesticides and herbicides. Most recently yields have been significantly raised by efficient plant breeding programs that have exploited the natural genetic diversity that is present in most species. These programs have improved yields by increasing disease resistance; harvest index; growth rate; tolerance to heat, cold and waterlogging; and so on.

A consequence of increased agricultural productivity and the availability of cheap fossil energy has been rapid growth of the human population. This population growth has been accompanied by the extensive replacement or modification of natural ecosystems by agricultural or pastoral activity, or by settlements and infrastructure—a process that is far from any equilibrium, despite the obvious ultimate incompatibility of an increasing population aspiring to greater consumption while dependent on a diminishing land base and finite resources of water and nutrients. Less obvious, but of great long-term significance, is the threat posed by loss of biological diversity—in our crop species, in potential crop species, in insects that have a role in pollination or are predators of pests, and so on.

FAO estimates that food production must increase by more than 75% in the next 50 years, and the resource base available for this will be inevitably diminished. The Crawford Fund was pleased that, coinciding with this conference, Julian Cribb's thoughtful analysis of this challenge—*The Coming Famine*—was released by CSIRO Publishing.

THE HON. NEIL ANDREW was born in the SA Riverland, where his family and later Neil had interests in horticulture. He was an active participant in the SA Agricultural Bureau movement, and was Chairman 1980–1982. In 1975 he was awarded a Nuffield Agricultural Scholarship to make an overseas study tour. In 1983, he was elected to the Australian Parliament as the member for Wakefield in the House of Representatives. With changes in the boundaries of his electorate, he later moved to Gawler. He held various positions including that of Government Whip from 1997, and from November 1998 became Speaker of the House of Representatives. Neil retired from the position and from his seat in November 2004. He now lives in Adelaide and became Chairman of the Crawford Fund on the retirement of The Hon. Tim Fischer in June 2005.He retired as Chair of the Fund in late 2010.

A major element of the potential contribution that biodiversity can make to future food security is to provide the basis for new varieties of established crops capable of producing under conditions more diverse than now entertained. Entirely new crops, especially in warmer or dryer climates, are also a real possibility, as has been shown by the recent commercialisation of hardy and nutritious indigenous vegetables in Africa.

Can we have our biodiversity and eat too? This was the pivotal question posed by Professor Hugh Possingham at this conference. His question, which neatly captures the dilemma faced by a hungry, resource-scarce world, was asked against a remarkable and stark background set by the conference's two outstanding keynote speakers: Professor Stephen Hopper, the Director of the world's most famous garden—the Royal Botanic Gardens, Kew—and Dr Cristián Samper, the Director of the National Museum of Natural History, Smithsonian Institution.

Hopper addressed the global ambition of sustainable healthy living for all, which he said was challenged by accelerating change, entrenched patterns of land and water use, biodiversity loss, rising consumption and population growth. There was, he said, little hope of continuing the green revolution if it remained focused on a few mainstream crops without new land and water ethics, and new economic and political systems that valued social and natural capital as much as financial assets.

Samper said that of the millions of species, some described but many more lost, only a few hundred plants and animals have been domesticated; whilst biological diversity remains vast and variable in space and time, it is being homogenised. Agriculture and trade are having major impacts on natural ecosystems through their transformation into production systems, habitat loss and fragmentation, pollution and species invasion. It is time, he said, to bring together knowledge from biodiversity science and agricultural research through a whole-of-system approach to ensure these opportunities are seized—biodiversity is the basis for agriculture and for a sustainable future. (This conference was one of few being held in the year of biodiversity specifically to bring these two groups together).

Hopper's view was that the world is at a turning point. What is not clear is whether we have yet found the policy visionaries to advise the world's leaders on the development of public policy that is both far-sighted and practical.

Just how difficult the policy challenge will be was illustrated by the presentation on tropical forest biodiversity loss by Luca Tacconi, Director, Environmental Management and Development Program at the Crawford School of Economics and Governance. He pointed to the need for governments to commit to changes in existing policies that drive deforestation and forest degradation, adjusted policies and property management rights, clearer lines of authority for every level of governance, addressing of corruption, and stronger law enforcement.

The conference is possible only because of the generous support of our sponsors, a full list of whom is incorporated in these proceedings. I thank both those who have provided sustained support for the conference since its inception some 20 years ago, as well as to those who have joined us more recently.

Finally, I should like to express my personal appreciation of the time and effort invested by all of our speakers in making the event such a success. In particular, I would wish to thank Parliamentary Secretary for International Development Assistance the Hon. Bob McMullan for his contribution; along with many of his Parliamentary colleagues from all sides of politics, he has been a long-term supporter of the Fund.

Watch for our announcement of the 2011 conference topic and timetable.

The Hon. Neil Andrew AO
Chairman
Crawford Fund Board of Governors

Biodiversity and World Food Security

THE HON. BOB MCMULLAN MP
PARLIAMENTARY SECRETARY FOR INTERNATIONAL DEVELOPMENT ASSISTANCE

I would like to take this opportunity to recognise the contribution of Neil Andrew and Meryl Williams to international agricultural research and Australia's international assistance effort.

Neil Andrew has been Chair of the Crawford Fund over the past five years, and the fund has thrived under his leadership. He has skillfully guided the fund through a period of growth and maintained support for the fund's work from government and the community.

Dr Meryl Williams has been chair of the Commission for the Australian Centre for International Agricultural Research for three years, following three years as chair of the (then) ACIAR Board of Management and president of the ACIAR Policy Advisory Council. Beyond ACIAR, Meryl has played a key role in marine science research over several decades, and she has represented Australia internationally on many occasions with distinction. She will be leaving ACIAR soon; it is in very good shape.

BOB MCMULLAN was sworn in as Senator for the Australian Capital Territory in February 1988, and went on to serve as a cabinet minister in the Keating government, including a period as Minister for Trade. Following a redistribution in the House of Representatives, he stood for the seat of Canberra in 1996 and was elected and served in various shadow portfolios. Following a further redistribution in 1998, he became Member for Fraser, a position he holds today. As Parliamentary Secretary for International Development Assistance, he oversees the implementation of Australia's international development policy and is responsible for the day-to-day management of issues related to the aid program. This involves working closely with AusAID, the Australian Government agency responsible for international aid, international development partners, other donor governments and international organisations to advance Australia's development objectives.

I also welcome conference participants to Canberra, particularly those of you who have travelled from other countries for this event.

Introduction

The Australian Government has a commitment to increase the size of the international aid budget and at the same time make its aid more effective.

The government remains committed to increasing official development assistance to 0.5% of gross national income by 2015–2016, a substantial increase in the aid budget. In 2010–2011 the aid program will increase by 14% to over $4.3 billion, up from $3.8 billion in 2009–2010. There is now bipartisan support for a larger aid program and for a program that is value for money and achieves results. A larger aid program allows Australia to not only play its part as a good international citizen, but to make a real difference to the plight of the poor in our region and around the world. We need an effective aid program if we are to help improve the lives of the billion people worldwide who live in extreme poverty.

A number of actions are being taken to ensure that the aid program is effective:

- AusAID is undertaking a review, together with partner governments, of advisers working in the aid program. The review will ensure that each adviser is the most effective, value-for-money response to meeting agreed needs and priorities.
- AusAID has new management arrangements, becoming an Executive Agency from 1 July.

This is an edited version of the Mr McMullan's speech

This strengthened management capacity is essential if the agency is to effectively handle growing aid volumes.

- The aid program is allocating increasing funds to research—from $70 million and 2.2% of the budget in 2006–2007 to an estimated $144 and 3.8% per cent in 2009–2010. These increases are important to ensure that we have an aid program that is evidence-based.

Australia has a role to play in the global struggle against poverty and hunger.

Because of our history, our expertise and the common challenges and characteristics that we share with many of our developing country partners as a vast, dry continent often remote from its key markets, Australia has made and continues to make an important contribution in developing agriculture overseas. Eighteen of our 20 nearest neighbours are developing countries. We have a stake in their success at the macro level because of the benefits that accrue to our own security and economy. We also have a stake in their ability to manage agriculture at the micro level—to control the spread of pests and diseases before they arrive on Australia's shores. Most of all, however, Australians want their aid program to be of real benefit to the lives of farmers, workers, families and children in developing countries.

We can do this in two main ways:

- First, we need to play an active role in the international discussions on food and agriculture.
- Second, we need to deliver high-impact programs in our region and further afield, and demonstrate those results to an interested Australian public.

Food and agriculture: international developments

Internationally, the Australian Government has demonstrated a commitment to food security and agricultural development over a number of years, and this commitment will continue into the future.

Australia pledged $464 million as part of the L'Aquila Food Security Initiative in 2008. This was a historical turning point in the global approach to food and agriculture, when the international community agreed to mobilise $US20 billion in response to emerging concerns around food security. From the mid-1980s to 2008 the dollar value of global aid to agriculture fell by half, and the proportion of aid to agriculture fell from 17% in the late 1980s to less than 6% in 2007. On a positive note, recent data show the beginnings of a reversal of this trend. Food security featured at the G20 summit in June this year and we can expect it to figure prominently in other international forums including the UN Development Summit in New York next month. Australia will continue to play a significant role in both the global policy debate and by making tangible contributions to agricultural development.

Global Agriculture and Food Security Program (GAFSP)

For example, we have provided funding to the World Bank's Global Agriculture and Food Security Program. The GAFSP is an ambitious flagship initiative of the World Bank targeting food security; it was formally established following its endorsement at the Pittsburgh summit of G20 leaders in September 2009. Led by the United States, groups such as the Gates Foundation and a number of other bilateral donors, the program hopes to mobilise up to $1.5 billion to address a wide range of food security issues, including:

- agricultural productivity and technology
- functioning markets
- managing the effects of climate change
- access to finance for farmers
- social safety nets and insurance.

I'm very happy to note that Australia made a $10 million contribution in the last financial year to the GAFSP and has indicated a willingness to make further contributions in the next three financial years.

Consultative Group on International Agricultural Research (CGIAR)

Australia is also doubling its funding to the CGIAR. In doing so, we are supporting the group's shift to funding high-priority research areas rather than funding the centres themselves. The centres will then work together to deliver results on priority programs. Like other donors, our funding will be performance-linked and we remain optimistic about the direction of the CG.

USAID MOU

AusAID will work more closely with the USAID in the future following the signature of a new Memorandum of Understanding. One of the ten priority areas for collaboration relates to food security and water management; we aim to jointly support research and innovation in agriculture, particularly in Sub-Saharan Africa.

Impact of international agricultural research

Turning now to the delivery of high-impact programs, evidence of significant benefit is already available. An evaluation of 37 ACIAR projects found they generated $12.6 billion in benefits from an investment of $234 million; the benefits were 54 times the costs. Although most of these benefits flow to developing countries, improving the livelihoods of poor farmers, there were also significant returns—$1.2 billion—to Australian agriculture.

The evidence shows that innovation in international agricultural research benefits Australian agriculture:

- through the new technology developed
- through protection from pests and diseases
- by increasing trade
- by increasing the stock of knowledge among Australian researchers.

This is an important message for the Australian community—helping others is not only the right thing to do, but it also brings direct benefits to Australia.

The Australian approach

Australian expertise in agriculture is in high demand for good reason. We have strong institutions such as ACIAR, CSIRO and the Crawford Fund with established reputations. We have state departments of agriculture, universities and centres of excellence that play a vital role. We have experts with an understanding of the problems and challenges facing developing countries. Australia has particular experience in adapting to harsh climatic conditions.

We cannot expect another 'green revolution' such as occurred in the 1950s. There are growing constraints on land, water and inputs such as fertiliser. Rather than technical advances, more of the future gains will come from building institutional capacity and improving the way farming systems work. This means building better connections between farmers, researchers, educators and policy-makers. Australian researchers and aid program managers are good at this work. Our experts have good relationships with our partner countries and can play a role as honest brokers of advice on best practice.

Examples of research success

In **East Timor**, the 'seeds of life' program of AusAID and ACIAR provides farmers with higher-yielding varieties of five staple food crops. Ten years of trials and research are paying off, with yields increasing by up to 80%; 70% of farmers approached by the program continued to replant with the new seeds. These gains improve food security and contribute to wider social and political stability.

In **Cambodia,** more than 200 000 farmers are estimated to have benefited from an AusAID research project to improve rice yields and reduce storage losses. The economic rate of return is conservatively estimated at over 80%. Most importantly, the project has laid the foundation for a commercially sustainable supply of high-quality rice seed.

In **South Africa,** an ACIAR project called 'Beef Profit Partnerships' has helped farmers earning less that $1 per day to organise themselves, to gain information on nutrition and cattle management and to access markets. The results were price increases of up to 55% and benefits of $2300 per farmer. The project is managed by the Cooperative Research Centre on Beef. It has been such a success in showing how small farmers can access markets that the methods employed have been extended to other countries such as Botswana. The methods have also been brought back and implemented in Australia. This is very positive because we know the effect that scaling-up can have, not only for agriculture itself but to the communities and individuals whose livelihoods depend on it. Scale needs to be considered in the early stages of research planning if expanded adoption is to be achieved as a long-term objective.

Communicating results

These are impressive results; it is increasingly important that we communicate them widely to policy-makers in developing countries and to other donors and researchers. We also need to communicate results to the general public, whose opinions are vital if we are to maintain support for large increases in aid spending in a tight budget environment.

We also need to communicate to a generation of young agricultural scientists the opportunity that international agricultural research provides to make a real difference to the lives of others. Our scientists need to regenerate, just as our crops.

Conclusion

Australia's commitment to international agricultural research is long-standing and substantial. In an expanding aid program over coming years, agricultural development and research will play an important role. We have achieved good results over the years, and many of the people in this room today have contributed to those results.

Our achievements bring tangible benefits to many livelihoods in neighbouring countries. They also bring identifiable benefits to Australia, whether in our economic relationships, our biosecurity or lessons learned that can be applied at home. I would like to thank you on behalf of the Federal Government for those efforts. Most of all, as a good global citizen we demonstrate to our neighbours, our friends and our multilateral partners that we are willing to do our part to tackle global challenges.

KEYNOTE PRESENTATION

Biodiversity, Nature and Food Security: A Global Perspective

CRISTIÁN SAMPER

National Museum of Natural History
Smithsonian Institution
Washington, DC, USA

Biodiversity is the basis for agriculture and for a sustainable future. More than 1.9 million living species have been described; millions more have gone extinct, including major branches of the tree of life. The distribution of this biological diversity is variable in space and time, although it is becoming more homogeneous as a result of globalisation. Only a few hundred species of plants and animals have been domesticated over the past 10 000 years, yet they are essential for the livelihoods of people worldwide. New tools are giving us insights into the origins of agriculture, as well as opening new possibilities for using and changing the genetic diversity of these crops and races. This can have a major impact on the well-being of present and future generations. Agriculture is also having major impacts on natural ecosystems. An estimated 25% of terrestrial ecosystems have been transformed into production systems, mostly in the past 50 years. Habitat loss and fragmentation, pollution and invasions are some of the impacts. Climate change is likely to have additional impacts that will alter the distribution and abundance of biodiversity, as well as the interactions among species. It is time to bring together knowledge from biodiversity science and agriculture through a whole-system approach. A better understanding of the diversity, distribution, evolution and ecology of life is essential for a sustainable future. It can also open new avenues for agriculture and food security.

Dr Cristián Samper is the Director of the National Museum of Natural History of the Smithsonian Institution in Washington DC. Prior to joining the Smithsonian in 2001, he was the founder and first director of the Alexander von Humboldt Institute, and was awarded the National Medal of the Environment by the President of Colombia in 2001. He served as the chairman of the scientific advisory body of the United Nations Convention on Biological Diversity, and was one of the leaders of the Millennium Ecosystem Assessment. He is Fellow of the National Academy of Sciences of Colombia and the Academy of Sciences for the Developing World. He currently serves on the boards of directors of the American Association of Museums, Bioversity, The Nature Conservancy, the World Wildlife Fund (WWF) and Harvard University.

Introduction

Our home is a little blue planet that is 4.56 billion years old; where we know there has been life for over three billion years. We share it with more than six billion people and more than ten million other species of plants, animals and micro-organisms. We know this thanks to the work of many generations of scientists who have explored this planet to understand nature and our place in it. Many of their findings have been gathered in extraordinary collections like that of the National Museum of Natural History in Washington. There are many kinds of collections—not only natural history collections but seed banks, germplasm and microbial collections. Some of the species in these collections are essential for agriculture and for the livelihoods and the quality of life of people all over the world.

It is important to remember that we are just one of many species: a very particular species in terms of our history and our impacts, but also our understanding of the past, present and future. My perspective is that of a biologist and a biodiversity scientist, and therefore different from that of many people in the audience. This different viewpoint, however, is precisely the reason for this kind of conference, providing as it does opportunity for dialogue across disciplines. I myself look forward to learning more about agriculture in the course of the conference.

I will focus on four main topics:

- the distribution of diversity—what we know and what we don't know
- the relationships between humans and this biodiversity
- some of the main drivers of change in diversity and what we understand
- ecosystem services and their importance to food security, and some choices and options for the future.

Biodiversity

We have described about 1.9 million living species of animals, plants and micro-organisms in the planet today; more than 50% of those are insects, and only a few tens of thousands are vertebrates like ourselves (Chapman 2009). But we've described only 15–20% of all extant biodiversity, a small proportion of the perhaps 10 million species out there (Fig. 1). Professor Hopper [page 92] mentioned that about 2000 new species of plants are being described every year, and about 35 000 species new for science are being described annually across various taxonomic groups. Fortunately, most of this information is freely available through resources like the *Encyclopedia of Life* (www.eol.org) . It is obvious that a lot of work lies ahead to understand global biodiversity—and understanding this diversity is fundamental to the choices that we need to make as a society.

We also know that biological diversity is not distributed uniformly around the planet. Tropical countries tend to have a very high diversity. Most terrestrial diversity is found in the New World and South-East Asian tropics. The pattern of marine diversity is somewhat different; the bulk is found in the area just north of here—the Coral Triangle and the whole region of South-East Asia. We also know is that the distribution has been dramatically different over time—the fossil record provides windows into the past. Fossil trilobites that lived 420 million years ago in present-day Morocco remind us that very different groups of organisms have previously dominated the planet. Fossil records indicate that more than 95% of all life on earth has already gone extinct (Erwin 2006).

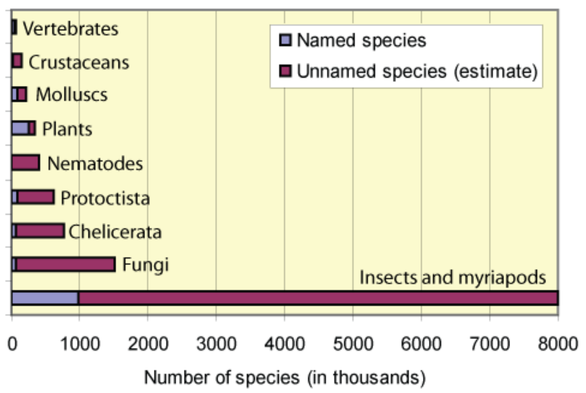

Figure 1. Some 1.9 million living species have been described

This poses a real challenge for those of us interested in science and environmental issues. We have to recognise that extinction is part of the natural history of this planet—the key question is whether our actions and activities are changing that rate of extinction. I use the word 'rate' because that is the essential element here: it is not just what is going extinct, but how fast and where it is going extinct. There is clear evidence that we as humans are accelerating the rate of extinction (Millennium Ecosystem Assessment 2005).

Humans and biodiversity

To start drawing the connection between biodiversity and human wellbeing, I want to take you back to my backyard. I grew up in Colombia in South America, and as a biologist I spent many months in the field studying tropical rain forests. These forests include extraordinary rock formations known as Tepuis, that are like islands over a sea of forests. Halfway up them you may find pictographs that were made by humans a few thousand of years ago. These pictographs are important and powerful reminders that our ancestors have always interacted with their environment, with different elements like the fish and mammals represented. Over thousands of years we have been hunter-gatherers who have depended on the interaction with biodiversity for food, clothing and shelter. We would not be here if it was not for that biodiversity. Indigenous people all over the world have selected particular elements of biological diversity and shaped it for their livelihoods, as in this case with capsicum and chili pepper.

We now have new tools at our disposal in science that are changing our understanding of the origins of agriculture in the world. Just to give you one example, one of my colleagues at the Smithsonian, Dolores Piperno, has been studying phytoliths—tiny silicon grains that are found inside the tissues of the leaves of plants. The phytoliths of chili peppers, corn and other crops, and archaeological remains, reveal that chillies were domesticated more than 6000 years ago by indigenous peoples in the Amazonian Basin (Piperno and Flannery 2001). For a handful of crops our influence has been dramatic; they have become incredibly important for our livelihoods. Only 12 crops probably feed about 80% of the people in the world. Figure 2 illustrates diversity in maize from the highlands of Ecuador. It is important to recognise that humans have selected many of the characteristics, now evident, from the rich variation present in undomesticated wild populations (Smith 2002). Under our influence this diversity has provided many traits and characteristic that are important in sustaining the livelihoods of people not only in local communities but globally.

One of the fundamental tasks in biodiversity work, in addition to documenting relevant diversity, is preserving it in genetic banks and using that diversity to improve the productivity of crops—the yields, the nutritional value—and thanks to that we have improved the lives of people. It is not enough, however, to preserve the genetic diversity of crops and their wild relatives alone. It is fundamental to understand the natural history behind these, and the interactions between relatives and the biodiversity around them.

Leaf-cutter ants from the rainforests of Panama were some of the first farmers: they collect leaves, use them to feed fungi and feed on the fungi to grow their colonies. This is an example of the co-evolution between plants and animals of which there have been many instances over millions of years. If we really want to understand the forces that are shaping nature, we need to understand how those interactions have happened in the past. We're barely scratching the surface of what we need to know.

Figure 2. Diversity in maize, Ecuador

I will give just two examples. If you go into a rainforest in Panama and look closely inside the leaves of plants you find endophytic fungi—fungi that are found only growing inside the leaves of some trees, and in a single species of crop, cocoa, *Theobroma cacao*. In one locality we have discovered and described more than 600 different species of fungal endophytes (Arnold 2001). We are starting to understand that the presence of these endophytes is fundamental to the lives of some of these plants: to their resistance to disease and to growth rates (Arnold 2007). We know of similar cases for some of agricultural crops. An incredible diversity of micro-organisms is shaping the growth and the natural history of life around us.

The other example, which is probably more familiar to many people working in agriculture, is that of insects—in this case parasitic wasps. These wasps have been very important for biological control over many decades. The remarkable thing is their mind-boggling diversity: we estimate that there are between eight and ten species of parasitic wasp for every single species of host insect. As we have described about 800 000 species of insects on the planet, the abundance of their parasites really begins to give a sense of incredible diversity. To what extent some of these species are specific, how they could have evolved and how they are related is really important in understanding not only genetic diversity but the interactions between multiple organisms. It can also have a major impact on agricultural systems.

Today, with the advent of new technologies in molecular biology we can probe deep into the genomes of the various crops to better understand their genetic diversity. We can reconstruct the evolutionary history of life on earth. We are opening the doors to being able to move genetic material between different kinds of crops and to use it in ways that can have major impacts on food security.

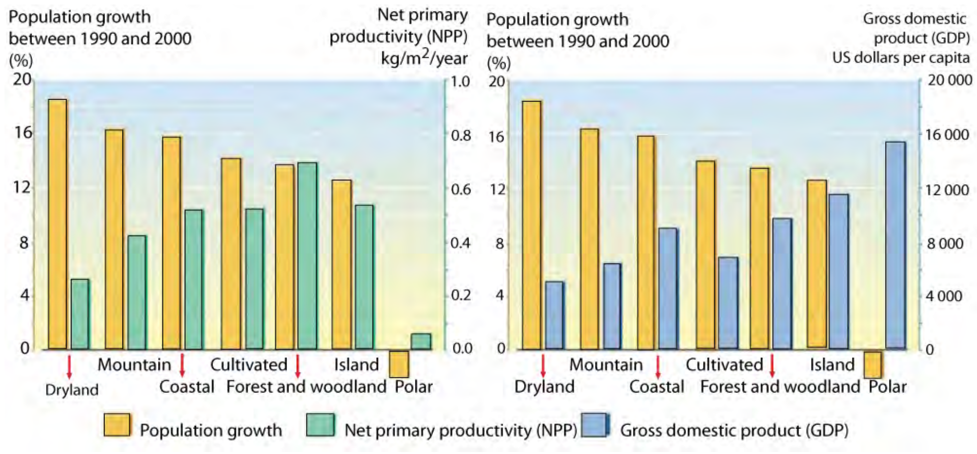

Figure 3. Population growth, primary productivity and gross domestic product in diverse environments. (Source: Millennium Ecosystem Assessment—Running *et al.* 2004)

Our impact as humans on the planet

There have been dramatic changes in this planet over the last 50 years. Between 1960 and 2000 the global population has increased from three billion to six billion people, more than doubling. Over that same period economic activity, measured as GDP, has increased six-fold and food production globally has increased 2½ times: that is, growth in food production has outpaced that of population, largely as a result of the green revolution. During that same time the demand for water has doubled and the amount of water impounded by dams has quadrupled, with major consequences for the flow of water in some aquatic ecosystems. Similarly the flows of phosphorous and nitrogen have more than tripled, largely as the result of the use of fertilisers for agriculture; this has had dramatic consequences for the ecology of some aquatic ecosystems. So our footprint as humans has dramatically increased and changed in the last 50 years—just two generations (Millennium Ecosystem Assessment 2005).

Where is this happening on the planet? We are not uniformly distributed; the bulk of people are found in Asia, China, India, the coastlines of a few of the continents, and Europe of course. This means that there are certain areas where there are particular challenges to food security. One way to look at this is to analyse the fraction of net primary productivity that is being used by people. Primary productivity is a good measure of how much energy is available for use by people. In some regions we are taking out more productivity than is actually being produced by the natural ecosystems. The biggest challenges are in places like China, India and parts of the Middle East. Australia is doing relatively well. The solution to many of these challenges directly relates to investment, especially in agriculture. The impact is very different in different ecosystems and biomes. The left half of Figure 3 shows the percent population growth by different kinds of ecosystem: dryland, mountains, coastal ecosystems and so on, and the net primary productivity. The real crises that is looming is to be found in dryland ecosystems—areas that have the slowest growth in net primary productivity and the highest growth in population (and, on the right half of the figure, gross domestic product per capita).

The work of the Food and Agriculture Organization (2010) highlights the problem of food insecurity across the globe. Figure 4 provides a global picture of the course of the response of agriculture to our investment in productivity from 1961 to 2003–2004. Total food production has increased by about 150%, and production per

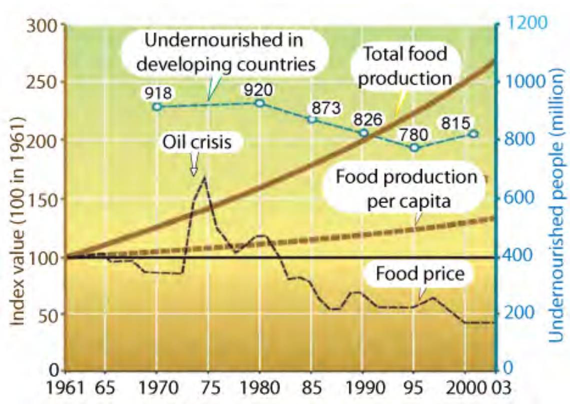

Figure 4. Food production and nourishment (Source: FAOSTATS, SOFI)

capita has also increased. Food price tended to go down, although there was a spike in the 1970s and another (not shown on the graph) in 2008–2009. The number (and more so the fraction) of people who are undernourished has fallen. So we have made dramatic progress in accommodating the doubling of the human population. Many people, however, still face huge challenges to their livelihoods, and more recent data from FAO (Fig. 5) is very disturbing Although there was a positive tendency to reduce the number of people worldwide who were malnourished, recent events—the economic crises and spikes in food prices—are increasing the number of people that are considered to be malnourished right now to over one billion. Most of those people are found in Asia (Fig. 6). It is important that the measures and the choices that we make are addressing some of these globally important areas.

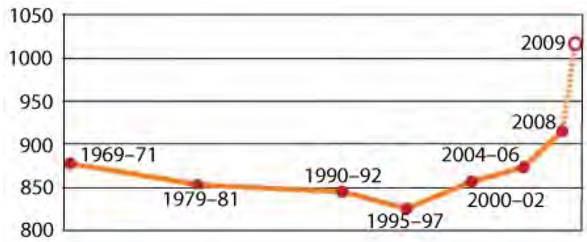

Figure 5. Learning from the past: the number of under-nourished people in the world (Source: FAO)

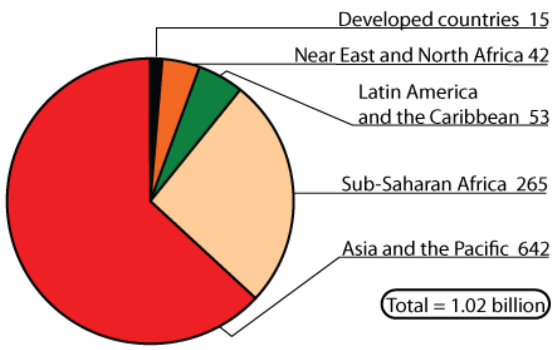

Figure 6. Under-nourishment in 2009, by region (millions) (Source: FAO)

Drivers of biodiversity change

There are five main drivers of change in biodiversity: habitat transformation, over-exploitation (which is a huge issue in marine systems), invasive species, pollution and climate change. Not all are equally important across ecosystems (Fig. 7). For example, in island ecosystems the single biggest problem is invasive species; in some mountain ecosystem climate change will be very significant. Understanding the importance of these drivers is fundamental to looking for and examining response options.

We estimate that 25% of the natural terrestrial ecosystems of the planet have been transformed into agricultural production systems (Millennium Ecosystem Assessment 2005). I expected this figure to be larger; its magnitude has to do with the definition of what's considered transformed. If we compare these changes with the distribution of the biomes and ecosystems on the planet, we can start seeing where the biggest impacts have taken place. Figure 8 shows the various kinds of ecosystems and the fraction of the original cover that was transformed by 1950, between 1950 and 2000, and the projection for the next 50 years. The temperate forest was one of the ecosystems hardest-hit historically, but the biggest changes in future will be in some tropical rainfor-

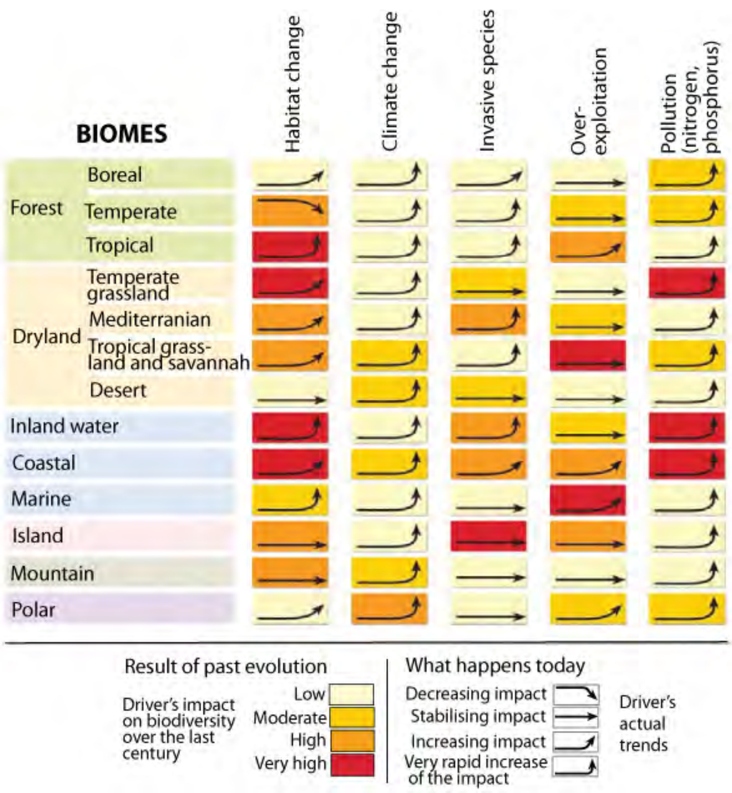

Figure 7. Drivers of change in biodiversity (Source: Millennium Assessment 2005)

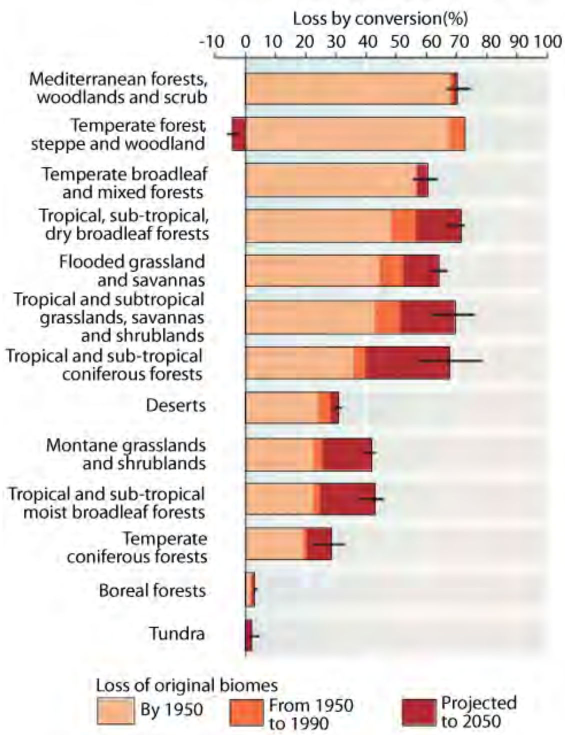

Figure 8. The temporal course of loss of major ecosystems

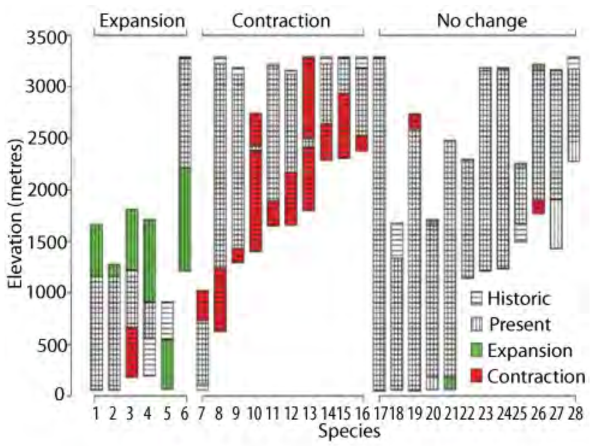

Figure 9. Change in altitudinal distribution of 28 small mammals over 100 years (Source: Moritz *et al.* 2008)

ests. A positive exception to the overall trend is that we project that there will be a net gain of temperate forest cover of about 5% in the next 50 years.

Another major driver of change that is often overlooked is the issue of invasive species. People in agriculture know this, but many other people don't. It is a huge problem; not only for crops but for native biological diversity. Many of the areas most affected by invasive species are directly related to global trade routes. In a globally interconnected world with increasing trade and other activity, this is going to get only worse. Not surprisingly areas like the Mediterranean are some of the hardest hit, but places like Australia and South America are becoming increasingly important for coastal marine invasives.

Climate has changed many times in the history of this planet. There have been moments in the past where the CO_2 levels have been higher than in any of the projected scenarios that we are looking at now. Climate change has shaped the evolution of diversity of life on earth. There is no doubt, however, that the rate of change has dramatically increased in the last 50–100 years and that this acceleration is directly related to human activities. We are starting to get data showing the impact that this is having on biological diversity. One example is a study by Craig Moritz in the mountains in California, showing the changes over 100 years in the altitudinal distribution of 28 small mammal species (Fig. 9). These data show that, in response to climate change, most species are moving up the mountains and their ranges are contracting. The number of species is not changing dramatically, but climate change is starting to have a real effect on the distribution of and the interaction amongst some of these species (Moritz *et al.* 2008).

Ecosystem services and food security

The interaction between biodiversity and ecosystem services and human wellbeing is fundamental. Ecosystem services are the services that we derive as humans from ecosystems. We readily think about 'provisioning services' such as agriculture or fisheries that provide food. What are less obvious are the regulating services like climate, water, nutrient cycling, or even the cultural and spiritual values (including recreation) relating to these ecosystems. Historically we have focused most attention of provisioning services at the expense of regulating, cultural and spiritual services. As most economists focus on the services that are traded through markets, those without a market value present a problem, although they may determine the livelihoods and wellbeing of people. Figure 10 is another graph from the Millennium Ecosystem Assessment (2005) portraying the various kinds of ecosystem services: although we are focusing on food now, we have to take a much broader look at other services. Without water, nutrient cycling and climate regulation

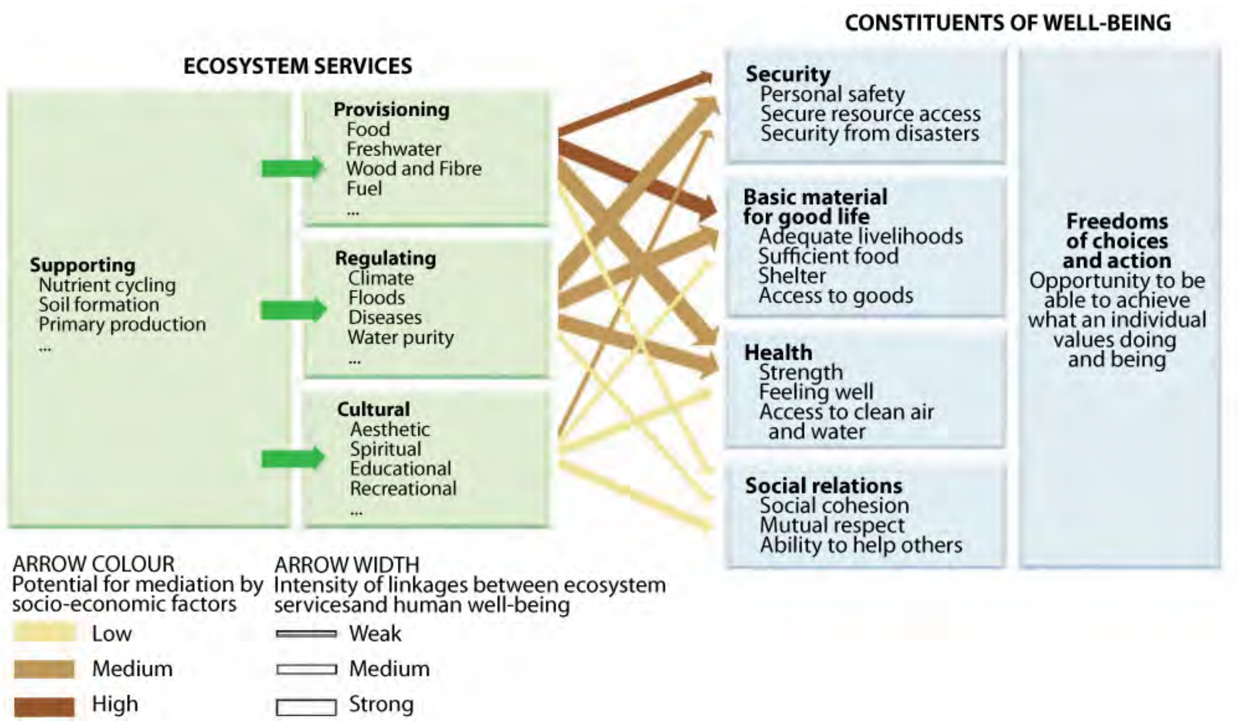

Figure 10. Consequences of ecosystem change for human well-being (Source: Millennium Ecosystem Assessment 2005)

there will be no agriculture. Human wellbeing requires more than food security and access to food; it includes health and social relations. We have been focusing on interactions between food and food safety and not necessarily taking a broader look at other dimensions of human well-being.

Response options

The Millennium Ecosystem Assessment (2005) also evaluated a variety of response options, which fall into five broad categories: (1) institutional responses, such as the establishment of protected areas; (2) economic responses including access to markets and removal of subsidies; (3) social and behavioural responses that directly relate to the choices that we make in society—where education and public awareness are very important; (4)technological responses, like optimising water use efficiency, are extremely important in areas like agriculture; and (5) access to the knowledge that we have gathered around the world.

The choices that we make as a society are critical. Figure 11 depicts four future scenarios that result from combinations of global or regional views and either proactive or reactive responses (Millennium Ecosystem Assessment 2005). These options, which have been characterised by brief labels in the figure, are of course extreme, and the likely answer is a combination of the four. The important point I want to make is the choices that we make as a society will have profound impacts on biodiversity and food security in the next 50 years. Three more graphs (Figs 12, 13 and 14) illustrate that point. All the scenarios suggest that population is going to increase dramatically by at least another couple of billion people in the next

Figure 11. Future scenarios

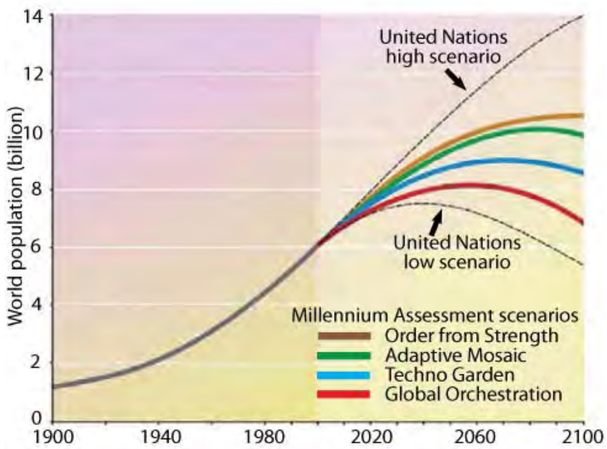

Figure 12. Changes in population. By 2050, the population is projected to grow to 8–10 billion and per-capita income to increase two- to fourfold.

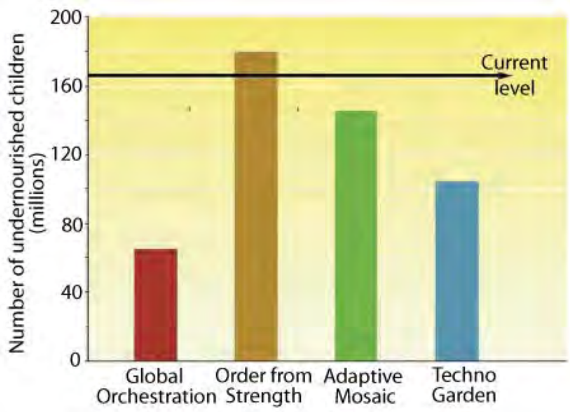

Figure 13. The number of undernourished children is expected to be influenced by the population scenario (Source: Millennium Ecosystem Assessment)

50 years (Fig. 12). But if you look a hundred years on, the difference between them is huge; some scenarios suggest we will be back to about 6 billion people 100 years from now. Some of them suggest that the number will increase to over 9 billion people—a lot of mouths to feed, with major implications for food security. Not only is how many people we have important, but how many don't have access to good food and good food security.

The good news is that under most scenarios the number of undernourished children will drop. The important thing is that the differences are tremendous, and some of the scenarios will have a much greater impact on food security globally than others. Global orchestration, focusing on a multilateral world readily transferring knowledge, food, food security and trade will probably be the single best one for improving food security, whereas others will actually potentially increase the number of malnourished children. These are choices that we need to make as a society.

The different scenarios will have very different consequences for the three main categories of services: provisioning services like agriculture, regulating services like water and nutrient cycling, and cultural services like recreation. Technology—extremely important in agriculture—will have a major effect by improving access to provisioning and regulatory services, but it will do so at

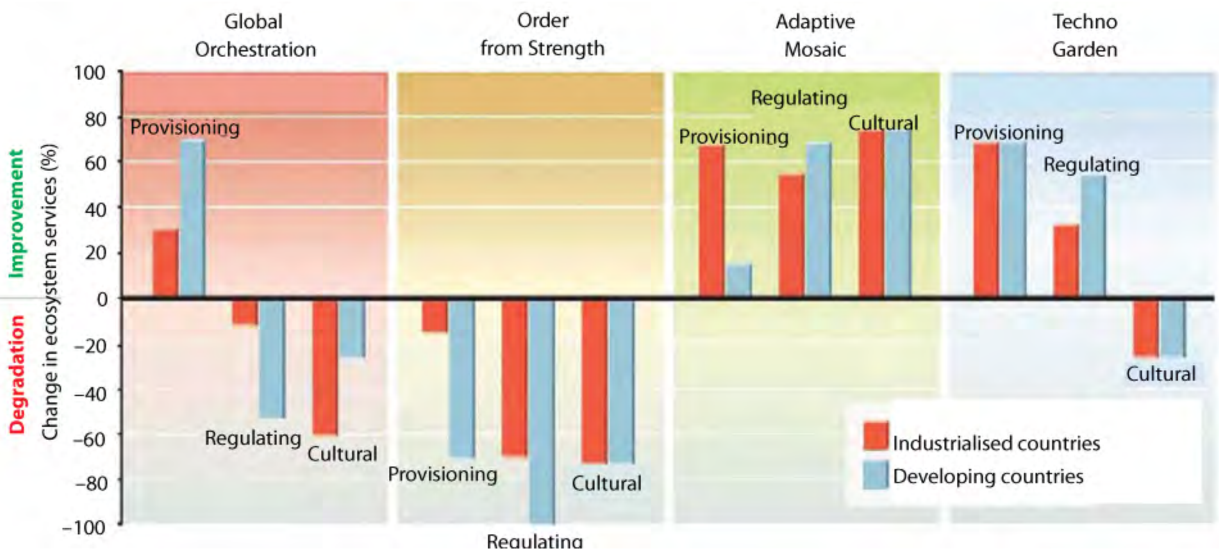

Figure 14. Changes that may accompany future scenarios (Source: Millennium Ecosystem Assessment 2005)

the expense of cultural services because technology will drive a lot of local practices and adaptations out of traditional knowledge.

The answer is going to be a combination of those five categories of responses options. The choices we make will have a dramatic impact on the lives of people because we are living in a constantly changing planet. As a species have already had a tremendous impact—like no other species before—and the choices that we are now making will shape the future.

Our agriculture and food security will be intimately dependent on biodiversity not only for genetic material. If we want to improve food security we have to base it on a better understanding of biodiversity and ecosystem services. Choices that we make related to agriculture and food security will also have a dramatic impact on the future distribution of biological diversity.

A conference such as this one brings together these two perspectives. A country like Australia, being a player in the region and in the world, can have a very important role in the future, helping to shape a better world where we achieve a balance between biodiversity and food security.

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Can We Have Our Biodiversity and Eat Too?

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Australia's isolation from other continents over millions of years led to the evolution of many species that exist nowhere else, so called 'endemic' species. Of the ten megadiverse countries in the world, we are the only one that is labelled as 'developed' so have a global leadership role in getting the balance right. However, European settlement and the introduction of exotic species animals and plants have perturbed ecosystems, leading to changes in the distribution and abundance of many species. Extinctions of species in Australia now occur at 100–1000 times the 'background' rate. Land transformation—the clearing of natural habitat for grazing, cropping and infrastructure—has been a major driver of change and species loss. Overgrazing of native pastures is a particularly widespread problem, compounded by a changing climate and a higher incidence of drought in some areas. Drought also exacerbates damage to wetlands, as river flows are reduced by over-allocation of water to agriculture and other uses. However, recent transformations in the agriculture sector (e.g. water efficiency gains) and government policy (e.g. land clearing legislation) have halted the drivers of biodiversity loss.

Now, agriculture should not be seen as the problem, but rather as the solution. The best chance for many species is persistence in an agricultural matrix, not the national parks system (which is inadequately funded to meet its management objectives). Significant progress can, for example, be made through habitat restoration, wetland creation and modifying grazing and fire management practices, all of which have major benefits through carbon sequestration. Biodiversity conservation areas should be integrated with agricultural land in ways that create almost win–win situations—*I think we can have biodiversity and eat too*. We need to prioritise ecosystems and species for conservation, and allocate resources accordingly. We also need to convince the conservation movement that preservation is only part of the solution—active and aggressive intervention is another way of conserving biodiversity. This will not be achieved easily without education of the Australian people and encouraging their love of the diversity of nature.

Professor Hugh Possingham FAA is an Australian Research Council Federation Fellow, a member of the Wentworth Group of Concerned Scientists, the Director of the Applied Environmental Decision Analysis Centre (AEDA) and the Director of The Ecology Centre at the University of Queensland. He completed applied mathematics at The University of Adelaide before attaining a Rhodes Scholarship to undertake a DPhil at Oxford; an ARC QEII Fellowship at ANU followed. In 1999 he was awarded the POL Eureka Prize for Environmental Research, and subsequently has been honoured with a number of other prestigious awards. He has a variety of broad public roles, and is a member of the Queensland Smart State Council, the Council of the Australian Academy of Science and NGO scientific advisory committees.

Introduction

I'm honoured to be here to day. Based on dinner last night and conversations this morning, probably I know less about food security than most people. I face an esteemed group of people in the audience who know an enormous amount about agriculture and biodiversity.

The first speaker today and Steve Hopper last night [page 92]set the scene. I suspect the conference organisers expected me to tell you now how much biodiversity we've got, how wonderful it is and how if we lose it we are all going to die, and that biodiversity is essential to food security. That is the standard talk, and a good one. Although I've wheeled it out many times, I don't think I completely believe it any more. I will take a different, and almost certainly unpopular, tack.

I'm going to talk about trade-offs. Both Bob McMullen and Cristián [pages 1 and 5] have already hit this nail on the head with respect to trade-offs. We do have to make choices—food security and biodiversity fight each other. It is lovely to be positive and think about the all the win–win things we can do, but in the end with many things, most things, the hard decisions will not lead to win–win. If there were a lot of win–win actions that increased the happiness of all sectors of society, we would simply do them. This will be the basic tenet of my talk.

Our research centre

I would like to acknowledge the Australian Research Council for providing me with a lot of my research funding, and the Department of Environment, Water, Heritage and the Arts[1] which funds our current research centre, the Centre for Applied Environment and Decision Analysis (AEDA). Both of these agencies have recently provided us with new and substantial support to continue to work on the science of environmental decision-making.

I was first trained as an applied mathematician and bio-chemist; I wandered into ecology and now I'm an aspiring economist (although I am not sure the economists want me). I'm very interested in making decisions and solving problems, not merely science—which means I have had to embrace economics. I have also been very interested in forming policy ever since I wrote my first letter to the newspaper objecting to the land-clearing that had destroyed our favourite birding spot, when I was eighteen. As I've been trying to influence decisions all my life I've drifted towards economic things, and I have found that knowing a bit of maths has made it a lot easier. I have been known to proclaim that economics is just applied mathematics with lots of jargon.

Before I get to the meat of the talk, I also point out that behind me is a vast lab of young people who are smarter and more energetic than I am. They do all the work and write all the papers. We also have a huge suite of colleagues. In summary, I am good at taking a lot of credit for the ideas and labours of others in other universities.

It is pleasing to see that universities like The University of Queensland, the ANU and The University of Melbourne have become global hotspots for biodiversity conservation research. Indeed, if you were to pick a research area where Australia was the strongest in the world, conservation and agriculture would have to fight it out.

Choices are inevitable

So what is the punch line? It is very popular to seek win–win solutions. About ten years ago, Steve Morton, myself, the late Peter Cullen and several others were asked to deliver a Prime Ministers Science, Energy and Engineering Innovation Committee (PMSEIC) report. PMSEIC was a great innovation of the Howard government. We told the Howard government about biodiversity—what we've heard this morning, that biodiversity is very important for ecosystem services. The millennium assessment has clarified all those issues, and therefore we tried to build a case that there are win–wins: if we secure the ten million species on the planet, that will help us secure all these other things that we need—food, water and so on—for us.

But I don't think that's generally true. We are going to have to sacrifice land for biodiversity, or take land away from food if we want to maintain all our biodiversity. There are fundamental trade-offs; there are a few win–wins. I'm going to talk about what that trade-off curve looks like. Can we move the shape of the trade-off curve? Furthermore, we have to make choices between biodiversity and ecosystem services. In particular, if we want to maximise water availability or carbon sequestration, that won't maximise biodiversity. Many people think the reduction in deforestation that occurs where we buy carbon credits through tropical countries is the best action for saving biodiversity. I will show you that it is not optimal—maximising carbon retention is not the same as maximising biodiversity. In the end people, the world, have got to decide whether they actually like biodiversity and how much are they willing to pay for it. If we walk away from that fundamental trade-off, like so many other fundamental trade-offs—e.g. health vs security—we are deluding ourselves.

The world's, and Australia's, biodiversity is a mess, but I don't think most Australians know how big a mess it is. We have stopped land clearing relatively recently, thanks a lot to the Wentworth Group and many others—but in fact

[1] Now Department of Sustainability, Environment, Water, Population and Communities, SEWPAC

biodiversity is declining here just as fast as anywhere else in the world, if not faster. Aside from that depressing fact, I'm going to talk about what I think we need to do to get *almost* win–win solutions to the biodiversity crisis. We can get really good solutions—not win–win, but almost win—and I will explain what do we have to do. This will mean that the conservation movement needs to be far less conservative, and Australians need to recognise the billions that this country makes from biodiversity. For example, birdwatching in the USA in 2006 was a $36 billion dollar industry that generated over $80 billion dollars of growth.

Identifying critical issues

The fact that biodiversity is in rapid decline was highlighted in an excellent paper in *Nature* in 2009 by Rockstrom *et al.* that pushes us ahead from where the Millennium Ecosystem Assessment report was. It identified a raft of fundamental global biological processes and subsystems and assessed whether we had pushed those systems beyond acceptable thresholds (see Fig. 1). The green circle in the middle is where they consider the acceptable threshold is for each process. The red wedges show far we have pushed processes or systems like ozone depletion or freshwater use at a global scale. Freshwater use is not too bad yet but getting worse fast. Two problems stand out—disruption of the nitrogen cycle and biodiversity loss. Specifically, they argue that if we kept biodiversity loss at about 10 times background rates it is vaguely acceptable (inside the green circle)—but we now think it is 100–1000 times background rates, way beyond an acceptable threshold. I recommend that paper wholeheartedly.

An example: Australian birds

You might think Australia is fine—a green nation. About ten percent of the Australian population voted for the green party, an increasing number—surely that is enough political support to secure the environment? The reality is otherwise. Professor Stephen Garnett, Dr Judit Szabo, myself and others have a grant to re-analyse all the data on Australia's threatened birds. We have only about 800 bird species; we are losing one a decade. At the sub-specific level (down to sub-species and races) we have 2400, and we are losing one every four years. Who can name the six taxa of birds we lost in the last 25 years? None of you can! The Mt Lofty Rangers spotted quailhrush has disappeared,

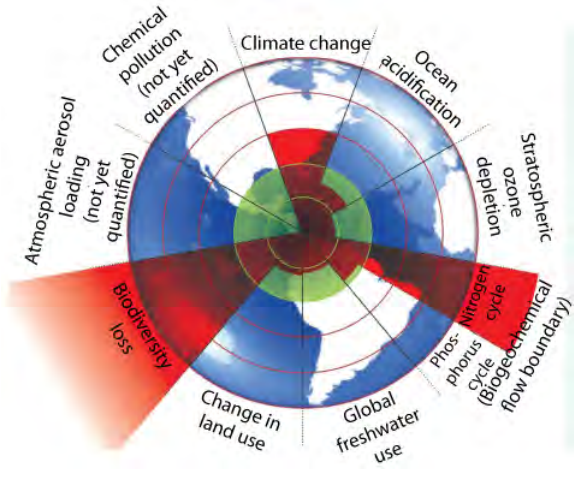

Figure 1. Biodiversity: the state of the world's biophysical processes/subsystems (Rockstrom *et al.* 2009)—we say that biodiversity is essential because …

it was last seen in 1983. Did anybody see the press release! This bird is gone. The Tiwi Islands hooded robin has disappeared, the southern subspecies of the star finch has disappeared. All have vanished in the last 10–20 years, mostly without a single dollar being spent on their conservation other than for the odd biologist going to look and exclaim 'they're not there anymore!'. That has been the extent of the expenditure.

This is a global embarrassment that would not happen in Europe or North America—they would be spending tens of millions of dollars on each of these birds. Obviously those places have huge economies and could afford to do those things. The current rate of expenditure on bird conservation here (for example) is roughly $12 million per year, about 1/1000th of defence expenditure. Maybe it is not surprising that we are losing a bird species every decade (and if maintained that means we would have none in 8000 years time). Of course we won't lose every species, we will have still have magpies and crows. But it is embarrassing, and from an economic perspective the infrastructure that underpins tourism and our culture is being squandered. No smart industry allows its capital assets and infrastructure to decline.

What is really going to happen? Probably in a few hundred years we will lose a couple of hundred bird taxa. Do we need those bird species to live, to eat, for food security? The short answer is no. Consider other aspects of biodiversity. There are a thousand species of terrestrial orchid in southern Australia. They could all go and ecosystem function would not change one iota. Our cultural heritage would be irreversibly diminished, but we would continue to live. So why should we care about species loss?

I care about biodiversity loss because it will take 2–5 million years for these losses to be recovered. This is the most irreversible of our environmental woes (something that is not accounted for in Fig. 1). We can sort out problems of air quality, water supply and food security in 10–100 years. Indeed we could solve the global food security problem—just stop feeding grain to animals—*don't eat something that ate something that you could have eaten*! It is simple. We can probably even sort out climate change in 200–300 years, *but if you lose biodiversity then 20 000 times as many people as has ever lived will suffer the consequences*. If only 5% of these are bird watchers, this issue is 1000 times more important than almost any other environmental change that we can currently recognise. In civilised developed countries 10–20% of people are avid natural historians. This is what people want to do with their time and money, and that fraction of the world deserves the right to keep those species just as we all also deserve the right to have things like food and liberty.

Food security and biodiversity

I believe that the world has plenty of food, partly because of efforts of people like those in this room and because there is space for the green revolution to progress. A small fraction (perhaps 5% or 10%) of the world's biodiversity is essential for fuelling that. But how much of the remainder do we really need? What's the evidence that it is essential for food security?

We've probably got about 10 million species of organism; a quarter of them are beetles, a quarter of them are fungi. Many have put the argument that you can't lose any of these species because everything is going to collapse. However, there is no evidence that this will happen. We have many interesting stories about how loss of biodiversity causes little wrinkles in the food production system and other aspects of life—honeybees come to mind. But these are really very small wrinkles. They may affect options for biological control: if you lose half the predatory insects in the world, then you are going to halve those options for biological control. That's bad, but you will still have some options. Bottom line, an unpopular bottom line: we can lose a lot of biological diversity without jeopardising food security. Why do I think that?

Dimensions of biodiversity

Biodiversity operates at three levels: alpha, beta and gamma. Alpha diversity is what's in a single locality. Beta diversity is the diversity of species between habitats—say from heathland to forest, in a single area. Gamma diversity is the diversity you get by moving to different regions: the diversity between England and New Zealand, which basically shared few or no species even though effectively they had similar environments and habitats. Gamma diversity explains most global diversity. The biodiversity of New Zealand could be replaced by the diversity of England (or New England) and it would still function: and that has already partly occurred. Go to the Canterbury Plains, the most productive irrigated agricultural system in New Zealand, and you see hedgehogs, stoats, chaffinches, blackbirds, European earthworms and snails: an enormous amount of European biodiversity that inadvertently or deliberately was transported by us. It is a functioning system. It is nowhere near natural: most of the local diversity has entirely gone, but the system is still functioning well. So, unfortunately, we can lose most of the gamma diversity, which is the biggest contributor to global biodiversity, without affecting the ways ecosystems function. I wish this wasn't true, as it would be nice to say that the loss of species is a large and immediate threat to our survival and economy.

The trade-offs

If Australians want to save biodiversity we've got to move away from the false, selfish utilitarian argument that biodiversity is essential—we have just got to say we like biodiversity and we want to keep it, and there are enough of us who want to keep it, now and in the future, that keeping it is worthwhile. We should spend more than $12 million a year on all bird conservation and stop losing a bird a decade. Our research centre has calculated that by spending $50 million a year on bird conservation we could basically stop Australian bird extinctions: we would have one species extinction in the next 100 years instead of ten.

This is where we get to the trade-offs. Why are we spending so much money on all other things and spending such a tiny amount on biodiversity? If anything, the trend has been for environmental

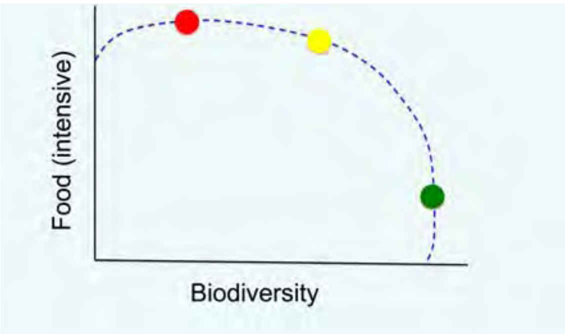

Figure 2. Trade-offs between biodiversity and intensive food production—not cost-benefit analysis. See text for explanation of dots.

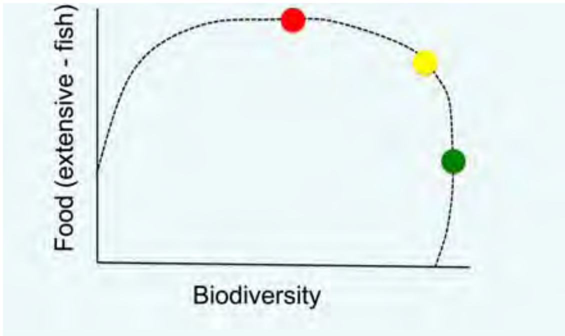

Figure 3. Trade-offs between biodiversity and extensive food production. See text for explanation of dots.

spending to move from biodiversity conservation to ecosystem services conservation, because people think, for example, 'water is good for me'. We've become extremely utilitarian and greedy—it appears that we believe that if an action doesn't do something for me here and now, it isn't worth my money and time. Although we actually have more wealth than any group of people have ever had in humanity's history, at any time in any place, we seem to be more depressingly utilitarian, greedy and self-centred than ever before. So what can we do about biodiversity and food production—is there a way forward for these two superficially competing demands?

To understand the relationship between biodiversity and food security we will look at some trade-off curves: Figure 2 is a hypothetical example. In this figure I show that to maximise food production in systems with intensive agriculture (e.g. monoculture crops) one would have little biodiversity in the long term: the red dot in Figure 2. To maximise biodiversity we would not have much intensive agriculture and make little food, the green dot. However, the yellow dot in Figure 2 is perhaps a reasonable compromise. It is a dot that includes a subdivision on the landscape into some conservation land and some intensive agriculture. When we are looking at the land of Australia we've ultimately got to decide how to allocate it. In the curves I have assume a small fraction of biodiversity is essential (food production goes down if there is very little biodiversity). Despite this, there is no obvious win–win. The compromise solution is not optimal for either sector.

Figure 2 is quite hypothetical. We don't know what this curve looks like and we do need to understand it more to make wise land use decisions.

In contrast to intensive agriculture, with extensive agriculture or extensive harvesting, like fisheries or grazing, you can get closer to a win–win outcome because of the diverse nature of the systems that are producing the food, although if you plundered them too much you'd lose biodiversity. Figure 3 is how I think food production in extensive landscapes relates to biodiversity. Again, biodiversity at some level is essential for maximum food production, and given these systems are complex we need quite a bit of biodiversity. There is still no win–win, but there are solutions that are close to win–win. While I don't know what these curves look like for the food–biodiversity trade-off, we have calculated them for the carbon–biodiversity trade-off.

Last year we published a paper in *Science* (Venter *et al.* 2009) in which we asked a question that the Norwegians have asked several times and acted on: if I have a heap of money and I want to store as much carbon as possible while also stopping people chopping down trees in tropical countries, where should I spend it? If a decision is based on land prices, you would spend most of your money in Brazil. In this case you would also save nine or ten threatened birds. (If I were interested in beetles, multiply that number by a thousand. We are talking about saving a lot of species.) That's good. This is why most people think 'Great. Payments for reduced deforestation and degradation will save biodiversity'.

If in fact I spent that same money to save as many species as possible and didn't care about carbon any more, I would get half as much carbon but four times as many species: so there is a clear trade-off. You can't have your carbon and save your species too: the bottom line is that you've got to accept these trade-offs, although nobody wants to talk about them, even in this case where we have two environmental objectives, there is conflict. In this case we've calculated there is an

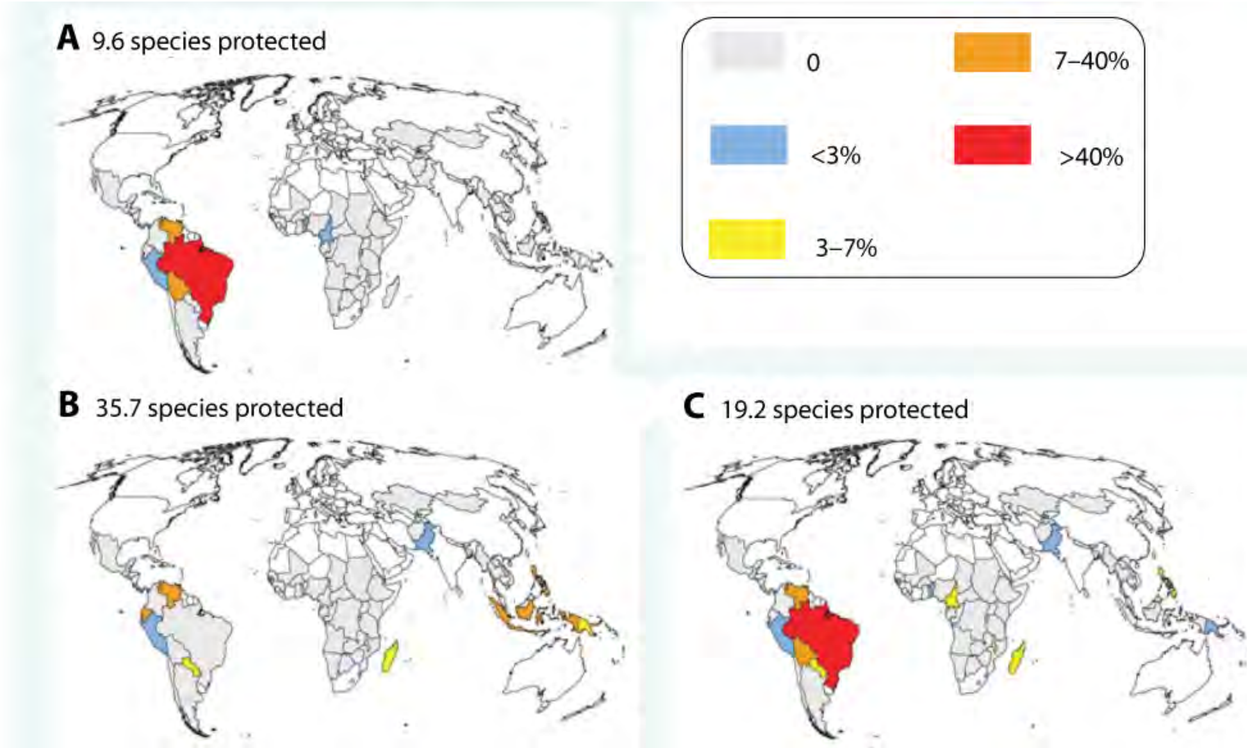

Figure 4. Unexpected trade-offs: for example, between carbon and biodiversity (Venter *et al.* 2009). See text for explanation.

almost win–win. We can save half as many species, so that's not really that good, and we get 96% of the carbon that we got in the plan, that was the optimised carbon plan. So for a tiny reduction (say a 4% reduction) in carbon storage we can save twice as many species (Fig. 4). I would say the same curves could be done roughly for the food–biodiversity trade-off: an optimum trade-off may result in some sacrifice; almost win–win. Better solutions will be found by thinking outside the box and shifting the shape of the trade-off curve.

Solutions

So far I have been deliberately depressing. Biodiversity is in rapid decline and there are no easy win–win solutions. Can I bring any light to bear on this problem, or have the conference organisers wasted their money?

I believe we need to take generally a far more aggressive and honest approach in dealing with these problems, and we need to be much more honest with the Australian public about biodiversity.

First of all there are a few win–wins, although later speakers will describe some interesting, albeit rare, win–wins that do give both better productivity and better biodiversity.

Biosecurity is the greatest win–win of all. If it wasn't for agricultural biosecurity Australian biodiversity would be in a serious mess. I wholeheartedly applaud people working in the area and I lobby continuously for more investment in it, because it is a real win–win economically from both food security and biodiversity perspectives.

There are two reasons, however, why we are not getting really good solutions to the food production – biodiversity nexus in a lot of cases. Firstly, we don't have decent planning tools and we don't stick to our planning. Queensland has just released a map that shows that just 4% of Queensland has soils that are incredibly good for agriculture. There is now an enormous fight with the mining and urban expansion industries. This planning should have happened years ago. This tiny area could probably feed Australia: don't turn it into a mine; don't put a house on top of it. Why didn't we isolate those areas decades ago and take a much more authoritarian approach to land-use planning? I'm sure people in this room have lobbied for such planning. One of our problems is that Australian land-use planning has never been sufficiently decisive nor authoritative. Governments are frightened of providing guidance on prudent land-use for the benefit of all Australians (existing or unborn), in case they tread on the 'rights' of land developers and landowners.

The second reason is lack of innovation. The conservation movement is obsessed with setting the continental clock back to 1750. Many things could be done in Australia in diverse semi-agricultural systems that cater for biodiversity, and there are many aggressive interventions we could try. For example, how many diverse, constructive, managed wetlands for biodiversity do you know of in Australia? Places where a piece of degraded agricultural land or a mine site has been turned into a wetland managed for diversity? The Europeans and North Americans have hundreds of them. They get much out of small areas by investing in biodiversity and actively managing it. We don't do that because we are obsessed with putting everything back the way it was, something which is often expensive, even impossible. In many cases we can take degraded land and create more interesting biodiversity more cheaply by NOT trying to put things back the way they were in 1750. We seal up areas, like national parks, say nobody can go there, nobody can use them, and then expect them to be really good. The world will never be the way it was because we've got climate change, we've got invasive species, we've lost most of our native top predators and we've got 20 million people.

We need another green revolution: getting more species packed into the small areas that are left purely for conservation. We need to give people plans that invest in intensive biodiversity management. We need to make tough decisions. We probably have to let some species go. We have spent an enormous amount of money propping up species that are completely dysfunctional and will disappear in the next one or two hundred years regardless of what we do. We need to be much more innovative.

Where are we now?

Because of poor planning we are not getting anywhere near as much food or biodiversity as we could get. We could emulate for biodiversity some of the innovations that agriculture has used to increase productivity—there is no discussion of how we could get more biodiversity by really investing in intensive biodiversity and getting more per unit area. Organisations like the Australian Wildlife Conservancy and Bush Heritage Trust are exceptions to this rule.

What are we going to do to improve the present position?

We could form a partnership with a regional body and develop, for each region, a multi-objective plan that involves food, biodiversity, carbon storage and water. That plan would include biodiversity investment—not lock-it-up and throw-away-the-key conservation.

Who has seen a plan like this for a region anywhere in Australia? One that tries to define that trade-off curve and suggest an optimal allocation of land in the region to maximise the benefits from different uses—forestry, sheep, intensive agriculture, national park and maybe intensive biodiversity management that might entail growing grain for finches and tubers for brolgas. This would be a solution with both good planning and innovation that actually moved the trade-off curve (Fig. 5). Who's seen that map? What has government been doing for two hundred years in the area of land-use planning? I have no idea.

We are going to make some of those maps. We will define that trade-off curve and point out that people can not only work out where the best land-use solutions are, but we can move the trade-off curves by innovative management—like managed wetlands and woodlands. There will be a minor sacrifice. It is impossible to maximise four things (biodiversity, food, carbon, water) simultaneously—if you maximise one thing the others will suffer—but we can get very close to having all of those issues very high on the agenda. If we had that plan, of course, the devil is in the detail. Economists will ask this 'How do you get to do it?' If we were Russia in 1960, we would just say 'Do it.'

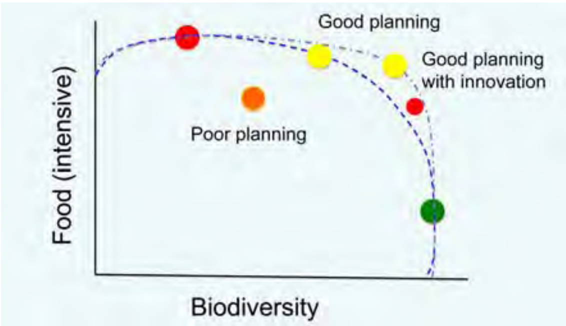

Figure 5. Opportunities for better planning and innovative solutions. See text for explanation.

So how can we move Australia closer to a land-use system that delivers more for everyone, now and in the future? We could legislate, take a heavy-handed top-down approach, but legislation is not palatable for a lot of politicians. We could push down the EU agricultural subsidies route, requiring for example that 20-m strips be left for flowers and forests beside fields of wheat or barley. We could actually say ‘you’re going to have to farm some biodiversity, and we will pay you to do it’. We could use some of the more innovative solutions like biodiversity trading, insurance mechanisms, providing people a safety net if they are going to do innovative things, and reverse auctions which pay people for biodiversity outcomes through a competitive marketing mechanism. Australia, in some respects, leads the world in some of these innovative areas. We haven’t started biodiversity trading yet, but we have to do it and we have to have the plan first. Then we’ve got to work with smart economists and political scientists and social scientists how we can actually get it done in a particular region.

To demonstrate that such plans can be done, the piece of software that my research group has developed over the past 15 years is actually being used to build the world’s entire marine reserve systems in over 100 countries. It is changing the face of 5% of the world’s oceans and some of the land. We’ve adapted it, with the Nature Conservatory, to deliver land use plans too in part of Kalimantan—why not Australia? The technical tools exist, now we need leadership.

Conclusion

I work with many colleagues as part of two new national centres for environmental decision-making. We try to communicate effectively with policy makers. We have a monthly magazine that we send to as many state managers and politicians as are willing to sign up to it, and about 2000 people read it every month. It’s called *Decision Point* [http://ceed.edu.au/dpoint-news], not ‘save the world’s biodiversity’. It has a name reflecting precisely what Bob McMullen talked about—making decisions and hard choices is an issue of trade-offs and leadership. Academics need to get out of our ivory towers, and politicians and the senior bureaucrats need to invite us into theirs.

A final message is to thank my many colleagues, none of whom would admit to agreeing with any of this rant, and other people who have contributed to work described in this presentation.

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Preserving Biodiversity, Promoting Biosecurity and Biosafety: Australian Perspectives

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Biosecurity is the management of risks to the economy, the environment and the community of pests and diseases entering, emerging, establishing or spreading. In Australia, biosecurity services are delivered by government and industry in partnership with farmers and the wider community as a shared responsibility. This is described in a biosecurity continuum to convey that biosecurity outcomes cannot be delivered if any element of the continuum is missing or ineffective. Biodiversity is both an outcome of and a contributor to biosecurity actions, for example as a source of biological control agents and genetic diversity for host resistance breeding. Biotechnology is a tool that can help deliver biosecurity outcomes, although it may also generate biosecurity concerns unless appropriately managed. Our environment and the activities it supports can be viewed as a large and complex ecosystem. Meshing the biosecurity continuum approach with an ecosystem concept can help government, industry and communities to identify priority actions to deliver trade, food safety and security and biodiversity outcomes through risk-based analysis and delivery of biosecurity actions. Valuing the outcomes of biosecurity actions, particularly in the natural or built environment where dollar values are not as clear as they are in commercial production systems, is difficult and generally a product of societal values and individual impacts.

LOIS RANSOM is the Chief Plant Protection Officer (CPPO) in the Australian Government Department of Agriculture, Fisheries and Forestry. She is a plant pathologist by training and practice and has worked in most areas of plant health spanning pesticide efficacy testing; research, development and extension for better disease management in Tasmania's vegetable and medicinal crops; and quarantine and export policy and operations with the Australian Government. She was Australia's Agriculture Counsellor in Tokyo from 2000 to 2003. As the CPPO she is a focal point for national and international plant health with a significant leadership role in the ongoing development of Australia's plant biosecurity system.

Introduction

It is a challenge to address the topic of this talk in the allotted time because each of the 'bio' elements is worthy of far more intensive discussion in their own right. I will start on definitions because these give a sense of how things fit together, and use examples from my experience in the biosecurity system in Australia that may be of some value in considering the issues that have been raised by previous speakers.

The ongoing evolution of Australia's biosecurity system has focused to date on the reform of a national framework to achieve clarity of purpose and to define roles and responsibilities, as well as to set priorities for ongoing development of biosecurity capacity and capability that will enable the delivery of the biosecurity outcomes expected by the Australian community. National planning and action to protect Australia's biodiversity may learn from the recent actions to ensure our biosecurity system is dynamic, responsive and flexible.

The foundation for achieving better biosecurity outcomes is the national framework that actively enables and supports effective local delivery of biosecurity. This can also set local action in the context of national priorities and outcomes where numerous small actions contribute to larger outcomes. It is inevitable that the biosecurity system, and those working within it, is judged on actual outcomes. No matter what else we do, if biosecurity outcomes for this country are poor and our place within the global community is poor, we will be judged poorly.

Definitions

The relationships between biodiversity, biosecurity and biosafety are as complex as the ecosystems they create or protect. At its most basic, biodiversity is safeguarded by Australia's biosecurity system, which can be assisted by the safe application of biotechnology.

The Convention on Biological Diversity (CBD 1992) defines 'biological diversity' as the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems. Biodiversity is both an outcome of and a contributor to biosecurity actions, for example as a source of biological control agents and of genetic diversity for host resistance breeding.

Biosecurity is the management of risks to the economy, the environment and the community of pests and diseases entering, emerging, establishing or spreading. Hence the biological diversity of an area, whether a small ecosystem or the whole of Australia, is protected from the impacts of pests that are absent from that area by effective application of biosecurity services.

Biosafety is a modern concept arising from the 2000 Cartagena Protocol on Biosafety, which encompasses the protection of human health and biodiversity by controlling the importation, release and use of genetically modified crops. Of itself, genetic modification is a tool that can help provide protection of plants from pests. However, modifications and their application in production ecosystems may have unintended consequences that must also be managed to mitigate damage to these and adjacent ecosystems. Biotechnology has been applied in Australia for integrated pest management and to reduce the use of pesticides. There have been observed increases in the biodiversity of insect fauna in genetically modified cotton crops.

Risk analysis is applied to the regulation of modified organisms to safeguard the environment and economy from adverse effects of their introduction in much the same way as biosecurity threats are assessed and managed through biosecurity import risk analysis processes.

The biosecurity system

In Australia, the biosecurity system is complex and operates at many different levels. Operations at the international border are obvious to importers of goods and to travellers returning through air and sea ports. Its operations off-shore to address pest risks on goods before they are exported and on-shore to limit their spread within Australia are not always as obvious. Off-shore activities include site visits to confirm biosecurity risks, the collection and analysis of international intelligence to identify new and emerging threats and measures to address them, and capacity-building, particularly in the Asia and Pacific regions, to improve pest management and reduce the risks that pests will move into Australia with goods, people or by natural spread.

States and territories operate a quarantine system to prevent the movement of established pests to new areas within the country. This is supported by animal and plant health legislation in each jurisdiction. Quarantine measures are applied to protect defined areas or habitats and ecosystems to support market access by maintaining these areas free of quarantine pests, or to safeguard them from diseases that severely affect their economic or ecological value. Biosecurity is also practised at a property level, to protect farms from diseases that may be carried by new livestock or stock feed.

This 'continuum' approach to biosecurity acknowledges the connectivity of off-shore, border and on-shore actions and the roles and shared responsibilities of governments, industry and the Australian community in protecting our farms, forests, cities and bushland from damaging pests and diseases (Fig. 1). It is reflected in the national biosecurity framework. The concept was first acknowledged in the 1996 Nairn review of quarantine and more recently in the 2008 Beale review of quarantine and biosecurity. These concepts reflect the value that we, as a nation, place on the ability we have to provide safe, wholesome food to our population, generate wealth from animal and plant exports and safeguard Australia's unique and diverse fauna and flora.

Biosecurity agencies are working hard to create a holistic focus that integrates all biosecurity activities within a national framework—ensuring that roles and responsibilities are clear, and that adequate resources and infrastructure are available to identify priority biosecurity risks effectively. The

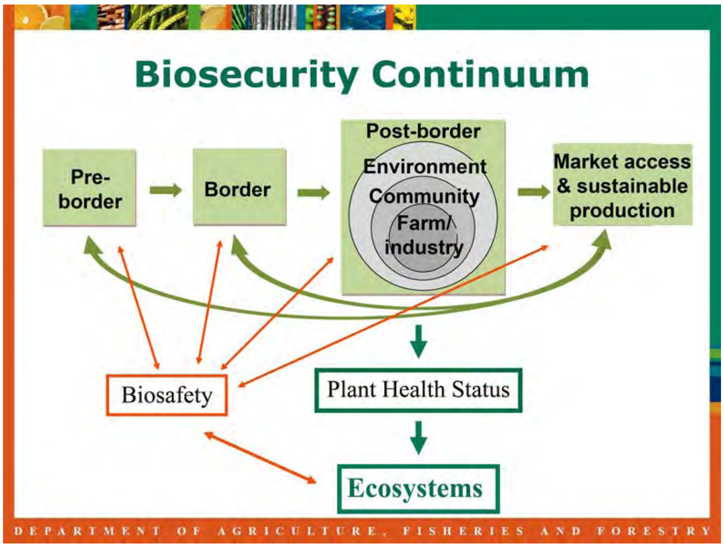

Figure 1. The biosecurity continuum

system, of necessity, must be risk based, as we simply do not have the resources to do everything, and if we are to import food and other goods, and support tourism, then there will be risks. Our ongoing focus is on the things that matter most.

What are we protecting?

Australia is one of the most biologically diverse countries in the world with 6.7% of the world's vascular plant species, 7.0% of the world's mammal species, 15% of ant species, 8.4% of the world's bird species, 3.8% of the world's amphibian species and 17.0% of the world's marine and freshwater fish species (National Biodiversity Strategy Review Task Group 2009). About 84% of plant species, 83% of mammal species and 45% of bird species are found only in Australia (DEWHA 2008). The gross value of farm production in Australia is in excess of $45 billion per annum (ABARE 2009). This includes the production and processing of animals and their products, which are also plant based.

As a large land mass, the climatic variation from north to south allows a wide range of habitats for both native and introduced species, including plants that are produced for food. These habitats are under ongoing threat from invasive species including vertebrates, invertebrates, diseases and weeds that are new to Australia, or that may be established or native species that are not widespread. Of necessity, Australia imports goods to support industries and households, and many millions of people cross our international border as tourists or residents returning home. The biosecurity system is in place to reduce the risk of entry of pest threats.

Not all threats are exotic. The Queensland fruit fly (*Bactrocera tryoni*) is a good example of a native species that has extended its natural range over time and which has become a significant cost to producers and exporters as they must meet interstate and international conditions to prevent its further spread in exported fruit. Pests also affect the natural environment to shape ecosystems. The impact of the soil-borne fungus *Phytophthora cinnamomi* on native forests in Western Australia has been significant and is probably irreversible.

The spectrum of plant pests in Australia defines our plant health status. It is this status that underpins quarantine actions at the international border and the conditions under which we can export plants and products to the rest of the world.

Protecting biodiversity

Our environment and the activities it supports can be viewed as a large and complex ecosystem. It includes native habitats, farms and cities. Meshing the biosecurity continuum approach with an ecosystem concept can help government, industry and communities to identify priority actions to deliver trade, food safety and security and biodiversity outcomes through risk-based analysis and delivery of biosecurity actions. A key challenge is identifying the outcomes sought and achieving a balance of interests and investment in a matrix of stakeholders, outcomes and resources, as well as local and national interests and imperatives.

There are some very clear parallels around decision making, priority setting and community values and expectations in relation to protecting biodiversity to which biosecurity is no stranger. I have framed this as a series of questions that will need to be considered in order to begin to set priorities and outcomes for preserving biodiversity in Australia, in balance with demands for land use to support our economy and our communities.

These include:

- Which ecosystems do we want to protect and why?
- What do you protect them from?

- Who makes this decision?
- What actions are needed, etc?

On face value these may be simple questions but they can be extremely difficult to answer due to a lack of information and knowledge of an ecosystem and the efficacy of measures that may be taken to protect it. However, setting a solid and consistent foundation to identifying ecosystems and or species at risk allows for more efficient and robust planning and delivery and, if integrated into a national framework, supports greater transparency and confidence in decision making. This framework can also support the application of risk analysis and benefit:cost analysis to define social values, ecosystem services, endangered species, identify and allocate roles and responsibilities and establish baseline capacity to deliver.

Balancing priorities in a way that accommodates the breadth of stakeholder views and values is also fraught with difficulty. Every member of our community will assign their own value on a place or a thing. Agreeing values that do not have a simple and unequivocal dollar value for example, the return made on a crop of wheat or apples, requires the determination of a range of values and their comparative weighting. This is an area where Dr Possingham's group [page 14] will be working to provide guidance to government. Some areas such as world heritage listed areas already have a set of values assigned to them by virtue of the listing process. This may be a useful starting point for determining non-dollar values affected by a pest, and has been considered in analysing the potential impact of the electric ant (*Wasmannia auropunctata*) outbreak near Cairns, Queensland, should it enter the nearby world heritage area.

We have used these fundamental questions in our planning to protect species of myrtaceae in Australia. This family of plants is dominant in the Australian environment and is widely used by the nursery and forestry industries. We know there are a number of very damaging pests affecting the health of these plants overseas that would have a significant impact on Australian species if they were to arrive. These include guava rust (*Puccinia psidii*) and the Asian gypsy moth (*Lymantria dispar*).

In 2006, a national workshop was convened as part of our preparedness for an incursion of guava rust using scenarios to test options for a response. Representatives from affected industries, primary production, emergency response organisations and environment agencies took part. The same questions as those posed above provided a useful guide to establishing roles and responsibilities in policy and response, the assumptions underpinning whether to continue with a response given the biology of rust diseases and our ability to contain them, and when to stop an eradication response. We also explored the ecosystems that should be protected, noting that primary production industries are best placed to develop their own disease management strategies. This forward planning has been applied to the recent detection and ongoing management of the closely related myrtle rust, which was first confirmed in Australia in April 2010 (Fig. 2). Identifying the location of threatened species in areas where myrtle rust is present has focussed planning and action on protecting these plants and the ecosystems they live in.

The challenge for protecting Australia's biodiversity, as I see it, is in establishing the national framework that integrates the processes to identify and then goes on to protect priority biodiversity targets in a way that is cost effective, reflective of community values, is flexible and adaptable and appropriately resourced. We have seen over the last 20 years the local impacts that community-based Landcare groups have made. Mobilising the 20+ million potential volunteers who have a strong vested interest in Australia's environment and ecosystems is a big task, but without commu-

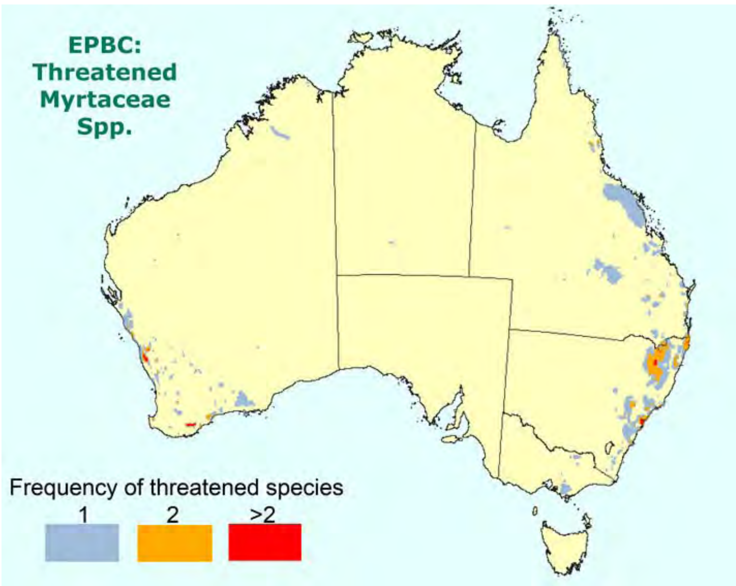

Figure 2. The distribution of myrtaceous species threatened by myrtle rust

nity ownership and a shared responsibility in protection of our environment these efforts will remain disjointed. Mechanisms that incorporate shared decision-making and stewardship will be critical to success and should underpin a road map that uses a national framework to enable local action.

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Preserving Biodiversity, Promoting Biosecurity and Biosafety: Developing Country Perspectives

KENG-YEANG LUM

CAB International Southeast and East Asia Regional Centre (CABI SEA)

ASEAN is host to seven of the world's 25 biodiversity hotspots. Failure of governments and their peoples to protect and conserve the region's rich biodiversity is one of the greatest threats to the over 500 million people of ASEAN. As in other areas of the developing world, biodiversity conservation demands a delicate balance between development and conservation. The region's rich biodiversity is inextricably linked to the livelihood of its people; about 65% of its population is dependent on its agricultural sector. The sector is a prime contributor to food security, employment, income generation and overall prosperity of the region. The linkage between biodiversity and agriculture is further emphasised as a result of global conventions and agreements that deal with the threats posed by invasive alien species to natural and agro-environments and issues of environmental sustainability.

Biosecurity, together with biosafety, proposes a strategic and integrated approach that encompasses policy and regulatory frameworks for analysing and managing relevant risks to human, animal and plant life and health, and associated risks to the environment. The concept of managing these risks in a holistic manner has, however, not yet been fully embraced by developing countries, where biosecurity continues to be managed on a sector basis, often with separate policy and legislative frameworks. The migration towards a more harmonised and integrated approach, with the different sectors and components of biosecurity working towards common goals to take advantage of the available synergies and complementarities is often plagued by difficulties in cross-institutional cooperation and commitment, and agreement on sharing of limiting human capacity and resources.

KENG-YEANG LUM first visited Australia as a Colombo Plan scholar to study agriculture at the University of Adelaide in 1966. As Chief Scientist he now leads a team of scientists in international development activities at CABI Southeast & East Asia. He chairs ASEANET, the Southeast Asian LOOP of BioNET International, is a member of the International Plant Protection Convention (IPPC) Technical Panel on Diagnostic Protocols, and has worked in various capacities with the AusAID-funded SPS Capacity Building Program, the ASEAN Australia Development Cooperation Program, the Department of Agriculture, Fisheries and Forestry, Australia, and the Asian Development Bank. He continues to lead various regional plant health capacity-building initiatives, including the ASEAN Regional Diagnostic Network.

Introduction

The United Nations Convention on Biological Diversity defines biodiversity as 'the variability among living organisms including, inter alia, terrestrial, marine and other aquatic systems and the ecological complexes of which they are part. This includes diversity within species, between species and of ecosystems.' Biological diversity or biodiversity is the very heart of our environment and is the web of life that includes the full range of ecosystems, their component species and the genetic variety of those species produced by nature or shaped by men. It includes plants and animals, and the processes and inter-relationships that sustain these components. Southeast Asia, consisting of Brunei Darussalam, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, the Philippines, Singapore, Thailand and Vietnam, which together form the Association of Southeast Asian Nations (ASEAN), is a treasure-trove of diverse plant and animal species. Despite occupying a meagre three per cent of the earth's total surface, the ASEAN region is home to some 20% of all known species of plants and animals, making it critically important to global environmental sustainability. The mountains, jungles, lakes, rivers and seas of Southeast Asia form one of the biggest biodiversity pools in the world. More specifically, the region includes three mega-diverse countries (Indonesia, Malaysia and the Philippines); several bio-geographical units (e.g. Malesia, Wallacea, Sundaland, Indo-Burma and the Central Indo-Pacific); and numerous centres of concentration of restricted-range bird, plant and insect species. Southeast Asia's coral reefs are among the most diverse in the world. Common land and water borders have allowed the ASEAN member states to share many species that are biologically diverse from the rest of the world.

Threats to ASEAN biodiversity

Beneath the wealth of biodiversity in the region, loss of biodiversity is one of the greatest threats to the people of ASEAN; seven of the world's 25 recognised biodiversity hotspots are in the ASEAN region. Eighty per cent of the region's coral reefs are at risk. Drastic environmental changes coupled with human practices are causing serious harm to plants, animals and their habitats. Out of 64 800 species found in the region, 1312 are endangered. Many animal species may be lost as a result of deforestation, wildlife hunting, climate change, pollution, population growth and other causes. Many species are threatened with massive decline and extinction in Southeast Asia if governments and their citizens fail to protect and conserve the region's biodiversity. Biodiversity is under pressure from modern development and the demands of a growing human population. So, despite its great wealth and biodiversity, and dependence upon the products and services it provides, the ASEAN region is losing its biodiversity at an alarming rate.

Biodiversity and invasives

Invasive species are a major threat to our environment because they:

- change an entire habitat, placing ecosystems at risk
- crowd out or replace native species that are beneficial to a habitat, or
- damage human enterprise, such as fisheries, costing significant economic loss.

The introduction of invasive alien species into ecosystems affects indigenous species. A classic example is the case of the janitor fish which infested the Philippines' Laguna Lake, and disrupted balance in its ecosystem. There are many ways in which the introduction of non-native or exotic species negatively affects our environment and the diversity of life on our planet. Compared to other threats to biodiversity, invasive introduced species rank second only to habitat destruction.

Keeping potentially damaging invaders out is the most cost-effective way to deal with introduced species. Targeting common pathways by which invaders reach our shores can slow or stop their entry. Ship ballast water, wooden packing material and horticultural plants are three prominent pathways for invasion that could all be monitored or treated more rigorously. A species that is introduced despite precautions can sometimes be eradicated, especially if discovered quickly. Even if eradication fails, several technologies often can keep invasive species at acceptably low levels.

Traditionally, biological, chemical and mechanical control of invasives has had limited success. A newer approach to managing invaders is ecosystem management, in which the entire ecosystem is subject to a regular treatment that tends to favour adapted native species over most exotic invaders. The specific ways in which ecosystem management can be employed must be determined in each type of habitat.

Biodiversity and biosecurity

Biosecurity encompasses policy and regulatory frameworks to manage risks associated with agriculture and food production. This includes, for example, the introduction and release of 'living modified organisms' (LMOs) and 'genetically-modified organisms' (GMOs) and their derived products, the introduction and spread of invasive alien species, alien genotypes and plant pests, animal pests, diseases and zoonoses (diseases that can be transmitted from animals to humans).

Biodiversity and biosecurity are inextricably intertwined—a successful outcome for biosecurity is a successful outcome for biodiversity. A major driver for the future of the success of any national biosecurity system is the implementation and on-going development of a national pre-emptive biosecurity strategy. In view of a number of developments, including globalisation, the rapid increase in transport and trade and technological progress, national and international frameworks and standards need to be developed and strengthened in order to regulate, manage and control biosecurity. Adequate biosecurity policy and regulatory responses need to be developed to address some of the risks associated with agriculture and food production.

Countries are increasingly taking a holistic view and are combining these regulatory activities. This trend is expected to continue, although many developing nations have yet to embrace this concept. The role of international agencies, such as FAO, is vital in building on an already significant range of activities and outputs that address biosecurity, including international instruments, biosafety in relation to LMOs and GMOs, biosecurity in relation to invasive alien species and closely associated concerns for food, agriculture, fisheries and forestry.

Integrating biodiversity, biosecurity and sustainable development objectives

Challenged by the unprecedented loss of biodiversity in the region, the 10 ASEAN Member States are working together to protect their biodiversity. All ASEAN states are signatories to the Convention on Biological Diversity, the first global agreement to cover the conservation of biological diversity, the sustainable use of its components, and the fair and equitable sharing of benefits arising from the use of genetic resources. By signing the convention, they committed to reducing biodiversity loss by 2010—the International Year of Biodiversity. The ASEAN states have also declared 27 areas as ASEAN Heritage Parks, and designated 1523 protected areas based on The World Conservation Union (IUCN) Category.

While the developing countries of Southeast Asia have yet to accord biodiversity conservation its rightful priority due to challenges of resource allocation and human capacity, there is growing awareness of the need to recognise this biodiversity as a treasure of biological resources that may be exploited for food production. However, the quest for agricultural and food productivity has brought to the forefront issues relating to sustainable agricultural development, which in turn directly affects the challenges of biodiversity conservation.

A common thread that runs across biodiversity and biosecurity objectives is the concern for the spread of invasive alien species (IAS). Developing countries lack the capacity to identify IAS to be able to effectively implement biosecurity objectives. They also lack the capacity to prepare inventories of their native biodiversity to be able to effectively carry out conservation measures. Taxonomic skills are key to understanding what biodiversity to conserve and protect, as well as the ability to identify invasive threats and biosecurity priorities and therefore raise levels of preparedness. A number of development assistance initiatives that support capacity-building in this area has been most useful, largely driven by Australian and New Zealand development assistance (AusAID and NZAid).

There is a need for developing countries to integrate or harmonise biodiversity conservation and agricultural production activities that have IAS as a common theme.

In recent years, some notable initiatives in the region have given impetus to the drive towards biodiversity conservation and sustainable development. The Heart of Borneo (HoB) Initiative is an ambitious conservation program encompassing 220 000 km^2 of highland forests at the core of Borneo Island. The project is supported by Brunei, Indonesia and Malaysia, and technically by WWF.

Other initiatives have arisen out of global demands for sustainability, for example the Roundtable on Sustainable Palm Oil (RSPO) formed in 2004 with the objective of promoting the growth and use of sustainable oil palm products through credible global standards and engagement of stakeholders. The RSPO is a not-for-profit association that unites over 400 stakeholders from seven sectors of the palm oil industry—oil palm producers, palm oil processors or traders, consumer goods manufacturers, retailers, banks and investors, environmental or nature conservation NGOs and social or developmental NGOs—to develop and implement global standards for sustainable palm oil. Palm oil is certified sustainable when determined to have been produced in a manner compliant with the set of RSPO Principles and Criteria as certified by accredited third parties.

Concluding remarks

Preserving biodiversity, and promoting biosecurity and biosafety, are merely different sides of the same coin, serving the common objectives of sustainability and food security and production. An equitable balance may be achieved as developing countries come to grips with global trends, build adequate capacity and rationalise resource allocation, while seeking to improve their economies and food security.

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Agricultural Biotechnology, Gene Flow and Biodiversity

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A sustainable strategy to nourish the planet and its people must also promote biodiversity conservation. This strategy will have to include reduction in land degradation and unsustainable overuse of fertilisers, pesticides, fungicides, herbicides, and irrigation water. A case can be made for conserving biodiversity as a source of traits for incorporation, by different genetic tools, into food plants and animals, but an even stronger case can be made for a conserved biodiversity to supply ecosystem services that will nourish the planet and its occupants into the future. Biodiversity is under severe threat from many angles. One of the best ways to promote biodiversity is to preserve native habitats. By maintaining or even increasing yields on existing land, biotechnology crops can help to minimise expansion of agriculture into natural areas. It has also been estimated that agricultural biotechnology has changed pesticide spraying so as to greatly reduce greenhouse gas emissions and decrease environmental impacts of insecticides and herbicides. Gene flow from cultivated, including biotechnology-based, crops to and from wild plants is known to occur. The consequences of this flow vary from species to species, but as a general rule, do not pose a significant threat to biodiversity.

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Introduction

The journal *Nature's* editorial of 29 July 2010, 'How to feed a hungry world' (Anon. 2010), said 'producing enough food for the world's population in 2050 will be easy'. This is a very controversial comment—although it did go on to say, 'that doing it at a acceptable cost to the planet will depend on research into everything from high-tech seeds to low-tech farming practices'. That second sentence is starting to sound more realistic, but not too many people—certainly not the Crawford Fund audience—would be as naive as the editor of *Nature* to say that all of our problems will be solved by technical fixes alone. Most people would subscribe to a much more complex set of conditions to be met if we are to feed and clothe the future 8–10 billion. At the very least we will need significant policy and social changes, and new regulatory regimes around food production as well as scientific and technological advances (Tilman *et al*. 2001).

The past five decades

The next 50 years is likely to be the last period of rapid agricultural expansion; thereafter the planet should be in a steady state. To anticipate the next 50 years, it is useful to look back on what has happened during the past 50 years.

The population has more than doubled and world crop production has more than kept pace with that growth—in fact it has almost tripled. An increase in land area of about 27% contributed to the production of that extra food. This amazing increase in yield was achieved by a combination of factors—better varieties, more pesticides, more fertiliser, more irrigation and more mechanisation, as well as an increase in cultivated area (Burney *et al*. 2010). Intensification has had undoubted benefits but, equally undoubtedly, costs. The benefits included sparing wild lands for nature and less malnutrition; some of the costs were more water use, more chemical runoff, more soil erosion and increased greenhouse gases.

The coming decades

To anticipate the changes that are likely in the food ecosystem by 2050, note that currently about 3.5 billion hectares (B ha) are under pastures, 1.5 B ha are cultivated and about 280 million ha are irrigated. There is heavy use of fertilisers, that is 87 million tonnes of nitrogen and 34 million tonnes of phosphorus. Already more than 3.5 million tonnes of pesticides are applied (Burney *et al.* 2010) (Table 1).

In summary, between 30% and 40% of the terrestrial area of the ice-free land is already under cultivation or in pasture. It is estimated (Tilman *et al.* 2001; Burney *et al.* 2010) that land committed to crops and livestock will have increased to 5.3 B ha by 2020 and nearly 6 B ha by 2050. This means that another billion hectares are going to be converted from wild lands, even assuming we are going to make gains through intensification at the same rate as in the last five decades. For example, the area of irrigated land is predicted to double by 2050, and there will be massive increases (three-fold) in fertiliser use, particularly nitrogen (N) and phosphorus (P), if they are affordable. If, as expected, we reach peak oil about 2015 and peak phosphorus in 2035, there is considerable uncertainty about the future availability and thus price of N and P. Crop and pasture legumes are a significant source of fixed nitrogen and have an important role in P availability, and it can be anticipated that more legumes will feature in future intensification of food production. Massive increases in the use of pesticides (up to ten from the current near four million tonnes) are predicted to be required to achieve the yields of food, feed and fibre that are going to be needed to shelter, clothe and feed humanity into the future (Table 1).

Table 1. Projected changes to the food, feed and fibre ecosystem by 2050 (adapted from Tilman *et al*. 2001)

Attribute	2000	Estimate for-	
		2020	2050
Crops (billion ha)	1.54	1.66	1.89
Pastures (billion ha)	3.47	3.67	4.01
Irrigated land (billion ha)	0.28	0.37	0.53
Fertiliser use:			
Nitrogen (M tonnes)	87	135	236
Phosphorus (M tonnes)	34	48	84
Pesticide use (M tonnes)	3.75	6.55	10.1

Exacerbating the risk that it may not be possible to meet future needs in food production is the fact that annual crop yield increases are falling below projected demand (Alston *et al.* 2009). Therefore yields per unit area have to increase or the area of land under cultivation and pastures must expand. This latter scenario would further threaten biodiversity conservation. While food security for humans is identified as absolutely vital to the future, the message needs to be 'food and ecological security' (Glover *et al.* 2010). There is a justified concern that if more land is appropriated for direct human use this will have a major negative effect on biodiversity (Cassman and Wood 2005; Glover *et al.* 2010):

The role of GM crops

What role might GM crops play in sparing wild land and thus promote biodiversity conservation? Of the near 1.5 B ha of crops that are currently grown, about 140 million ha were GM in 2009 (James 2009). This amounts to 9% of the total. The 14 million farmers who grew those GM crops amount to about 3% of global farmers. GM crops have been grown for about 15 years—long enough to evaluate what contribution they have made and estimate what they are likely to do in the future.

There have been a significant number of peer-reviewed studies of genetically modified (GM) crops (Carpenter 2010) (Table 2). There are almost 170 reports on yield alone, from both developing and developed countries. Some of these (13 in total) reported that there was a reduction in yield in the GM crops compared to the non-GM counterparts; while a further 31 reported no change in yield.

Table 2. Number of peer-reviewed surveys of yield changes when comparing GM crops with non-GM crops (adapted from Carpenter 2010)

Countries	Positive	Neutral	Negative	Total
Developed	36	18	7	61
Developing	88	13	6	107

A majority (124) reported that there were increases in yield when GM crops were grown. In developed countries, for instance, 36 out of 61 show that there were positive yield gains; 18 showed no gain and 7 reported a reduction in yield. In developing countries—and these countries are the biodiversity-rich areas—88 out of the 107 reports showed gains in yield, 13 were neutral and 6 were negative (Carpenter 2010). Yield gains are a step towards intensification and the sparing of land for natural ecosystems.

The economic effects of these yield gains, when combined with reduced costs of pesticide inputs, can have an impact on poverty. There are almost 100 peer-reviewed studies of the economic impact of GM crops (Carpenter 2010): 71 of those 98 are positive, 11 are neutral and 16 are negative. Most of the positive gains were in developing countries.

Despite these benefits there are risks associated with GM crops which could have negative effects on biodiversity. Herbicide-tolerant crops risk the development of herbicide-tolerant weeds. Insect-resistant crops risk the emergence of resistant pests. These risks are significant and they echo similar risks in conventional agriculture. Management of these new crops requires sophisticated skills that are vital to the long-term usefulness of gene technology for the ecosystems of the future.

Following are examples of the land-sparing and input-sparing effects that GM crops have had over the last 12–15 years, largely in developing economies.

Cotton in India and China

The average yield of cotton increased by about 70% between 2001 and 2008 in India (James 2009). Half of this increase has been attributed to insect-resistant cottons containing genes derived from the soil microbe, *Bacillus thuringiensis* (Bt). The other half of the gain was made by improvements to conventional agriculture. There was a 56% decrease in cotton boll insecticide used between 1998 and 2006 which is cost saving for the six million Indian farmers who grew Bt cotton in 2009. In 2009, seven million Chinese farmers also grew Bt cotton. In China, yield was increased by almost 10% and insecticide use decreased by 60% (James 2009).

Soybeans

Brazil has enthusiastically adopted GM crops and there have been significantly fewer herbicide sprays on their RoundUp-Ready soybeans. Between 1997 and 2008 they reduced diesel and water use, and CO_2 emissions were reduced as a result. Further improvements are expected between 2009 and 2017. Combining (James 2009) GM cotton, maize and soybeans , the projected savings of inputs of diesel and water are over 800 000 tonnes and 105 million tonnes, respectively, with a concomitant reduction in carbon dioxide emissions of two million tonnes (James 2009).

Maize

In certain parts of the developed world, e.g. the United States, there has been rapid uptake of GM crops, especially corn, soybeans, cotton and sugarbeet. Cassman and colleagues (Cassman *et al.* 2006)) note that corn yields have doubled over the last 40 years (Fig. 1). Between 1965 and 2005 the average yield of corn in the US went from just under 5 to almost 9 tonnes per ha. Several factors have contributed to this gain and the almost exclusive use of hybrids has been very important. Although these were first developed in the 1930s they really came into their own in the 1960s. Over time more irrigation, increased fertiliser (NPK) rates and conservation tillage, as well as integrated pest management, became significant contributors as well.

Some of the yield gain has been attributed to the adoption of GM corn in the 10 years to 2005 (Cassman *et al.* 2006). They also pose a question about how reduced application (due to higher prices) of nitrogen fertiliser and irrigation will affect the upward yield trend in the future.

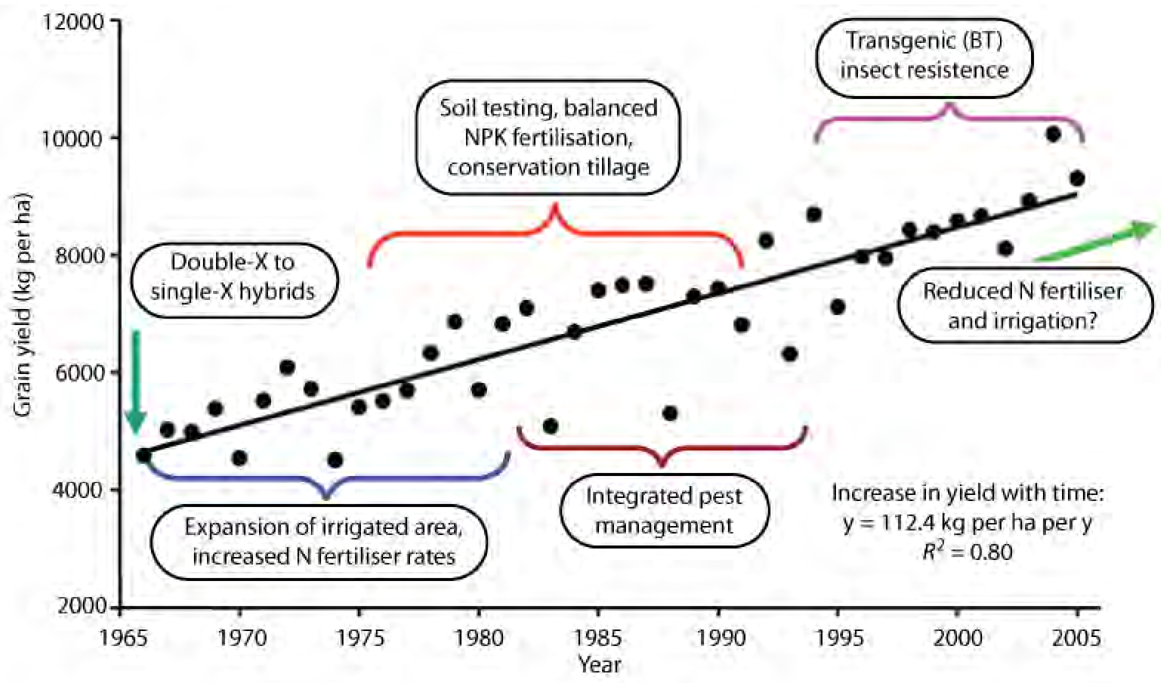

Figure 1. Corn yield trends in the United States from 1966 to 2005, and the technological innovations that contributed to yield increases. Reproduced with permission from Cassman *et al*. (2006) Council for Agricultural Science and Technology (CAST), *Convergence of Agriculture and Energy: Implications for Research and Policy*. CAST Commentary QTA2006-3. CAST, Ames, Iowa.

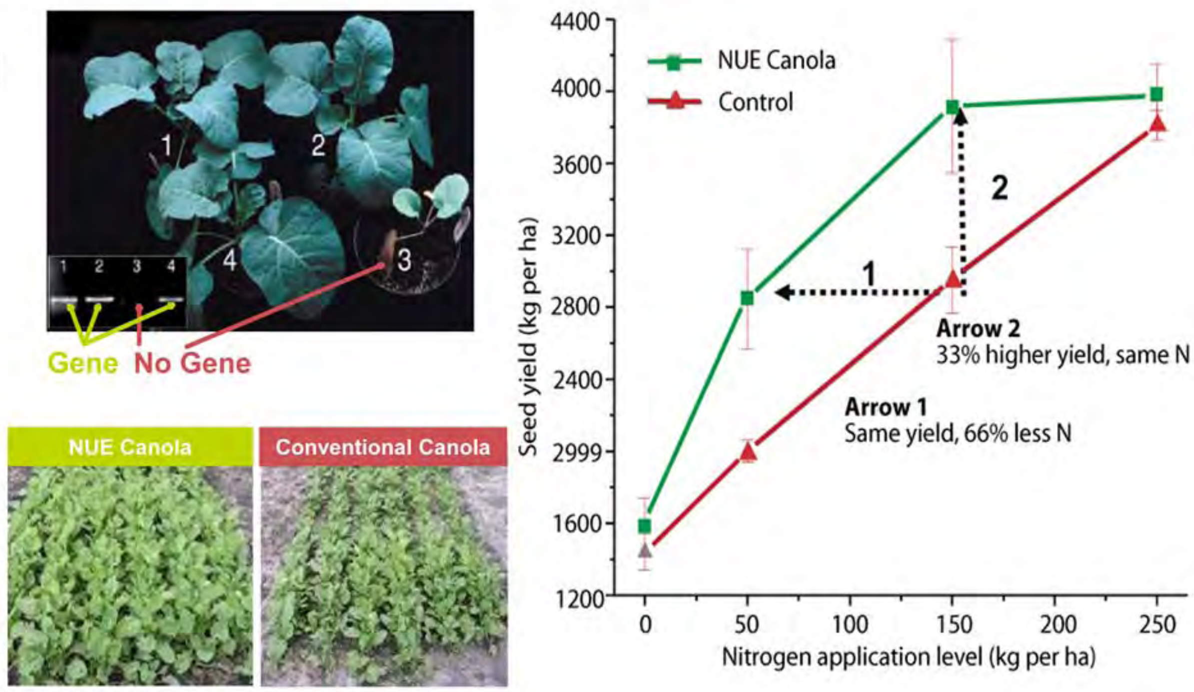

Figure 2. Grain yield in canola with a nitrogen use efficiency (NUE) trait in field trials (Source: Arcadia Bioscience). Reproduced with permission.

Efficiency of fertiliser use

Fertiliser nitrogen and phosphorus have a vital projected role in future food. As indicated in Table 1 fertiliser use is likely to more than double by 2050. Unfortunately, less than half of the nitrogen applied is absorbed by plants and this constitutes an economic inefficiency for farmers. The unabsorbed nitrogen ends up contributing to eutrophication of water and producing additional greenhouse gas.

Conservation of nitrogen (and phosphorus) in the production of food feed and fibre for the future is an area of very active research, using advances in both genetics and in agroecosystem management. One way in which GM may play a role is illustrated by an example from nitrogen-use-efficient (NUE) canola. Scientists at Arcadia Bioscience transferred a gene involved in nitrogen metabolism from barley to canola and, in field trials, showed that the efficiency of nitrogen use was increased such that a yield of about 2.8 tonnes per ha could be produced with 50 instead of 150 kg of N per ha (arrow 1 in Fig. 2) using the NUE canola. Alternatively, a higher yield of nearly four tonnes can be obtained from the same application (150 kg ha^{-1}) of nitrogen to the NUE canola (arrow 2 in Fig. 2). Thus, if this concept of NUE (and in future, a similar approach to phosphorus use efficiency) is transferable to other crops as well as pastures and forestry, GM technology may help with at least one of the major inputs into agriculture.

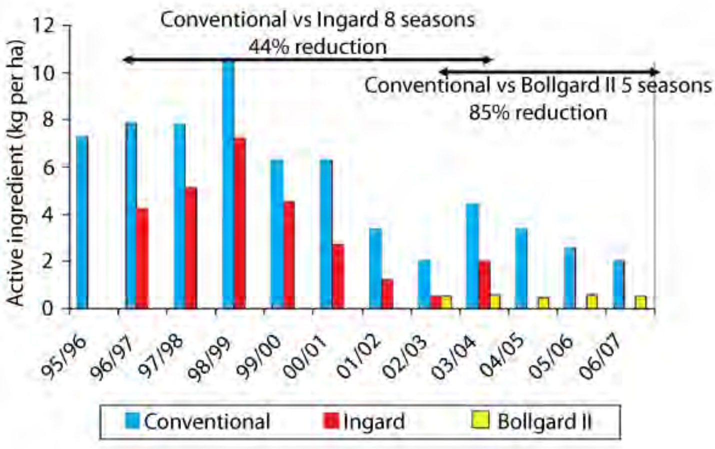

Figure 3. Reductions in active ingredients applied to insect-resistant cotton in Australia in the period 1996 to 2007 (Fitt 2008). Reproduced with kind permission from Springer Science+Business Media B.V.

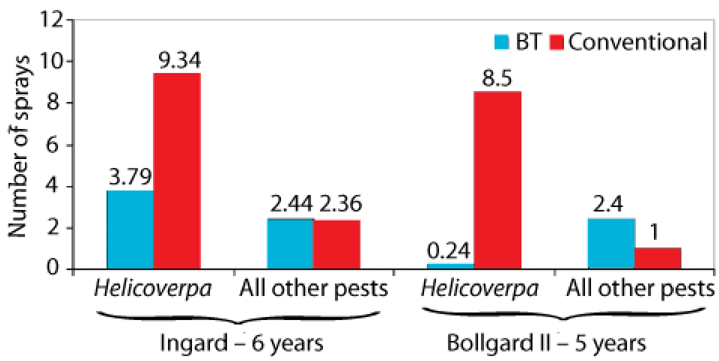

Figure 4. Changes in the number of pesticide sprays applied to insect-resistant cotton ('BT') between 1996 and 2007 (Fitt 2008). Reproduced with kind permission from Springer Science+Business Media B.V.

Integrating pest management

In Australia GM cotton has been grown for over 14 years. A close analysis of pesticide application (Fig. 3) over that period shows the amount of insecticide (as active ingredient) applied to conventional versus two different types of Bt cotton. Ingard was introduced in 1996 and contained a single insect-resistance gene for the control of *Helicoverpa armigera*, the major insect pest in cotton. Ingard was replaced by Bollgard II in 2003 and it contains two different insect-resistance genes for *H. armigera*.

The quantity of active ingredients applied was reduced by 44% for Ingard and 85% for Bollgard II compared to conventional cotton. With Ingard, the number of sprays fell from about 9 to about 4 sprays per season for *Helicoverpa*, with no change in the number of sprays for the other pests that attack cotton. When Bollgard II was introduced those numbers dropped from 8.5 to less then 1 spray per season for the *Helicoverpa* (Fig. 4) but there was an increase from 1 to 2 sprays for the other pests, which took over the vacated niche. The cumulative effect was to reduce 9 sprays down to 2 or 2½ sprays per season.

Similar results have been obtained for insect-resistant maize (Brookes and Barfoot 2008).

The use of less pesticide permits better survival of predators and parasites such as wasps, giving, in turn, better control of secondary pests that are not controlled by Bt. Bt crops are described as living crops, not biological deserts that existed when nine or ten sprays were applied each season. Bt crops are seen as a foundation for long-term integrated pest management (Fitt 2008).

Conclusion

GM crops will be a part of the solution to the dilemma of increasing food, feed and fibre production while at the same time conserving biodiversity. They are not going to solve all problems, and it is worth remembering that they are a relatively minor component (less than 9%) of the total system at present. They have been shown to increase yields around the world, particularly in developing countries, and these higher yields will spare land for natural ecosystems to co-exist with agroecosystems. GM crops have been shown to increase income and thus help reduce poverty in developing countries. They can also help reduce the level of inputs needed to produce the food needed in the next 50 years, thus protecting water and soils. Solving the needs of the food ecosystem of the future will also require new regulatory regimes and political and social changes as well as the technical advances foreshadowed here.

Cooperation and community involvement will be essential in order to successfully address the issues raised at this Crawford Fund conference.

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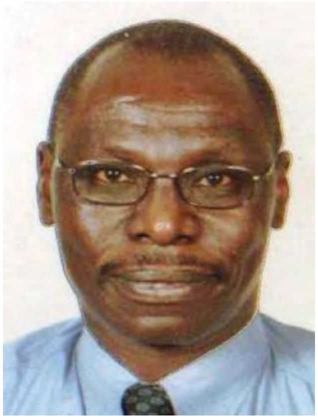

Livestock and Biodiversity: The Case of Cattle in Africa

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Africa is home to diverse and genetically unique ruminant livestock and wildlife species. The continent, however, faces huge food security challenges, partly due to low productivity of the livestock. As a centre of cattle domestication, Africa hosts genetically unique cattle, being products of generations of co-evolution with diverse people, each selecting for different attributes under different production systems and environments.

Over millennia, this diversity of purpose has led to rich and unparalleled blends of indigenous and exotic cattle. Different parasites and pathogens, whose vigour has been buoyed by variable but generally favourable tropical conditions, have co-evolved and served as critical drivers, making African cattle some of the world's most scientifically interesting and valuable populations. This diversity is being lost at an alarmingly rate, and in-situ conservation will not significantly save it.

These cattle can potentially provide adequate food and income to their keepers. First their genetic and phenotypic diversity should be understood, and then carefully tailored to specific production systems to improve their productivity.

To realistically conserve these cattle, for which no conservation plans currently exist, available modern bio- and information technologies are needed to assemble and analyse complex sets of information on them. As the climate and pathogens all change, by smartly conserving (ex-situ*)* those at risk the genetic attributes critical for the world's future food security challenges would be saved.

This paper discusses the diversity of the African cattle and the need for their system-wide characterisation in order to allow their keepers to cope with the changing system, and minimise the loss of these unique genotypes.

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Introduction

Globally about one billion people keep livestock, while up to 60% of rural households (i.e. more than 1.3 billion people), most of whom are poor, draw income from livestock and livestock products value chains (Pica *et al.* 2008; ILRI 2009). In sub-Saharan Africa, unlike in the developed west, livestock play significant and multiple roles (Rege and Gibson 2003; FAO 2009; Hanotte *et al.* 2010). Livestock provide food (meat, milk, etc.) of high nutritional value (nutrient density and composition), especially important to women and children; generate income; store wealth (i.e. are a 'living bank'); provide safety nets against risk; and are critical and essential components of mixed farming systems, where they provide traction, are used to transport goods, thresh grains and turn crop wastes into useful organic manure, thus helping in recycling nutrients that support crop agriculture (Anderson 2003). In addition, livestock have a role in maintaining rangeland health and turning poor-quality herbage into valuable meat and milk as long as appropriate stocking rates are maintained.

Although Africa is home to more than 275 million head of cattle, which equates to 21% of the total world cattle population, this large population produces less than 2% of annual total world beef (FAO 2009). No wonder the per capita meat consumption is an appalling 30 kg y^{-1}; a similarly low per capita figure is recorded for milk. In a region (sub-Saharan Africa) where 556 million people earn less than $2 US per day and hence are too poor to afford livestock products—which, together with fish, are the main sources of protein and essential micronutrients for human nutrition—such low meat and milk intakes are catastrophic (Pica *et al.* 2008; FAO 2009).

Unlike in developed countries, especially the United States of America, in sub-Saharan Africa, livestock products are not hazardous to health of the poor people. To the contrary, nutritional status and health of the many poor mothers and children would significantly improve through relatively marginal increases in daily milk and meat intake. Such improvements, however, are currently undermined by low productivity (Mwacharo *et al.* 2009; Rege and Gibson 2009). Sub-Saharan Africa's cattle numbers need to be substantially reduced in order to allow their productivity to improve. Such intervention would not only mitigate current environmental degradation caused by overgrazing, but also help reduce environmentally harmful methane emissions (Herrero *et al.* 2008; Herrero and Thornton 2009).

However, given:

- sub-Saharan Africa is home to unique cattle diversity of peculiar evolutionary background (Hanotte *et al.* 2002; Freeman *et al.* 2005; FAO 2007a; Hanotte *et al.* 2010)
- these livestock directly support more than 70% of the rural poor—in terms of daily food supply, crop production through manure supply, draft power, income and savings as well as social–cultural satisfaction (FAO 2008),

any intervention must be guided by well-informed conservation programs or unique genes could be lost forever. Thoughtless replacement of Africa's cattle with fewer but potentially more productive ones could—and often has —ended up as an expensive failure.

The threat to genetic diversity of Africa's cattle—the need to conserve it

Recent estimates suggest Africa hosts 180–200 million cattle of 150 indigenous breeds, of which 47% are under threat while 22% risk going extinct (FAO 2007a). Given the complex history of African cattle breeds, such losses would be undesirable. Although global institutional arrangements for sustainable management of animal genetic resources are in place (FAO 2007b; Boettcher and Akin 2010; FAO 2010) and while tools for effective monitoring of threats are generally available (Martyniuk *et al.* 2010), threats to their continued existence are real (FAO 2000; Seré *et al.* 2008; Mwacharo and Scherf 2009) and continue to rise.

The reasons for the escalation of threats to Africa's indigenous cattle are varied, but include:

- unfair competition from vigorously promoted commercial European breeds, even where such genotypes are inappropriate (King *et al.* 2006; Hanotte *et al.* 2010)
- unplanned crossbreeding with commercial European breeds (Rege and Gibson 2009)
- globalisation and the supermarket revolution, where standards of livestock products are made to mirror the developed world's tastes and requirements (Seré *et al.* 2008; Pilling 2010)
- absent or poor breeding program design and implementation plans (Philipsson *et al.* 2006; Nimbkar *et al.* 2008)
- lack of infrastructure (e.g. recording systems, breeders organisations etc) and policy frameworks to support sustainable breed improvement programs (Scholtz *et al.* 2010; Wasike *et al.* 2010; Zonabend *et al.* 2010). In addition, a general lack of human capacity (Ojango *et al.* 2010) remains a huge hindrance to full implementation of the FAO's Global Plan of Action (GPA) on animal genetic resources, however well-intended the plans are (FAO 2007b; Boettcher and Akin 2010).

Examples of unique African cattle breeds include the Sheko of Ethiopia, with less than 3000 now left, and the N'Dama of West Africa (DAGRIS 2007; DAD-IS 2010), which can withstand high levels of trypanosomosis challenge and remain productive, whereas other breeds do not (Lemecha *et al.* 2006; Stein *et al.* 2011). Trypanosomosis is a fatal un-vaccinable disease that hugely limits livestock productivity in Africa.

Trypanosomosis is the largest single disease that greatly constraints livestock, especially cattle production in sub-Saharan Africa. Kristjanson *et al.* (1999) and Swallow (2000) indicated that the potential benefits of improved trypanosomosis control, in terms of meat and milk productivity alone, are $700 million to $1.3 billion per year in Africa. This disease costs livestock producers and consumers an estimated $1340 million annually, excluding indirect livestock benefits such as manure and traction. Others have put the annual losses due to the disease in Africa even higher (US$ 4–5 billion). In the absence of a vaccine, and given that the only drugs against the parasite were developed over 25 years ago and are no longer effective, the potential role of genetically trypano-tolerant cattle breeds is enormous.

Hanotte *et al.* (2003) and Orenge (2010) have mapped trypano-tolerant quantitative trait loci (QTLs) in N'Dama and Boran cattle that are functionally transmissible to their back crosses, although each QTL has relatively little effect.

Ankole cattle that are indigenous to Uganda have unique features, notably extremely large and long horns that compare to no other livestock breed in the world; well marbled meat cuts and milk that is rich in protein and lactose (DAGRIS 2007; DAD-IS 2010). In the last 10 years, however, through rampant crossbreeding with the Ayrshire or Holstein-Friesian European commercial dairy breeds, a significant fraction of Ankole herds is disappearing. The driver of change here is the increasing demand for processed milk in the main Ugandan cities, and lucrative prices offered for this product. In herds where only a few years ago pure Ankole cattle were predominant, today only small proportions are pure Ankole cattle and the bulk of the young stock are crossbreds. If the current trend continues, in 50 years or so the gracious Ankole breed could be no more. Similar scenarios and trends are common elsewhere in Africa. For example, the indigenous Nandi cow, which at the turn of the last century was kept by the Nandi people of Kenya and could produce more than 10 kg milk daily from unimproved tropical pastures of western Kenya, is now totally extinct, and so are the indigenous Kenyan highland zebu cattle (FAO 2007a, Kenya Country Report).

Unless and until the Global Plan of Action (GPA) on animal genetic resources is mainstreamed in national and regional livestock improvement plans and implementation programs (Peters and Zumbech 2002), indigenous breeds will continue to disappear before their true values are known. Global efforts aimed at identifying and conserving the useful genes therefore require urgent action. More importantly, we must not expect poor African farmers to sacrifice their incomes and livelihoods by keeping relatively less productive but potentially valuable indigenous cattle breeds in order to preserve potentially important diversity for posterity.

The origin and depth of Africa's cattle diversity

The genetic diversity of Africa's cattle is unmatched (Hanotte *et al.* 2002; Freeman *et al.* 2005; Hanotte *et al.* 2010). The complex nature of African cattle has, over several millennia, been influenced by:

- original domestication in Africa (Hanotte *et al*. 2002; Gifford-Gonzalez and Hanotte 2011)
- human migration—leading to multiple admixes from other centers of domestication in the Near East—and including north–south migration to the southern part of Africa (Hanotte *et al.* 2002)
- more recent introductions of European, mainly commercial, breeds following colonisation (Hanotte *et al.* 2000; Freeman *et al.* 2005), coupled with unparalleled co-evolution in a rich mix of variable, but generally favourable, tropical conditions.

Any loss of resultant unique genes would be lamentable and should be prevented from happening at all costs.

Hanotte *et al.* (2010) have further observed that in Africa disease and parasite challenges occur hand-in-hand with the rich grasslands. These factors, together with the wide variety of their keepers' preferences (breeding objectives) and constant human and animal movements and exchanges, have moulded these animals into a complex mix of genotypes whose values cannot and should not be underestimated.

Potential for increased productivity and better match to unpredictable future production environments

Although only a few African cattle breeds are currently being raised commercially for beef and none for commercial dairy production, there are notable cases where these breeds have contributed to improved beef and milk productivity, and continue to be of significant commercial value. Examples include the Kenya Boran and the Tuli from Zimbabwe that have been successfully introduced in Australia (http://dagris.ilri.cgiar.org) and parts of the USA. These introductions have significantly improved herd fertility, calving ease, tolerance to heat and water stress, and ability to efficiently convert relatively low-quality forages into good-quality beef.

Where recording and breed development through sustained selection programs have been appropriately implemented (Philipsson *et al.* 2006), huge progress has been made. Examples include the Nguni cattle in South Africa (Scholtz and Ramsay 2007), the Kenya Boran (Okeyo *et al.* 1998; Wasike *et al.* 2006, 2007) and the Tuli cattle of Zimbabwe (Ntombizakhe 2002)—now all world renowned for commercial beef production.

In planned beef cattle crossbreeding programs, especially as dam breeds under relatively challenging local ranching conditions, the Boran, Tuli, Ankole and Nguni have all performed very well. The Nguni breed has also been instrumental in the successful development of synthetic beef breeds such as the Bonsmara in South Africa. In general, where crossbreeding involves the use of European dairy breeds and the indigenous African breeds, it has been observed that the first cross (F1) exhibits the highest levels of heterosis and complementarity for milk production and adaptability (Cunningham and Syrstad 1987; Rege 1998; Gibson and Cundiff 2000; Goshu 2005). The F1s best combine the tolerance traits of the indigenous zebu or Sanga cattle breeds with the productivity of the exotic temperate traits, and thus are best suited the low-input commercial mixed crop–livestock production systems that characterise most of the sub-Saharan Africa (Rege and Gibson 2009; Mwacharo *et al.* 2009).

Opportunities for informed conservation programs

Opportunities for applying old and new sciences to exploit the desirable attributes of African cattle breeds are huge (Mwacharo *et al.* 2009; Marshall *et al.* 2011; Rege *et al.* 2011). New genomic, information and communication technologies provide untapped potential for quick and more accurate characterisation of populations to better inform conservation and breed improvement programs (Hanotte *et al.* 2010; Martyniuk *et al.* 2010; Marshall *et al.* 2011). Great advances in computing power and the science of genomics and bio-informatics, combined with current telecommunication technologies (IT), allow collection and real-time remittance of such data for safe storage and management. These advances provide opportunities for fast turnover and feedback, potentially to a wide variety of stakeholders. If aptly and smartly used, these technologies, either singly or in combination, permit timely and informed decision making—in this case, for better sustainable management of animal genetic resources (Rege *et al.* 2011).

The speed and power of today's computers allow in-depth analysis of extremely large and complex datasets. In contrast to what was available to the developed world 50 or so years ago, the above scenarios and tools allow simultaneous synthesis of environmental variables, phenotypic and genotypic data, and results for better probing of livestock systems and populations to better inform conservation and genetic improvement programs (Martyniuk *et al.* 2010; Hanotte *et al.* 2010).

Available suites of advanced reproductive technologies, such as sexing of semen, embryos, ovum pick-up and in-vitro fertilisation and embryo transfer, if smartly practised, will allow better use of indigenous cattle breeds for specialised and planned crossbreeding programs (McClintock *et al.* 2007; Mutembei *et al.* 2008; van Arendonk 2011). In Africa today, however, lack of a supporting policy framework, poor infrastructure, shortages of skilled staff and inadequate budgets for agricultural science continue to limit the impact of these technologies (Martyniuk *et al.* 2010; van Arendonk 2011). Field application of technologies such as genomic selection are, in our view, currently inappropriate for most African situations—hence in this case a waiting brief is the best strategy (Marshall *et al.* 2011). In the meantime, more efficient and wiser application of

IT, computing and bioinformatics will enable great progress in sustainable cattle conservation and improvement programs.

Conclusions and recommendations

Africa's indigenous cattle breeds are unique and harbor genes that are likely to be of future value, especially in view of the on-going climate change and unpredictable scenarios for future production systems—new disease may emerge, currently less-important pathogens and diseases may become more important and broader system-type approaches may be required.

Existing and emerging information, computing, telecommunication, genomic and reproductive technologies offer potential solutions to conservation's current dilemma—how to save the unique global public good that African cattle breeds represent. Resources should be mobilised for this task now—not later, by which time losses will surely occur, as poor African livestock keepers, who are the current custodians of this great world heritage, cannot be expected to forgo income and better livelihoods to provide in-situ conservation of these cattle.

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Food from the Water: How the Fish Production Revolution Affects Aquatic Biodiversity and Food Security

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The production of food from marine and freshwaters is undergoing a profound revolution—from hunting to farming or from fishing to aquaculture. Fishing and aquaculture exploit and alter the biodiversity on which they are based, each in different but convergent ways. Fishing harvests a much larger range of biodiversity at ecosystem, species and genetic levels than aquaculture. Nearly 400 aquatic species are cultured and more than 5000 species captured in fisheries. Aquaculture and fishing tend to reduce genetic, species and ecosystem diversity, but along different pathways. Fishing reduces genetic and species diversity through selectively removing target individuals with desired characteristics, such as large size, and alters ecosystems. Aquaculture is currently developing across a broad front, using many different species but in inefficient ways. A deliberate program of careful species selection using a broad range of criteria for farming and markets, including food security, should be encouraged, along with research to close the lifecycles of the selected species, improved farm breeds and conservation of germplasm. Aquatic biodiversity for food production receives little policy and management attention but international research provides major support to its sustainable use and conservation.

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A myriad of aquatic biodiversity uses, benefits and threats

Aquatic biodiversity is one of humanity's most important food resources. Most of the world's oceans and all inland waters are fished, providing a protein and micro-nutrient rich food source (FRDC 2004). Fish is a vital brain food that played a role in brain evolution (Crawford *et al.* 2008).

Demand for fish and other aquatic products is rising, driven by a growing global population and escalating demand for animal protein that add to mounting pressures on the supply side: overfishing, climate change, ocean acidification and deoxygenation, water pollution from chemicals and dumping of rubbish and disruptions to nutrient, carbon and water cycles.

And on top of this is the added pressure from aquaculture, which continues to compete for space and to source some feeds and significant amounts of its seed and brood stock from wild fisheries, particularly young and juvenile fish.

The World Bank and the United Nations Food and Agriculture Organization report (World Bank 2008 and www.worldbank.org/fishnet) that the export value of world trade in fish, some US$63 billion in 2003, is more than the combined value of net exports of rice, coffee, sugar and tea.

Fishing is also a vital and valuable source of employment and income in both the developed and developing world. The OECD (Schmidt 2010) estimates that some 30 million fishers around the world make a living directly from the sea. An additional 200 million are dependent on fisheries-related activities and industries. Most of the one billion people who rely on fish as their main source of animal protein live in developing countries.

Fishing is based on harvesting diverse aquatic resources that have, over millennia, become a vital part of human life, so much so that many take eating fish for granted. And aquatic biodiversity is much more than just fish for food. It also provides raw materials for medicines and cosmetics, clarifiers for beer and wine, jewelry and ornaments, and is a tourism drawcard. Most importantly, it provides vital ecosystem services such as carbon sequestration and most of the oxygen we breathe.

For many, the popular image of fishing today focuses on the people involved, and the dangers in getting fish to the plate. The Discovery Channel, for example, is shaping this perception with its documentary series *Deadliest Catch*, now shown in 150 countries.

The program documents the Alaskan crab fishing seasons, from the perspective of crewmen on crab fishing vessels operating in the dangerous Bering Sea. Although the series highlights the dangers of the race to fish, it does not discuss sustainable harvesting levels.

Where do questions of sustainability reside in the public's imagination? How many people are aware of efforts to establish certification processes for aquatic resources sourced from sustainable fishing practices? Do consumers understand, and care, where their fish is sourced? Do they value sustainability, and how much premium would they pay for it? Have these issues been overshadowed by the drama of fishermen struggling in the extreme conditions of wild seas, hauling in cages of crab, as seen on *Deadliest Catch*?

The revolution in fish production

A more compelling drama than *Deadliest Catch* is played out each day in fisheries around the world, the daily struggle of fish workers, many of whom are women, to survive. Many of these people are poor. Indeed, most of the poor relying on fishing are labourers on other people's boats or in processing factories. Few of them have job and resource security.

Many fisheries are still engaged in a 'race to fish' approach, with catches often determined by the size of the boat, rather than sustainable management approaches. In these cases, fishers are eager to meet the rising demand for fish in the hope of an increased income and a better life.

The challenge is two-fold: ensuring that aquatic resources continue to contribute to food security and poverty reduction, without compromising aquatic biodiversity or at least minimising the trade-offs.

The successful management of fisheries and aquatic biodiversity requires an integrated approach, utilising fisheries and aquaculture policy initiatives, natural resource management approaches and aquaculture and genetic improvement. Although it is tempting to hope that aquaculture can solve the problems of overfishing and save wild fisheries, this is a false hope, no matter how tantalising and alluring. Instead we must deliver sustainable catches **and** productive aquaculture, underpinned by complementary policy environments, to meet human demand for nutritious aquatic resources.

The development and management of aquaculture is critical to sustainable wild fisheries and aquaculture is the key to future increased fish production.

Today almost half of all fish eaten are from farmed sources, not wild capture resources (Fig. 1). The change from the dominance of fish from wild capture fisheries to near parity from aquaculture has been rapid and is caused by two trends. The first is that global capture fisheries production has stalled since 1990 and is unlikely to grow further as most fish stocks are fully or over-exploited and, if well-managed, their catch levels are controlled to sustainable levels. The second trend has been the dramatic rise of aquaculture production since the early 1980s.

These trends represent a revolution in fish production, akin to, but much more rapid than, the transition from hunting to farming that started on the land 10 000 years ago and took several thousand years.

Any revolution has its consequences. Fishing and aquaculture have impacted the three levels of biological diversity—genetic diversity, species diversity and ecosystem diversity—in ways that challenge but also create opportunities for sustained fish production.

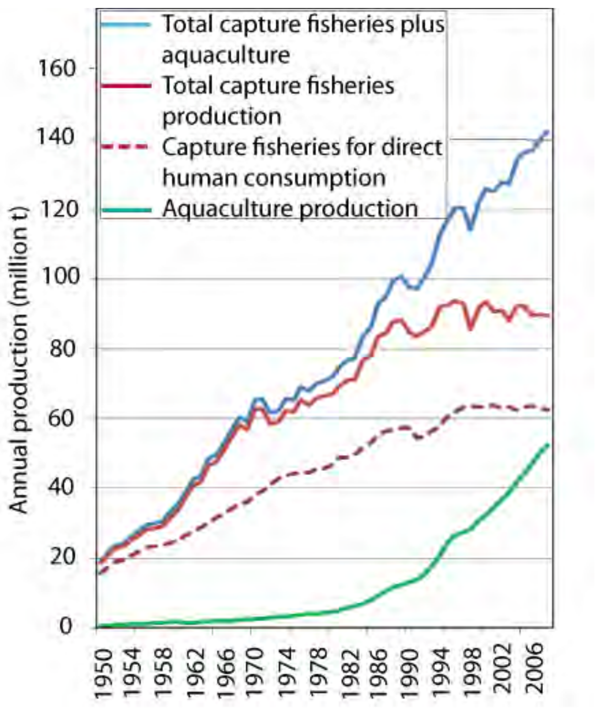

Figure 1. World fisheries and aquaculture production 1950–2008 (Source: FAO). All production statistics exclude aquatic plants and mammals.

Impacts of fishing on aquatic biodiversity

Fishing compromises genetic diversity in several ways. Fishing enterprises typically target one or several species, eventually removing some genetic stocks from the fisheries (Marteinsdóttir and Pardoe 2008) and likely reducing the long-term productivity and even survival of the species—the ‘portfolio effect’ (Schindler *et al.* 2010). The targeting of particular species is usually focused on larger fish, decreasing the species reproductive capacity (Field *et al.* 2008) and causing greater fluctuations in stock levels over time (Anderson *et al.* 2008).

The long-term result of fishing is to slowly shape species evolution towards lower productivity. A second longer-term result may be diminishing the diversity of discrete genetic stocks within a species (Schindler *et al.* 2010).

Fishing also changes species diversity. Within fisheries the composition of fish communities can change, with larger, valuable fish targeted, resulting in a decline in these species (Silvestre *et al.* 2003). This process of weakening the biodiversity of species can also be accelerated and exacerbated as non-target species are caught, such as marine mammals, sea turtles, sharks and other fish species taken on tuna longlines or the many non-target and undersized specimens taken in trawl nets. Such fishing impacts on species subsequently reduce the diversity of ecosystems and habitats.

Fisheries take a broad range of species. The FAO records about 2000 fish, crustacean, mollusc, echinoderm and aquatic plant species or species groups annually. But since about 10 million tonnes of **unnamed** marine fish also are landed annually, the total number of species harvested is likely to be more than 5000. Indeed, for fish species alone, not counting crustaceans, mollusks, echinoderms and aquatic plants, nearly 5000 species are used by humans (Williams 1996).

History has a lesson that we should apply to managing the apparent abundance of fisheries species today. Our ancestors developed a taste for fish and meat, with the added protein, fat and micronutrient intake helping accelerate our development, especially brain development. Many large land animals that were considered fair game were hunted to extinction by early humans. Anything that was good eating was taken. Wild food still constitutes a vital food security element for many rural people (Bharucha and Pretty 2010), but although important, this dependence is a tiny remnant compared to the period before agricultural development 10 000 years ago.

Fisheries in the modern world is driven not only by the taste for fish as basic food but even more by the strong incentives of economic gain through the market and trade. Despite the vastness of the oceans, the end result of harvesting wild fish stocks could be similar to those of many land species millennia ago—extinction of targeted stocks and even whole species.

While some would argue that such an eventually is remote, proof is mounting that humans have already had an enormous impact on aquatic species for hundreds and sometimes thousands of years (Holm *et al.* 2010). Many current fisheries are under stress. The FAO estimates that about 25% of the world’s marine fish stocks are overexploited. In addition, an estimated 50% of stocks are fully exploited (FAO 2009). The depleted state of wild fish stocks is attributed to overfishing combined with increasing degradation of coastal, marine and freshwater ecosystems and habitats.

Growing coastal populations also exert increasing pressures on natural resources.

Aquaculture and aquatic biodiversity

Farming fish presents its own set of biodiversity and sustainability challenges. Aquaculture uses and affects a wide range of species, but in different ways to fishing.

In many cases cultured species are still collected from the wild at some stage in their life cycle because captive breeding has not yet been achieved (Lovatelli and Holthus 2008) or is not the object, such as in reseeding, sea ranching and restocking production systems where the progeny are released to the wild (Bell *et al.* 2008). Aquaculture is usually focused on capturing the young within a species. Culturing can involve growing out larvae through to fattening juveniles. Sometimes adults are captured for breeding.

These unimproved varieties may or may not grow well or even survive the capture and growout, wasting resources in the attempt.

If local species are not readily available for culture, then another tactic is to introduce exotic species. Depending on the situation, this may be highly successful, or highly risky because the exotic species can become established invasive species (Naylor *et al.* 2001), wrecking other forms of havoc on aquatic biodiversity.

Aquaculture is at a crossroads. It can continue to utilise available species sourced from the world's waterways and oceans, or it can narrow its focus and domesticate fewer species (Bilio 2008)—but not too few. The first road will place increased pressure on fisheries worldwide, as biodiversity is tapped in an indiscriminate and inefficient way. The second road, while longer and more challenging, is also the more sustainable, as the genetic resources of a smaller number of species are used to build reliable systems for domestication, aiding the preservation of species in the wild.

Taking this second road towards domestication will be highly dependent on international agricultural research for success. If current trends continue without the steadying hand of this research, we may find the choices of species to domesticate made for us as overfishing and inefficient
aquaculture reduce biodiversity and our choices.

Domestication, species selection and germplasm conservation in aquaculture

Aquaculture of fish species has proven to be a hit and miss affair. Some species defy all attempts at culturing, others can be grown out after being captured and some can be raised from the larval stage.

As noted above, capture fisheries production uses thousands of different aquatic species. Aquaculture has a narrower base of species but this base is still broad by comparison with food production in agriculture. In 2008, FAO reported global production statistics for 348 named aquaculture species and species groups, for which the top ten species accounted for 44% of the total volume of production. This is less concentrated than for beef, for which six cattle breeds produce 90% of world production, and food from plants, for which 12 cereals account for 80% of world production. Although terrestrial plant and animal food production runs the risk of being too narrowly based, aquaculture development is moving forward on too broad a front to be efficient and effective. Too little attention is going into the breadth of species development and its consequences.

Bilio (2008) investigated the domestication status of 202 aquaculture species and found that the likelihood of domestication was much higher in the species of greatest production. For species for which more than one million tonnes is produced annually, 75% of the species were domesticated (Fig. 2), although he did not determine whether all the production from each species was from domesticated stock. For species from which lesser quantities were produced, on average only about 20% of species were domesticated.

The goal for aquaculture, and research, must be full domestication of a carefully selected set of species. Already we have a significant body of research addressing the many stages of aquaculture for a variety of species.

This research is the foundation on which full domestication of selected species should proceed.

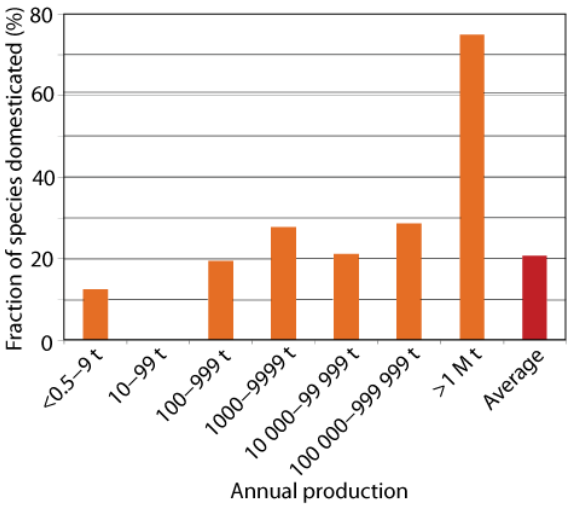

Figure 2. Fraction of animal species domesticated in relation to annual production (FAO 2006; Bilio 2008; *n* = 202 species)

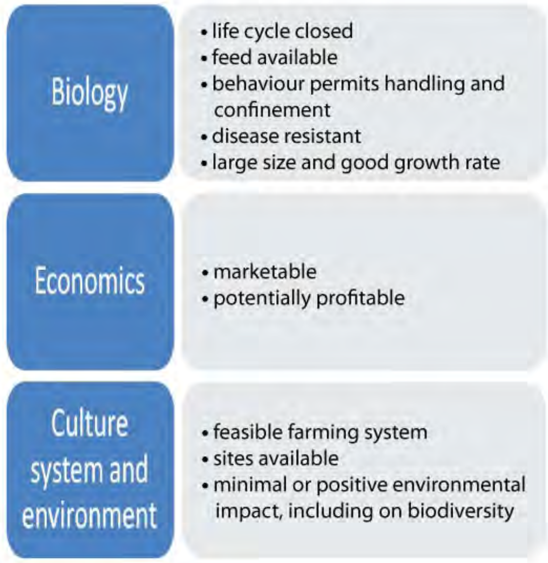

Figure 3. Species choice criteria for aquaculture

A careful selection of species with the potential for whole-of-lifecycle culturing must be based on a set of criteria emerging from these research endeavours (Fig. 3). Such research must be used to define, test, develop and prove criteria for selecting species suitable for domestication across their lifecycles (e.g. see examples in Williams and Primavera 2001).

Suitable species will be those that can be farmed throughout their lifecycles. This requires available and affordable feed. Often aquaculture is built on feeding fish with other fish, further creating pressures on aquatic biodiversity. Available feed must be sustainable and preferably from non-fish sources.

The selected species must have other traits: the ability to grow to large sizes at a suitable growth rate, and a tolerance to confinement and handling that allows farming.

Economically such species must be viable. This requires a combination of marketability and profitability.

A key component of these criteria will be species that can be efficiently cultured. From a food security perspective at least some species must be available to smallholder aquaculture producers in the developing world. Achieving this result for smallholders must also cater to issues such as space, environmental management, available finances and assets, along with training and education.

All of these factors need to be present in species selected for domestication.

As with agriculture, the improvement of farm breeds relies on biodiversity at species and genetic levels. To achieve this, conservation of fisheries resources, including germplasm, is vital. The selection of a smaller number of species must be carried out in conjunction with the preservation of genetic diversity of the selected species. To do otherwise is to limit the potential for breeding improved fish strains suitable for domestication.

The remaining link in a sustainable system for aquaculture improvement (Fig. 4) is breed improvement (Neira 2010; Rye *et al.* 2010), taking care to maintain the diversity within the improved breeds (Dixon *et al.* 2008) and addressing the many policy, economic and practical challenges of maintaining adequately diverse germplasm collections for future use (Greer and Harvey 2004). Of particular concern is the lack of policy attention, at national and international levels, to aquatic biodiversity, even in the processes of the Convention on Biological Diversity.

By focusing on fewer species, the negative effects of aquaculture on other species will be lessened, although threats will remain as aquaculture is but one factor impacting most aquatic biodiversity.

International research has already achieved much of the technology and know-how needed to develop systematic domestication, and to support sustainable management of wild fisheries.

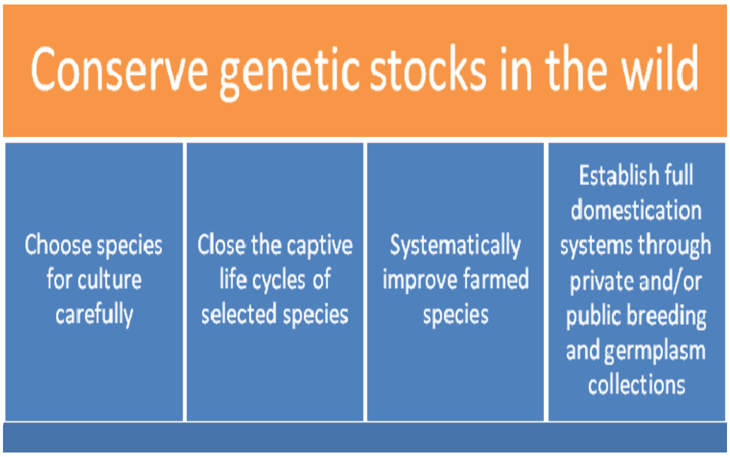

Figure 4. An integrated approach to species selection, domestication and germplasm conservation

Practical examples of taking aquatic biodiversity into account

The Australian Centre for International Agricultural Research has designed and supported fisheries research since 1984. This research has a dual focus: managing wild fisheries through innovative management approaches and better utilisation of existing harvests, in concert with improved aquaculture through the development of productive and sustainable aquatic farming systems.

As an example the WorldFish Center, in partnership with the Australian Centre for International Agricultural Research, is implementing this dual approach to sea cucumber aquaculture, focusing on viable culturing and restocking of depleted resources.

This project, active in the Philippines, Vietnam and Australia, builds on past research that developed technologies for culturing 'sandfish' (*Holothuria scabra*) in hatcheries, and for releasing this species in the wild.

This combination of technologies has the potential to assist communities, through the development of a new livelihood option, in the Philippines and Australia. Cultured sandfish are released in managed inshore habitats tended to by participating communities, which can then harvest these sandfish once they reach market size after three years.

In many areas where sea cucumber has been overfished, the culture technologies can be used to replenish selected sandfish populations. In the Philippines restocking of sandfish into marine reserves is building up a critical mass of spawning adults. The research will help to speed stock recovery, generate income and conserve wild breeding stocks.

One of the most effective means of sustaining fisheries and protecting against over-fishing is through management and monitoring. The diverse capture fisheries within Indonesian waters are among the largest and most important in the world for their value and the number of people they support (Williams 2007). These fisheries provide a food and income resource for tens of millions of people.

ACIAR is working with Indonesian partners to build capacity in monitoring catch levels and cataloguing fisheries. Research has identified deficiencies in Indonesia's fishery data/statistics that severely limit their usefulness for stock assessment. For example, catch has often not been recorded at the species level. National statistics group all the species under the single category of 'tuna'.

Complementing research on fisheries management is research to develop viable aquaculture systems. This focuses on sustainability and productivity, both vital to conserving and using biodiversity wisely.

ACIAR's support for aquaculture has helped in defining the basic taxonomy of the four Indo-Pacific mud crab species (*Scylla* spp.) (Keenan *et al.* 1998) and development of appropriate technology for hatchery and nursery production of crablets, with improved productivity in the grow-out phase (Allan and Fielder 2003; Lindner 2005).

Guidelines for the design of pens for farming crabs were developed. Building a range of pens in different types of mangrove forests, and using different techniques, was proven to be a benign, environmentally sustainable activity where guidelines are followed (Primavera *et al.* 2010).

When farmers were provided with appropriate crablet species and equipment to manage grow-out in the ponds, the growth of the crablets was rapid, with relative conformity in size and a viable survival rate compared to stocking ponds with wild seedstock.

The development of such a system for mud crabs demonstrates that aquaculture systems can be viable from both economic and environmental viewpoints.

Conclusions

Despite these good news stories, aquatic biodiversity faces huge challenges, as other fields show us. For example, let me draw a parallel. Recently the renowned fruit collection of the Vavilov Institute, housed within the Pavlovsk Experimental Station on the outskirts of St Petersburg in Russia, made headlines following pressure from developers eager to buy the station's land. The Vavilov Institute was the world's first dedicated to storing supplies of grain seed stock. During World War II a dozen scientists based at the station starved to death, rather than consume the seeds held within the collection. Yet less than a century later developers are arguing their case for buying some of the Institute's land before the Russian courts.

That one of the world's pre-eminent grain, fruit and berry seed collections can be viewed as more valuable for the land on which it is housed, than for its germplasm, says much about the challenge ahead for preserving aquatic biodiversity, much of which still needs to be conserved in-situ in water bodies threatened by dams and land reclamation for ports and cities.

The challenge has to be addressed on a number of fronts: sustainable management of wild resources, the development of domestication systems for selected fish species, and strategic and integrated policy interventions. There is no single key to unlock this challenge. It can only be approached in combination, supported by coordinated research initiatives.

Sustainable management must be integrated across fisheries and borders. This in turn requires policy action that is both strategic and sound, catering to the needs of public and private sector drivers and challenges. Food security must be a leading concern in these approaches. Yet neither policy nor fisheries management can be successful without the development of sustainable systems that domesticate farming of selected fish species. Only by closing the lifecycles for selected species, and making aquaculture production more efficient through improved breeds, can aquaculture sustainably reduce pressure on wild fisheries.

We cannot afford to give up on any facet of this challenge, otherwise there will come a day when the richness of oceanic and freshwater biodiversity may only be seen on repeats of television programs on the Discovery Channel, and not within our planet's seas and waterways.

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Forest Biodiversity, Climate Change and Governance

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The main drivers of tropical forest biodiversity loss are land clearing for agriculture, pasture and timber plantation development, followed by logging activities that degrade forests. Deforestation and forest degradation also significantly contribute to climate change, given that they contribute about 12–15% of total greenhouse gas emissions. Climate change in turn negatively affects biodiversity and agricultural activities in tropical countries. Therefore the governance of forest biodiversity needs to be closely connected to the governance of the climate.

The following governance factors need to be addressed to reduce tropical forest biodiversity loss. First, corruption and illegal logging appear to contribute to deforestation and forest degradation. Second, the roles in forest management of the various government levels will need to be clearly spelt out, and the appropriate performance-based financial incentives (and related capacity) for forest conservation be provided to the appropriate government levels. Third, economic incentives need to be present for countries to commit to changes in the policies that drive deforestation and forest degradation. These economic incentives will be most effective when they directly reach the holders of the property and management rights to forests. Property and management rights will need to be adjusted for economic incentives to be effective and equitable, and benefit local and indigenous communities. The paper suggests policies and activities that the Australian government could implement within Australia and through the development assistance program to support a mechanism for Reducing Emissions from Deforestation and Forest Degradation (REDD), to reduce biodiversity loss, reduce carbon emissions, and contribute to local livelihoods.

LUCA TACCONI'S research focuses on the economic, political, and social factors that drive environmental change, resulting in loss of biodiversity and climate change—and their implications for rural livelihoods and poverty. His current research concerns governance, social and economic aspects of deforestation and climate change, payments for environmental services, and research methods for environmental management. Prior to joining ANU, he had been a senior scientist at the Center for International Forestry Research and a Rural Development Adviser with AusAID. His latest book regarding payments for environmental services, livelihoods and deforestation will be published later this year.

Introduction

Deforestation and forest degradation result in loss of biodiversity and contribute about 15% of global anthropogenic emissions of greenhouse gases. Land clearing for agriculture and pastures is the main cause of deforestation, and logging is also a major cause of forest degradation (Geist and Lambin 2002). These activities fundamentally occur because those who degrade and convert forests benefit from them. The benefits may be financial, for example from higher returns generated by oil palm plantations compared to sustainable logging, or simply subsistence benefits, for instance through the conversion of forest to crops for domestic consumption. In the short term, deforestation may contribute to an increase in the production of crops with more land coming under cultivation. However, the long-term effects are likely to be negative. Climate change is expected to reduce crop production in developing countries as a result of decreased rainfall, changes in the seasonal distribution of rainfall and higher temperatures. The loss of biodiversity may also lead to a decrease in the production and diversity of agricultural crops, with possible negative effects on human health as emphasised by the World Health Organization.

There has been so far a failure to develop effective international consensus on actions to reduce the loss of biodiversity. There has been progress, however, on an international agreement to reduce emissions from deforestation and forest degradation (REDD+)[1] in developing countries. The need to implement such a mechanism was recognised in the 2009 Copenhagen Accord on climate change. A REDD mechanism would provide developing countries with financial incentives to reduce deforestation and degradation. These payments are a form of compensation for the revenues from agriculture and plantations that they would have to forego. Given that there is a significant but not complete overlap between carbon stocks and reservoirs of biodiversity, positive developments on the REDD front also need to take into account forest biodiversity and the implications for rural livelihoods.

The land use activities that deforest and degrade the forest may have, in some cases, national benefits that are greater than those that could be generated by conserving forests. However, this is not necessarily the case. In that case, deforestation and forest degradation would not be justified on the basis of the national public good, but they may still occur as a result of corruption and illegal logging. For these reason, this paper also addresses the issue of corruption and illegal logging. Furthermore, it is important to address corruption because it may affect the implementation of REDD+.

Whilst there is a need to address deforestation and forest degradation, community and indigenous advocacy organisations have expressed concern about REDD+, particularly because of the lack of clarity about local entitlements to benefit from REDD+ schemes in countries with poor governance. Griffiths (2007) states that the implementation of REDD+ schemes without due regard to rights, social and livelihood issues could increase the risks of renewed and even increased state and expert control over forests to protect lucrative forest carbon reservoirs, violations of customary land and territorial rights, zoning of forest lands without the informed participation of forest dwellers by the state and or non-government organisations, unequal imposition of the costs of forest protection on indigenous peoples and local communities, unequal and abusive community contracts, land speculation, land grabbing and land conflicts.

It is clear from the above that the implementation of REDD+ would require the implementation of several new policies to ensure that i) reduced deforestation and degradation targets are achieved and that ii) the rural people living in and near forests benefits from REDD+.

To implement REDD+ policies and measures within countries effectively and sustainably, there seems to be a need to link national with sub-national initiatives (Angelsen *et al.* 2008), which would involve the distribution of (or some of) the revenues from REDD+. In this context, the paper considers the issue of decentralised forest management. In relation to the issue of providing benefits to rural people, the paper addresses some issues concerning payments for environmental services.

Corruption and illegal logging

Corruption and illegal logging are widespread in countries that are expected to become eligible for REDD+ schemes. There are, therefore, concerns that unless corruption is controlled, it would be difficult for countries to implement REDD+ in an effective, efficient and equitable manner. Let us first summarise how corruption can result in deforestation and degradation.

The impact of corruption on deforestation may start with the design and implementation of land use plans. Land use plans classify forests for various uses, such as conservation, production and conversion to other uses. The land use allocation process should take account of ecological criteria to identify areas that are significant for conserving biodiversity (i.e. allocation to conservation class) or where soils are not suitable for conversion to other uses (i.e. allocation to production forest). Corruption could lead to deforestation by undermining the land use allocation process and the enforcement of land use plans. Overlaps between production and conservation uses have been documented (e.g. Wells *et al.* 1998), but there is a lack of knowledge as to whether this was due to corrupt behaviour or other causes, for example poor coordination of activities between government officials. If land is put to unsuitable use as a result of corruption, then corruption is a cause of the emissions associated with the change of land use. However, corruption is not a cause of defor-

[1] The remainder of the paper continues to use the term REDD+ but it focuses only on deforestation and degradation.

estation when it affects the allocation of, for example, agricultural concessions (to one company instead of another) in areas that have been allocated to conversion through due process.

Corruption can result in forest degradation in a number of ways. First, logging operators bribe forestry officials to allow them to harvest timber without a legal permit (Smith *et al.* 2003). This also makes legal logging less competitive. Second, bribes may be paid to officials to allow the transport of illegally logged timber (Southgate *et al*. 2000). Whilst this type of corruption takes place after the degradation of the forest, it contributes to degradation because if loggers could not transport the logs they would not harvest them. Third, logging operators bribe local officials to obtain logging permits that are not recognised by the forestry regulatory framework (Casson and Obidzinski 2002) or that are really for other purposes (REM 2006). Fourth, logging concessionaires pay bribes so that over-harvesting on their concessions, or harvesting outside the boundaries of their concessions, is not monitored (Barnett 1990; Friends of the Earth 2009). Fifth, bribes contribute to degradation by increasing logging costs, thus leading loggers to over-harvest their concessions to recoup the costs of bribes (Richards *et al*. 2003).

Illegal logging has been estimated to affect some 70 countries (World Wildlife Fund 2002). Most country-level estimates of illegal logging focus on the rate of illegal harvest, and it has been reported that these rates are above 50% of the total harvest in many countries (Contreras-Hermosilla 2002; SGS Trade Assurance Services 2002; World Wildlife Fund 2002; Tacconi *et al*. 2003; Seneca Creek Associates and Wood Resources International 2004). Reported statistics appear to be, however, rather uncertain and show a large degree of variation, partly because different definitions are often used and confusion arises. There may be significant problems with the statistics reported, as demonstrated by the fact that the illegal harvest in Cameroon may not be as significant as previously thought and it takes place in the small-scale logging sector, which was illegally outlawed by the ministry of forestry (Cerutti and Tacconi 2008). All that can be said, therefore, is that the size of the illegal harvest may be significant in many countries but that there are considerable problems with available estimates. Similarly, there is lack of knowledge of the actual contribution of illegal logging to deforestation and forest degradation. There are reports showing that illegal logging contributes to deforestation (e.g. Curran *et al.* 2004), but it can be expected that, due to its nature (i.e. normally involving logging rather than land clearing), illegal logging is more likely to result in forest degradation than in deforestation.

To develop appropriate policies, we need to understand what drives corruption and illegal logging. Multiple causes of these problems have been identified (Tacconi 2007; Tacconi *et al*. 2009), but the most significant driving force of these economic activities is the financial benefit resulting from them.

In relation to corruption, one approach is to describe it as depending on the levels of monopoly, discretion of decision makers and accountability (Klitgaard 1988):

Corruption = Monopoly + Discretion – Accountability.

Another way (complementary to the above) to look at both corruption and illegal logging is that for them to take place, their benefits need to be higher than the costs, such as loss of income (and business for the companies) following conviction. The costs may be less than the benefits if the anticipated benefits from these activities are large (such as significant extra profit for companies and significant extra income for public servants), penalties are low, and or the likelihood of being discovered and convicted are low. Attention needs to be given, therefore, to both the benefits and costs of illegal activities.

On the government side, forestry ministries have traditionally had sole control (i.e. monopoly power) over the allocation of forest resources to a (often) limited number of company logging and plantation companies. The introduction of a REDD+ mechanism is likely to reduce the 'monopoly' power of forestry ministries and their discretion in the allocation of forests.

On the private-sector side, the business opportunities generated by a new commodity (i.e. forest carbon) would attract new companies (as already demonstrated by the voluntary carbon market and the emergence of carbon traders), thus increasing competition in the sector and reducing the power of the traditional logging and plantation companies. Some caveats apply, however. It could be argued that if a ministry of forestry successfully maintained monopoly over the allocation of forests, corruption could still take place and, due to the presence of more competitors, forestry ministers and officials could ask for larger bribes. Two issues that make the outcome uncertain need to be considered: i) if 'carbon conservation' companies offered bribes to acquire a concession, this would still be an undesirable outcome from a legal and moral viewpoint, but it would lead to forest conservation; ii) 'carbon companies' may be less likely to offer bribes given that they are more likely to be concerned about corporate reputation, thus still leaving the traditional logging and plantation companies in a position to offer bribes and acquire concessions. The increased accountability noted above would still imply, however, that this is less likely than in the without-REDD+ scenario.

In relation to illegal logging, government commitment to reducing it is influenced by the economics of forest management (Tacconi 2007). The economics of sustainable forest management would need to see significant changes for governments to increase their commitment to sustainable management and to promote its implementation throughout the forest estate. REDD+ related payments for reduced degradation could make sustainable timber harvesting competitive with non-sustainable harvesting (Pearce *et al.* 2003), thus providing a further incentive for governments to control illegal logging.

Decentralised forest management

Forest conservation requires local governments to set aside, within their administrative jurisdictions, a considerable amount of land where revenue-generating activities are restricted. These activities are the land uses responsible for deforestation and degradation. Conservation activities involve opportunity costs because forest exploitation and land-use change generate revenue for local governments from local taxes and revenue sharing. Some revenue-generating activities that can be performed in conservation areas, such as ecotourism and non-timber forest product collection, are often less profitable than forest exploitation and other land-use change activities. While forest conservation involves local costs, it generates global benefits, such as biodiversity conservation and carbon sequestration, across jurisdictions. Local decision-makers often neglect the benefits that would accrue to the outsiders and take into account only those benefiting local residents. Financial incentives to support conservation at the local level need to be provided to induce the localities to provide an efficient level of public goods and services.

In order to ensure the successful implementation of REDD+ in decentralised countries, it is important to consider which tasks could be devolved at what level in these countries. The basic principle of subsidiarity in decentralised public administration is that tasks and powers should rest at the lowest-level subunit possible. Local authorities are considered to have better specific information related to local resources, which results in better-targeted policies and lower transaction costs. Several benefits of having local governments involved in the implementation of REDD+ can therefore be summarised as follows: (i) to ensure greater participation of sub-national groups in the decision-making process where the decision making regarding land-use has been devolved; (ii) to increase the efficiency of REDD+ implementation through internalising costs and reducing transaction costs; and (iii) to tackle the specific causes of deforestation at the local level, as the drivers vary from one location to another within a country depending on the economy and the population's needs.

The involvement of the sub-national level in the implementation of REDD+ can vary depending on the extent of authority devolved in forest management. The implementation process can involve a top-down or a bottom-up model. In a top-down model, local governments implement REDD+ based on certain prescriptions provided by the national government. In contrast, local governments have the authority to develop local implementation plans and to implement them under a bottom-up model. Irrespective of the model adopted, the local governments' involvement in the implementation of REDD+ is under the national-based approach, which should be situated within a framework of intergovernmental relationship between the central and sub-national levels.

Because of space constraints, let us consider only the 'ideal' option in which 'the central and local governments decide on a national reference level jointly and the local governments implement REDD+ measures at the local level'. In this option, the central and local governments jointly decide on a national reference level and the local governments implement REDD+ measures based on their own proposals. The implementation process under this option would apply a bottom-up model, which views policy implementation from the perspective of the targeted population and local governments, as service providers at the local level. The national government would devise a national program at the macro-implementation level such as establishing strict rules and regulations on illegal logging prevention and sustainable forest management. Local governments, at the micro-implementation level, would then develop their own programs to ensure the implementation of the national rules and regulations in their localities. The implementation of REDD+ under this approach would ensure the widest participation and acceptance from local stakeholders. Participation of local stakeholders in the development of REDD+ strategies or policies is possible when the planning process is conducted at the lowest governmental level. Local stakeholders, who would be directly affected by REDD+ policies and measures, are often geographically distant from national authorities. When the planning process is devolved to the local level, local voices and socio-economic conditions are more likely to be taken into consideration in the development and implementation of REDD+.

This approach would require significant resources and time to be allocated to the consultation and planning process. Furthermore, the problem of leakage applies to this option if some local governments choose not to participate following the consultation process. Leakage could lead to an insignificant reduction in emissions in the country as a whole. As a result, the local governments that implemented measures to reduce land use change would not receive payments, unless the national government took on the burden of providing the payments even in the absence of international payments, which is unlikely. In order to address this issue, a robust enforcement and monitoring system would be required to avoid national leakage. This would involve setting reference levels for participating and non-participating local government areas. The non-participating local governments would not be allowed to exceed their reference levels and could be punished with fines if they exceed those levels. It is obvious that to avoid leakage, even the local government areas that would not commit to reductions would still have to be accounted for in the scheme. The national government would also need to nurture the understanding and capacity of local governments in order for the implementation of REDD+ to be successful. There is, however, lack of precise information related to time and resources required to complete bottom-up land use planning processes. A high-quality plan requires professional technical planners with specified skills and experience. The development of the capacity of local governments to prepare high-quality land-use plans may be necessary in some cases, although in some decentralised countries, such as Indonesia, local governments already carry out land use planning functions. A share of the revenues from REDD+ would need to be provided to local governments to compensate them for the opportunity costs noted above.

Payments for environmental services

Payment for environmental service (PES) schemes provide the custodians of environmental services such as clean water, biodiversity and carbon sequestration with financial or other rewards for their role in providing these services. Community and indigenous advocacy organisations and academics have cautioned that the implementation of REDD+ without due regard to rights, social and livelihood issues could have negative effects on local communities. Distributive mechanisms to share REDD+ income at the local scale are therefore considered integral to the equity and effectiveness of REDD+.

The likely significance of PES as a distributive mechanism for REDD+ calls for a clear understanding of the livelihood impacts of existing PES schemes, so that critical lessons can inform the development of REDD+ mechanisms. Several of these lessons have been detailed elsewhere (Tacconi *et al*. 2010). Here it is relevant to consider the issue of land tenure.

A necessary condition for PES is said to be the identification of ‘land stewards with reasonably good control over clearly delimited lands’ (Wunder 2009, p. 211). However, in many countries, the state owns the largest share of forest land, the primary focus for REDD+. Tacconi *et al.* (2010) show that PES schemes can proceed outside of land under private ownership, on common property and on state lands.

Where there are conflicting claims over ownership and use rights over state forests, tenure reform has been advocated as a precondition for effective, equitable and efficient implementation of REDD+ (Sunderlin *et al.* 2009). Such reforms could include changes in the ownership of land or in use and or management rights over forests and their products. The latter approach of devolving more limited use and management rights reflects the situation with all of Asia's community forests (Mahanty *et al.* 2009). Transferring land rights from the state to communities (that is, to common property ownership) would be a better option from the perspective of rural communities because it enables more choices over the use of forest land. An alternative proposal is the transfer of rights to the use of forests and the carbon they contain (Streck 2009). Although the architects of PES have emphasised the role of private landholdings, the case studies presented by Tacconi *et al.* (2010) demonstrate the viability of PES schemes focused on common property resources. PES schemes that involve communities instead of individual landholders in implementation have the further benefit of reducing transaction costs, while building on local community institutions—and if necessary supporting new ones—to strengthen social capital.

What can Australia do to support the implementation of REDD?

Supporting tropical forest conservation through development assistance

With the allocation of $273 million to the International Forest Carbon Initiative (IFCI), Australia was one of the first countries, in 2007, to devote significant support to the development of a REDD mechanism. This is an important initiative, but a more encompassing view of policy options is needed to improve tropical forest management in a way that leads to reduced emissions as well as biodiversity conservation and benefits for rural people.

To be more effective, IFCI should implement demonstration activities at a provincial level rather than at only a project level. Demonstration activities are aimed at showing how REDD can be implemented in practice. Many tropical forest countries, including Indonesia which is the main recipient of funding from IFCI, have a degree of decentralised management of forests. Appropriate systems to involve lower levels of government in forest conservation need to be designed and tested. These programs have to address the governance factors that influence forest management.

Corruption and illegal logging are widespread in tropical forest countries. There are, therefore, concerns that unless corruption is controlled, it would be difficult for countries to implement REDD in an effective, efficient and equitable manner. The impact of corruption on deforestation may start with the design and implementation of land use plans. Land use plans classify forests for various uses, such as conservation, production and conversion to other uses. The land use allocation process should take account of ecological criteria to identify areas that are significant for conserving biodiversity or where soils are not suitable for conversion to other uses. Illegal logging has been estimated to affect some 70 countries. Reported statistics, however, appear to be rather uncertain and show large variation, partly because different definitions are often used and confusion arises. Similarly, there is a lack of knowledge of the actual contribution of illegal logging to deforestation and forest degradation, but it can be expected that, due to its nature, illegal logging is more likely to result in forest degradation than in deforestation.

Capacity-building programs should therefore support improved regulatory frameworks aimed at reducing corruption and illegal logging, and support the strengthening of law enforcement capacity.

Strengthening activities should also build national-level institutional capacity to map carbon stocks and deforestation, coupled with the design of protected areas for biodiversity conservation and the allocation of agricultural lands. Unless biodiversity conservation and agricultural production are explicitly considered, carbon conservation activities could have less than desirable effects. These assessments should also consider politically acceptable outcomes: protected areas would ideally be evenly distributed across local government areas, to avoid burdening too much any one area.

Community and indigenous advocacy organisations and academics have cautioned that the implementation of REDD without due regard to social and livelihood issues could have negative effects on local communities like those of some existing protected areas. To provide benefits to local stakeholders, governments of tropical forest countries could use a mechanism of 'Payments for Environmental Services' (PES) to share funding obtained through REDD activities. PES schemes provide the custodians of environmental services such as clean water, biodiversity and carbon sequestration with financial or other rewards for their role in providing these services. Governments could therefore use PES to provide incentives for reducing emissions on private or community lands, according to the amount of carbon conserved by those stakeholders. Recent research conducted at the Australian National University shows that PES can have positive livelihoods impacts, but certain design and property rights issues need to be addressed. Programs to strengthen the capacity of governments to implement PES should therefore be supported.

Policy initiatives in Australia

To support forest conservation in neighbouring countries such as Indonesia and Papua New Guinea in an effective and efficient way, policy initiatives should also be adopted within Australia.

The Rudd government had assessed the options to reduce the import of timber derived from illegally harvested logs. However, it did not reach the point of implementing any of the measures. The new government should consider the introduction of a domestic regulatory framework on illegal timber products. This would complement the support provided through the aid program to reduce greenhouse gas emissions and to conserve biodiversity.

Finally, funding is needed for the actual implementation of REDD after the initial capacity-building phase. Various assessments, including the Stern Review of Climate Change, have noted that to substantially reduce deforestation developed countries will need to allocate significant financial resources for developing nations: estimates range between $10 and $40 billions per year. This large amount of resources is unlikely to be available from government coffers, especially in the current environment of high public debts. Markets will have to be tapped. We come therefore to one of the most politically sensitive issues, the pricing of greenhouse gas emissions.

While designing a carbon pricing mechanism, the new government should consider the development of regional or bilateral carbon markets with tropical forest countries. Allowing a regulated, limited share of emissions from forestry in the region to offset emissions in Australia would contribute to lower carbon prices in Australia. Limiting the amount of forestry credits allowed as offset would ensure the price of carbon is sufficiently high to bring about a reduction in emissions by Australian polluters. This proposal could be implemented regardless of whether Australia adopts an emission trading scheme (ETS) or a carbon tax. Forestry carbon certificates could be exchanged directly in the ETS market. In the case of a carbon tax, a fund could be set up to hold some of the revenues from the tax and purchase forestry carbon credits.

Setting a price on carbon would provide an increased incentive to governments in the tropics to address illegal logging. And the lower the carbon price, the larger the size of emission cuts that could be achieved at the same cost in Australia. This would provide a significant contribution to our efforts to address climate change and to reduce the loss of biodiversity.

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Biodiversity and the Role of Microbial Resource Centres

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Micro-organisms were the first forms of life on earth and have evolved into the most ecologically, genetically and metabolically diverse species known. Micro-organisms belong to all three Domains of life: The Bacteria, Archaea and Eukarya as well as the Viruses. They have shaped the evolution of the planet and continue to nurture and sustain the environment, plants and animals on which human society depends. While we continue to face difficulties posed by emerging animal, plant and human pathogens, most micro-organisms are beneficial. Exploitation of microbial genetic diversity has been fundamental to advances made in biodiscovery and biotechnology. Micro-organisms are major sources of important pharmaceutical and industrial products for world-wide community benefits in health, agriculture and industry. Cultures of micro-organisms have been essential for the production of enzymes, fermentation products and metabolites. With advances in molecular biology, genes of micro-organisms and whole natural communities are being exploited and fuelling accelerated interest in biodiscovery. The OECD is strongly promoting that biological resource centres are essential to underpin advances in biotechnology, the life sciences and the bioeconomy. Microbial resource centres are more than collections. They work within the Convention on Biological Diversity (CBD) that was implemented to support the conservation and utilisation of biodiversity and recognises the principles of fair and equitable benefit sharing. They preserve and provide authenticated, genetically stable microbial and cell cultures, provide access to information on cultures and their characteristics, and undertake identification and description of new species. In Australia, the Council of Heads of Australian Collections of Micro-organisms is collaborating with the NCRIS Atlas of Living Australia project to develop the Australian Microbial Resources Information Network (AMRiN) integrated collections database to provide access to information on Australian microbial cultures for use in research, industry, government and education.

EMERITUS PROFESSOR LINDSAY SLY was Professor of Microbial Systematics and Microbial Ecology, Director of the Centre for Bacterial Diversity and Identification, and Curator of the Australian Collection of Micro-organisms at the University of Queensland where he undertook research and teaching of the biodiversity, physiology, metabolism and ecology of bacteria from natural and industrial environments. He has made major contributions to knowledge of microbial diversity, to the understanding of phylogentic relationships amongst species in diverse bacterial and archaeal divisions, and to the development of molecular tools for the identification of bacteria. In 2001 his contributions were recognised with the prestigious international Bergey Award. He was president of the World Federation for Culture Collections from 1996 to2000 and is currently Chair, Council of Heads of Australian Collections of Micro-organisms.

Importance of microbial diversity

Micro-organisms were the first forms of life on earth and have evolved into the most ecologically, genetically and metabolically diverse species known. Micro-organisms belong to all three Domains of life: the Bacteria, Archaea and Eukarya (algae, fungi, yeasts and protozoa), as well as the Viruses. They have shaped the evolution of the planet and continue to nurture and sustain the environment, plants and animals on which human society depends. I have previously reviewed the importance of microbial diversity and the role of microbial resource centres (Sly 1998a) and the following highlights the important issues raised in that publication.

Micro-organisms are an essential component of biological diversity, without which there can be no sustainable ecosystems (Hawksworth 1991, 1992; Hawksworth and Colwell 1992; Sly 1994; Center for Microbial Ecology 1995; Staley *et al.* 1997). It is estimated that at least 50% of the living biomass on the planet is microbial (Center for Microbial Ecology 1995) yet probably < 0.1% have been characterised. Micro-organisms provide a major source of genetic information for molecular biology and biotechnology (Bull *et al.* 1992; Nisbet 1992; Center for Microbial Ecology 1995; Staley *et al.* 1997). While some micro-organisms are serious pathogens of humans, animals and plants and pose a threat to health, food security and food safety, most are beneficial and sustain the environment and soil health. Plants and animals depend on microbes to grow and perform optimally.

Most advances in knowledge of the function and role of micro-organisms have been derived from pure culture studies, while most advances on the ecology and interactions of micro-organisms are likely to come from the application of molecular studies using signature DNA and rRNA probes. These studies have highlighted many important functions of micro-organisms in relation to agricultural processes and food security. However, until we have more complete knowledge of microbial species and functional diversity, decisions about the role of micro-organisms and their influence on sustainable ecosystems are being made on the basis of very incomplete information. Without a thorough knowledge of microbial diversity and ecology, decisions concerned with sustainability are likely to be flawed.

Recent advances in molecular methods (Woese 1987; Ward *et al.* 1990, 2008; Liesack and Stackebrandt 1992; Stackebrandt *et al.* 1993; Olsen *et al.* 1994; Amann *et al.* 1995; Hugenholtz and Pace 1998) have revealed the inability of traditional culturing methods to fully show the diversity of bacteria and other micro-organisms, and have shown that the species diversity in most terrestrial and aquatic environments is far greater than expected. The vast majority of microbial diversity (> 90%) remains to be discovered and its function determined as there are no or few cultured representatives in an increasing number of phylogenetic lineages. Consequently, actions which lead to loss of microbial diversity are likely to result in the loss of valuable knowledge of our natural microbial resources and understanding of sustainability drivers.

Micro-organisms occupy important niches in all ecosystems and are responsible for much of the recycling of the elements in nature, and are important components of food webs. Micro-organisms often have unique functions (e.g. nitrogen fixation, nitrification, denitrification, chemolithoautotrophic carbon dioxide fixation, methane formation and sulfate reduction) in the biogeochemical cycles, in soil formation and in climate regulation, and influence atmospheric composition (including greenhouse gases—Rogers and Whitman 1991). The first micro-organisms evolved over 3.8 billion years ago and consequently exhibit the greatest breadth of genetic and metabolic diversity on the planet, far greater than that of the plants and animals combined (Center for Microbial Ecology 1995; Staley *et al.* 1997). Some are able to grow under extreme conditions, and also in anaerobic environments that cannot sustain plant or animal life. Micro-organisms often exhibit symbiotic relationships with plants (e.g. *Rhizobium*, *Frankia* and mycorrhizal fungi in plant roots) and with animals (e.g. tube worms and mussels). Animals depend on micro-organisms in their intestinal tracts for digestion and for the production of nutrients and essential vitamins.

The genetic and metabolic diversity of micro-organisms has been exploited for many years in biotechnological applications such as antibiotic production, food, food processing, alcoholic beverages, fermented foods and waste treatment. Micro-organisms are the major sources of anti-microbial agents and also produce other important pharmaceutical and therapeutic compounds including antihelminthics, antitumour agents, insecticides, immunosuppressants, immunomodulators and vitamins worth $35–50 billion annually in global sales (Center for Microbial Ecology 1995).

The scientific benefits of microbial diversity research include a better understanding of the role and function of microbial communities in various terrestrial, marine and aquatic environments; a better understanding of the sustainable ecology of plants and animals; improved capacity to maintain soil fertility and water quality; and a better understanding of the full consequences of animal and plant extinctio; and of perturbations on ecosystems. The economic and strategic benefits are the discovery of micro-organisms for exploitation in biotechnological processes for new antibiotic and therapeutic agents; probiotics; novel fine chemicals, enzymes and polymers for use in industrial and scientific applications; for bioremediation of polluted environments and bioleaching and recovery of minerals; as well as preparedness against exotic and emerging pathogens of humans, animals and plants.

The signing of the Convention on Biological Diversity in 1992 (CBD) (UNEP 1992) focussed attention on the value of micro-organisms as sources of genetic information (Bull *et al.* 1992; Nisbet 1992; Center for Microbial Ecology 1995; Staley *et al.* 1997). At about the same time the development of molecular methods for detecting micro-organisms in the environment revealed the poor state of knowledge of both cultured and non-cultured microbial diversity (e.g. Ward *et al.* 1990; Liesack and Stackebrandt 1992; Stackebrandt *et al.* 1993; Amann *et al.* 1995; Hugenholtz and Pace 1996). Subsequently, extensive research effort and substantial research funding has been directed to the areas of microbial diversity, microbial ecology and biotechnology in Asia, the European Community and the USA (Clutter 1995; Staley *et al.* 1997). North–South attention has also been directed towards collaborations with developing countries in the tropical 'megadiversity' regions. In addition, many developing countries have become appreciative of the need to explore, protect and exploit their own microbial resources. Australia is in a unique position to take advantage of the wide range of ecological habitats of microbial diversity within its own boundaries and in the Asia–Pacific region through collaboration (Hawksworth 1994). Access to microbial resources and sovereign rights with respect to micro-organisms in environmental samples and cultures in collections have been the focus of international meetings (Kirsop and Hawksworth 1994; Sands 1994; WFCC 1996) Australia, like most signatory countries to the CBD, has been developing national and international protocols for access and benefit sharing.

Microbial resource centres

Microbial resource centres have an extremely important role underpinning the conservation of microbial biodiversity and enabling advances in agriculture, food security, biotechnology and education. They constitute essential scientific infrastructure that maintains collections of cultures of micro-organisms—living libraries of our natural scientific heritage. Depending on their research roles, services provided and quality systems, they are also referred to as Microbial Genetic Resource Centres, and more recently as Biological Resource Centres (OECD 2001, 2007). Microbial resource centres are more than collections. They work within the CBD that was implemented to support the conservation and utilisation of biodiversity and recognises the principles of fair and equitable benefit sharing. They preserve and provide authenticated, genetically stable microbial and cell cultures, provide access to information on cultures and their characteristics, and undertake identification and description of new species. The fundamental role is the ex-situ conservation and supply of viable and genetically stable cultures and genes for scientific research and testing. Important cultures resulting from research are accessioned, studied and conserved. These functions enable and add value to research for applications in industry and biotechnology. Microbial resource centres also maintain extensive databases and thus provide access to information on cultures, their characteristics, literature and DNA sequences, for example. They also are centres of taxonomic expertise for identification and characterisation of micro-organisms and provide training in taxonomy and preservation. With the decline in the teaching and research training in microbial taxonomy in universities, microbial resource centres are likely to have an increasingly important role in taxonomy research training that needs to be recognised and funded accordingly.

Maintaining living microbial cultures requires specific conservation skills and quality assurance to ensure genetic stability. It is essential that microbial cultures are considered as a global resource for the orderly progress of science and technology. However, such a strategy necessitates that each country meets its obligations wherever possible. There are strategic advantages for the ex-situ conservation of micro-organisms within the country of origin. Worldwide there are almost 600 culture collections of micro-organisms in 68 countries registered with the WFCC World Data Centre on Micro-organisms (http://www.wfcc.info/datacenter.html). These collections hold 1.5 million cultures of micro-organisms and cultured cell lines, with by far the majority being held in Europe, North America and Asia. It is concerning that only 11 collections are listed for Africa and none in the Pacific region. Currently there are 35 collections listed for Australia, down from 50 in 1998 (Sly 1998b). In 1998, these microbial resource centres in Australia held 65 000 cultures and it is important that the microbial diversity in these collections is protected and the on-going loss stabilised. Culture collections in Australia primarily have institutional roles and the host institutions are usually universities, CSIRO and government laboratories, together with a few industries (DEST 1966). Most cultures are bacteria and fungi with minor holdings of protozoa, algae, viruses, plasmids and vectors, and animal cell lines. A number of collections are engaged in plant pathology, taxonomy, mycorrhizal microbiology, insect microbiology, forest microbiology, food science and ecology, as well as plant breeding and biodeterioration of significance to agriculture and food security.

Key functions in agriculture and food

Microbial resource centres have played a key role in agricultural and food research over many decades. The Food and Agriculture Organization (FAO) recognises the important role of microbial genetic resources and microbial resource centres for productive agriculture and food security (FAO 2009) and also in understanding the consequences of climate change (Fujisaka *et al.* 2009). Examples of areas where microbial resource centres contribute to agriculture and food security are shown in Table 1. Table 2 lists examples of significant international collections that have had a long-term involvement in the conservation and supply of cultures for research and regulatory compliance. Not only do these collections provide valuable resources and expertise; the cultures from this research are available for extension of this research. The intersection of existing knowledge and resources with often new independent discoveries frequently leads to accelerated innovation (e.g. development of PCR). Table 3 lists examples of significant Australian collections which continue to contribute to Australian microbial resources for agriculture, food microbiology, plant pathology, quarantine and trade.

Table 1. Examples of areas where microbial resource centres contribute to agriculture and food security

Plant endosymbionts (e.g. *Rhizobium* for biological nitrogen fixation)
Plant growth-promoting bacteria
Biocontrol agents (e.g. pathogens of weeds, fungi, insects)
Inocula to restore soil health and nutrient release (e.g. phosphorus)
Source of genes for plant improvement (e.g. insect resistance)
Reference cultures for food safety testing, quarantine, trade
Reference cultures for animal and plant disease testing
Enzymes for food improvement and processing
Cultures for food fermentations and nutritional supplements
Innovative biodiscovery

Table 2. Examples of significant international collections

National Collection of Plant Pathogenic Bacteria (UK)
CABI Genetic Resource Collection (UK)
Centraal Bureau voor Schimmelcultures (Netherlands)
USDA ARS Culture Collections (USA)
American Type Culture Collection (USA)
Canadian Collection of Fungal Cultures (Canada)
Agricultural Culture Collection of China (China)
International Collection of Micro-organisms from Plants (New Zealand)

Global networking initiatives

The World Federation for Culture Collections (WFCC) is the peak international body that fosters culture collections, their documentation and networking. The WFCC and the OECD Directorate for Science, Technology and Industry, Committee for Scientific and Technological Policy (OECD 2001) recognise that biological resources in culture collections are a world resource that needs to be accessible across national boundaries for the orderly progress of science and biotechnology. UNESCO, through its Microbial Resource Centres Network (MIRCEN), has fostered and supported the development of collections in developing countries and the training of scientists in the management and maintenance of collections as well as long-term cryopreservation techniques. In 1972 the WFCC with the support of UNESCO and UNEP established the WFCC World Data Centre for Microorganisms (WDCM) at the University of Queensland to document the metadata and species holdings of the worlds' microbial culture collections. In 1986 the WDCM was transferred to the RIKEN in Japan and subsequently to the National Institute of Genetics, and will move to the Insti-

Table 3. Significant agricultural and food microbial collections in Australia

Rhizobium Research Collections, Sydney, Adelaide, Perth
Australian Legume Inoculants Research Unit, NSW Department of Primary Industries, Gosford
BRIP Plant Pathology Herbarium Collection, Queensland Primary Industries & Fisheries, Brisbane
CSIRO Food and Nutritional Sciences Collection, Sydney
IMVS Culture Collection, Institute of Medical and Veterinary Science, Adelaide
Department of Agriculture & Food Western Australia Plant Pathogen Collection, Perth
Phytoplasma DNA Collection, Charles Darwin University, Darwin
Australian Wine Research Institute, Adelaide
CSIRO Livestock Industries, Brisbane
Plant Pathology Herbarium Collections, New South Wales Agriculture, Orange
Australian Collection of Micro-organisms, University of Queensland, Brisbane

tute of Microbiology of the Chinese Academy of Science in 2011. The WDCM remains the authoritative record of the worlds' microbial resource centres and continues to adapt to new information technologies and develop to meet changing global needs.

The OECD has recognised the essential role of biological resource centres for the life sciences and biotechnology (OECD 2001) and has developed best-practice guidelines for biological resource centres (OECD 2007). To progress the development of standards to implement the best-practice guidelines, a demonstration project for a Global Biological Resource Centre Network (http://www.gbrcn.org/index.php) commenced in 2008 involving BRCs in 15 countries including Canada, United Kingdom, Netherlands, France, Belgium, Germany, Finland, Portugal, Spain, Italy, China, Japan, Brazil, Uganda and Kenya. In order to maximise Australia's global collaboration and to provide world-class microbial resource centre facilities, there is an urgent need to develop a network of OECD-compliant biological resource centres by establishment of purpose-built facilities and or up-grading of suitable microbial culture collections (Sly 2008). This infrastructure will enhance current and future progress in many areas of the life sciences, biotechnology, industry and education, and will allow Australia to join the emerging OECD Global Biological Resource Centre Network (GBRCN).

Australian Microbial Resources Research Network

The Australian Microbial Resources Research Network was established within the framework of the ARC Research Network Seed Funding Program in 2004. While not receiving further funding for the development of a full ARC Research Network, the seed funding played an important catalytic role. The Research Network aims to provide integrated electronic access to Australian collections of micro-organisms and to bioinformation databases to meet national strategic needs for microbiological resources and to support the competitive development of the life sciences and biotechnology industries in Australia. This objective is now being fulfilled through collaboration in the NCRIS 'Atlas of Living Australia' project. The network links researchers and fosters the discovery and exploitation of Australian microbial resources and associated information.

The Australian Microbial Resources Information Network (AMRIN) web site (http://www.amrin.org/Home.aspx) has been developed to improve access to information sources and to facilitate scientific advances and efficiency through collaboration. AMRiN will be further developed as a database hub within the Atlas of Living Australia to integrate the data within Australia's microbial culture collections. Recently, AMRRN established the Council of Heads of Australian Collections of Micro-organisms (CHACM) (http://www.chacm.org) as the peak body to foster and oversee the development of microbial culture collections and development of BRCs in Australia.

Atlas of Living Australia

The 'Atlas of Living Australia' (ALA) (http://www.ala.org.au/) is a very welcome outcome from the Australian National Collaborative Research Infrastructure Strategy (NCRIS) initiative to develop science infrastructure capacity for the future. NCRIS identified the need to have access to information in Australia's biological collections to foster research and help in government and community decision-making. The ALA is being developed in collaboration with the

Australian biological collections communities in museums, herbaria, government, research institutes and universities to provide integrated electronic access to data and biological material for research and other applications. The ALA project enables free access to Australian biodiversity information online with the first public release of information scheduled for October 2010. The atlas will provide online access to biodiversity information from museums, herbaria and biological collections, including information previously not available to the public, research literature, observations, maps and images.

The development of the ALA is evidence of government recognition of the importance of this information for innovative science. However, to maximise the impact, funding is also required for maintenance and expansion of collections. This is particularly so for microbial collections and biological resource centres seeking compliance with OECD GBRCN best practice guidelines for incorporation of quality systems for living material such as microbial and cell cultures.

Issues, challenges and recommendations

Microbial resource centres underpin the life sciences and enable advances in agriculture, food security, biotechnology and education, but their important role needs more recognition and support from government, funding agencies and host institutions. Apart from their fundamental role for the conservation of microbial biodiversity, they are necessary for the supply of reference control cultures essential for regulatory compliance for health and trade. Many government ministries and agencies support programs in agriculture, food, health, quarantine, industry, science and education which depend on taxonomic decisions and access to standard cultures for quality assurance and regulatory compliance. There is also a growing need to manage impediments limiting exchange of cultures between researchers due to quarantine requirements, commercial IP, biosecurity, and access and benefit-sharing protocols.

New long-term infrastructure funding mechanisms are needed to support microbial resource centres. Apart from the ex-situ conservation and supply of current microbial genetic resources, there needs to be more comprehensive accession of cultures used in research publications and publically funded research projects than is currently the case. In order to be internationally relevant and engaged in collaborative programs, collections will also need to meet emerging international OECD GBRCN best-practice standards that will in most cases require improvements in facilities and staffing levels. There is a need to improve the future security of microbial resource centres by inclusion in national and international infrastructure programs. This move will help reverse the loss of collections and the microbial biodiversity when researchers retire or institutes change direction and priorities. Exploitation of the untapped potential of microbial diversity and innovative biodiscovery will be fostered by the support of microbial resource centres.

Making biological collections eligible for long-term infrastructure funding will enable fulfillment of the recommendations to strengthen and support culture collections of micro-organisms made in *The National Strategy on the Conservation of Australia's Biological Diversity (1992)*, the House of Representatives Standing Committee on Primary Industries and Regional Services report on *Bioprospecting: Discoveries Changing the Future* (2001), and the report on the *Review of the Innovation System*, Department of Innovation, Industry, Science and Research (Cutler 2008).

There is an urgent need to train and mentor the next generation of taxonomists and curators of microbial resource centres. Many curators of collections are approaching retirement and many who have already retired are not being replaced. Likely global changes (e.g. climate change) will probably affect microbial ecology and species' ranges and affect demand on microbial resource centres and their expertise.

Various reports have called for accelerated research on microbial diversity. Such an initiative would expand knowledge and opportunities for biodiscovery and innovative agriculture and food industries. It would also help to reverse the decline in teaching and research training in microbial taxonomy and ecology in universities. One model which should be considered is the establishment of 'research centres of excellence' in microbial diversity, taxonomy and ecology in collaboration with collections. This would assist in training the next generation(s) of research scientists and academics in microbial biodiversity and taxonomy to meet future challenges. As taxonomic expertise has been run down across the biological disciplines, biological resource centres will become the centres of taxonomic expertise to manage these resources and will be important for providing high-level research training and careers in taxonomy and identification for young PhD and postdoctoral scientists.

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James Moody

Questions and Answers

Moderated by James Moody

Panel members:

Dr Cristián Samper
Dr Emile Frison
Dr T.J. Higgins
Professsor Hugh Possingham
Dr Gabrielle Persley
Dr Meryl Williams

Preliminary panel discussion

James Moody: Cristián, what are some of the threads and commonalities of today?

Cristián Samper: The discussions have raised my awareness of issues like micro-diversity and trade-offs or contrasts between say marine systems, terrestrial systems and other elements. I heard from most people that we have to think about food security in a much broader context: not just food production, but other dimensions of human wellbeing, including the concept of ecosystem services. I heard of the not-surprising tensions between preserving biodiversity and food security.

I didn't hear enough about trade-offs between issues like forestry and livestock; or carbon and water. Such trade-offs are interesting, particularly in an Australian setting—Australia is in an interesting position because from a global biodiversity perspective it is an extremely important continent. It has made major advances in food production and food security, and it has some major scientific capacity as well. It may well be in different position compared to say Europe in seeking a balance between biodiversity and food security. I do agree that we can't conserve all biodiversity and at the same time retain the same production systems. Hugh Possingham's title poses a question: 'Can we have our biodiversity and eat too?' My short answer is that we can, but we need a different recipe.

James Moody: Emile, you will talk tomorrow about health and nutrition. Have we introduced those issues adequately today? Are we missing some of the trade-offs or other issues?

Emile Frison: Since I haven't spoken yet, I will talk about things I haven't heard yet in order to whet your appetite for my talk tomorrow morning. I have the impression that we've been talking about food security too vaguely—as if it was just a matter of producing any type of food anywhere in sufficient quantity, almost in macro-economic terms. The real problem is to address the issues that concern the one billion poor people in the world who are not food secure. Most of these people are in developing countries; if we want to address their problems, it's not just about producing any type of food anywhere. We want people to fully develop their capacities, so we must have not only food that fills the stomach, but food that provides appropriate nutrition and permits full development. This recognition has been lacking, not just in discussion today but in the whole debate about food security for the last two decades. Only in the last few years have we seen greater attention to the issue of nutrition. It is important that we go beyond using the term food security as if it was only about producing more food: it is much more complex than that. Producing better food for people will address both poverty and health outcomes.

James Moody: You panellists are broadening this discussion. Australia's unique contribution to food security is more than shipping large quantities of protein and fat around the world. TJ, what have you thought?

T.J. Higgins: I have talked about intensification of food and even fibre production using the best genetics and the best management tools that are available so as to maximise the space for essential biodiversity. But I see a new challenge in the need for intensive management of biodiversity—a challenge that includes the question, is there a role for genetic modification in the intensive management of biodiversity?

James Moody: Hugh Possingham, some participants have described your views as controversial—what have you gathered?

Hugh Possingham: If the conservation of biodiversity is largely about values, we need to understand people's values. If you don't have enough food to eat, your values are quite clear. But in emerging economies like Indonesia and Brazil where the value system is rapidly changing and the middle classes are growing quite large, how do we work out what their values are? And how do governments work out what those values are? I am not sure if the Australian government knows what the values of the Australian people are—they were not very clear for agriculture, for the environment or for conservation in the recent election.

If we are to consider and possibly accept trade-offs, we need to assess the values accorded by Australian people to competing interests. And what do they perceive as risks?

Another property that we haven't talked about is resilience, especially of ecological systems. Resilience comes into food security: not only total production and quality are important. What is the probability of something going really wrong? How much productivity should be traded for consistency? There is a trade-off between variance and mean in productivity, and in eco-systems as well. We don't really know how people weigh these factors; at almost every conference I attend on conservation I end up feeling that we need more social scientists who can work with us on values.

James Moody: People will be very happy to hear you talk about resilience and the trade-off between efficiency and resilience of complex production systems systems.

Gabrielle Persley: Perhaps I can tell you of a lesson I learned when I was a young bureaucrat in Canberra working with Sir John Crawford. When he would produce brilliant syntheses at meetings, an even younger Denis Blight would say, 'Sir John, I didn't exactly hear them say that' and Sir John would say, 'It's want they would've said if we had just stayed a little longer'. Bob McMullen said this morning that 'there needs to be some choices'. This is particularly necessary when it comes to investment of either public or private sector money; some priorities have to be set and choices made as to what biodiversity to conserve and what sadly will be left to nature to take its course.

My experience over some years in working with development agencies has been that it is hard to mobilise funds for biodiversity per se. In the current reform of the international agricultural research system, is proving to be quite difficult to keep such funding on the agenda. Because of this difficulty, people make cases that biodiversity is essential for food security; I tend to be sympathetic with Professor Possingham's view that sometimes these links are tenuous at best. Therefore in making the case for investment in biodiversity we need to make a much better case for the broader values of biodiversity, and not claim in every possible case it is absolutely essential for food security, because in fact it's not. We are not doing the cause of conserving biodiversity justice by pretending that it is always essential for food security. Once we do make that case as a community and set the priorities, we have quite a challenge to communicate these to decision-makers. This conference is the start of making that case, rather than an end in itself.

James Moody: There is the whole question of who will pay for this. Does it just have to be linked with food security?

Meryl, you know of some compelling things around what Australia has done overseas. What were the threads that you drew out of the speeches today?

Meryl Williams: I'd like to offer two reflections. First, we need a better framework to conceptualise biodiversity and the world food system. Food security is a subset of the issues in the world's food system and it can't be dealt with in its own right. Any better framework will have to go across the scales from microbial to natural systems to cultured systems and cultured species, and incorporate the necessary connections between these levels. The reason it is important to have this framework being developed is that when the new international panel on biodiversity and ecosystem services gets going (the interested countries have now all agreed that they will do it), a lot of details have to be worked out as to how it will be done. This will be an IPCC-type process for global biodiversity and ecosystem services, the latter being a follow-up to the Millennium Ecosystem Assessment. Then agriculturists need to be ready to tap in or to contribute to the IPSS process with some clear thinking about how biodiversity and the food systems fit together.

The second point is very much an aquatic matter. Within 50 years agriculture will dramatically increase the already horrendous nitrogen and phosphorous outputs, most of which is wasted—50% has been mentioned. I'm working with the scientific and technical advisory panel of the Global Environment Facility (GEF) on hypoxia in coastal zones, and I can tell you we don't want more of these outputs in the water. Hypoxia is already causing tremendous and increasing problems; the hardest parts to tackle are the agricultural and livestock sources. Sewage, industry and other sources are somewhat more tractable if you have the money. The good news for biodiversity with hypoxia and anoxia is that there is tremendous biodiversity in hypoxic and anoxia water—but it is all based on totally different ways of living. It's like getting back to four billion years ago, before there was oxygen in the world. This biodiversity is all at the microbial level.

James Moody: Meryl, you may be able to answer the question Cristián posed, of balance between different parts of the system: the livestock, the plants, the microbial, the marine—have we got that balance right, and if not where've we got it wrong?

Meryl Williams: Each sector—and scientists around each sector—has to look very broadly. I've often found agricultural specialists—whether they're industry or farmers or scientists—think that that term 'off farm' means the nearest river or little stream, rather than out in the ocean, 100 or even 1000 km away, which is where a lot of the farm ends up. Each sector really needs to be engaged with the others. If you are the sector that's emitting, you my not care too much until the sector that is receiving (often fisheries) complains about what's been emitted. It becomes a victim's role to remind the emitter that there are problems. This is one of the things we are grappling with in the hypoxic work at the moment. How do we get to agriculturalists to tell them we don't want their nitrogen and phosphorous: keep it on the farm?

Everybody has to take a broader view than generally they have been taking.

Question from the audience

Q1. Unidentified member of audience: *This conference didn't tell us enough about the state of biodiversity in Australia, but two speakers, Professor Sly and Dr Lum, said there is a great shortage of taxonomists here to assess the wide range of biota present. Large increases in global population were noted without much discussion. The UN has classified Australia as a least developed nation because of our rapid population increase. What has the panel to say about food supplies, region by region, rather than globally? Each region has to look after itself, surely?*

James Moody: We have a question about taxonomists … Cristián?

Cristián Samper: Taxonomy is clearly part of my business; we are facing a problem with taxonomy and taxonomists in developed nations including the United States of America. Universities and science have changed and people are not addressing fundamental taxonomy; it is being taken for granted. Fortunately in some countries, like Brazil, there is a stronger, younger taxonomic community than in the United States. This question may be amenable to a more regional approach, and fortunately advances in communications technologies assist this. The paradigm of global centres like the Smithsonian or Natural History Museum in London has shifted; we need to build capacity in different regions of the world.

James Moody: Who will pay? Expenditure is declining …

Cristián Samper: The short answer is we all pay—this is one of the lessons I have learned as a mentor. I grow up in Columbia, and it was interesting trying to be a biologist in a developing country. Some of the things I have at my reach right now, what Columbians have in their reach right now, are very different from what they were 20 or 30 years ago. Not only have we made tremendous partners in say training taxonomists, but in building the institutions where those taxonomists can work. There are certain elements of biodiversity where private industry will invest, but some public funding will also be necessary because there are many elements of biological diversity that don't have a direct application. Public–private partnerships will be significant, as well as overseas development assistance for building capacity in developing countries.

Hugh Possingham: Having chaired the Australian Biological Resources Study for a few years and tried to get taxonomy more money, I found it was a big problem, partly because the taxonomic community is not the best marketer of its science. The importance of taxonomy for biosecurity has been illustrated very well in the talks this morning. In biosecurity, prevention is clearly better than cure, but we never spend enough on prevention—this is true for public health, for the environment and for biosecurity. This is a global policy problem of the capitalist system—somehow we cannot work out the institutional processes to get the balance correct between prevention and cure. For every dollar spent on taxonomy there is almost a ten-fold benefit, but that return has been impossible to sell to the government.

Q2. Walter Jehne, from Healthy Soils Australia: *I have a question for Hugh about trade-offs. To what extent is this a problem of homo hubris? The fact is that we have a mind set, because if we look at ecology and the evolution of our biosystem it has obviously optimised processes by improving efficiency via the development of biodiversity. As niches get more and more sophisticated we get more and more species with more and more efficiency. If we are going to have integrity in our food system, when are we going to start employing these concepts rather than the simple issue of 'we have to trade-off the very things that drive the productivity and resilience of the systems that we need to survive on'.*

Hugh Possingham: If I understand the question, you are saying, why can't we manage complicated systems and harvest them?

Walter Jehne: No, you are saying there is a trade-off. I'm simply saying that in fact biodiversity drives the efficiency on which our food security and the integrity of production depend. We don't have to trade it off; we have to build on the symbioses and the functional efficiency that biodiversity gives us.

Hugh Possingham: But how much biodiversity do we need? There may be 4000 bacteria in a gram of soil: how much do we need?

Walter Jehne: If we only know 0.1 of them, how do we know what we don't need?

Hugh Possingham: That is always a question: how do we know what we don't need? We have many examples where far less diverse systems of soil or plants function productively and we have successful monocultures. There are a couple of examples from sugar cane where crop failures seemingly occur because the soils are just structurally full of biodiversity—but only very few. Arguably we haven't pushed systems to completely fail because of lack of biodiversity. This gets back to resilience: how do you know when you are about to cross the threshold? By the time the threshold is crossed it is too late. Thresholds are hard to measure. We don't have enough data on most of those issues.

Emile Frison: The issue brought up here reminds me that the whole ecology discipline has focused to a large extent on wild biodiversity, and there has been much too little interaction between ecology and agriculture. There are cases where the threshold has been crossed, in particular in soils that have been degraded and that will be very difficult to restore. There are a lot of potential synergies to be gained from better interaction between ecology and agricultural sciences. The whole agricultural education system has been geared towards a single model of agricultural intensification—monocultural, industrial agriculture. It is much easier to do an NPK study on one variety on one particular type of soil than it is to look at the complex interactions between different species in an agricultural ecosystem—and farmers do manage complex agro-ecosystems. We have been trying to simplify that complexity, and any success has been possible only because of external inputs—nitrogen and phosphorus, for example. The sources of those inputs, however, are finite. We have to better understand agriculture ecology, so I make a strong plea for much better integration of those disciplines.

Q3. Bob Redden, Australian Gene Bank[1], Victoria: *We have in Australia thousands of years of history of aborigines surviving off the land as hunters and gatherers. Hundreds of different species were used as 'bush tucker'. I know that the biodiversity of under-utilised crops has been investigated in many countries, but such work may not have has not received the emphasis in Australia that it could have. Is there a need to collect these Australian materials for gene banks, and are there deficiencies in the present organisation of Australia gene banks?*

Cristián Samper: We have been discovering biodiversity for thousands of years. Although the food production systems that we tend to think of

[1] Australian Temperate Field Crops Collection, Horsham

are largely driven by just a few crops, the fact is that a wide range of plants are used. Probably one out of every ten plants species that have been described today are being used by humans for food, medicine or other purposes, and very few of those have actually undergone domestication. A key issue is how to document traditional knowledge, because we are losing a lot of that extremely rapidly, along with linguistic and cultural diversity. Of the some 6000 languages in the world, we estimate probably 80% will disappear this century. There are probably 2000 languages that are spoken by less than 1000 people. The loss is of not just the language, it's all the knowledge and experience of past generations. It's not just the species and it's not putting it into a seed bank. It's all the production system, and knowledge of how it adapts and responds to change.

An interesting example is from the Arctic region where we are gathering traditional knowledge of the use of these resources and assessing the effect of global climate change and how the production system and the extraction system are responding to this. The opportunities to gather and use traditional plants and knowledge have been understated during this conference because we are focusing on contemporary western production systems.

James Moody: TJ, nature is a pretty good designer—should we be spending more time on biodiscovery rather than gene manipulation?

T.J. Higgins: They really go together—you have to do one before you can do the other. Meryl gave me a very good idea: to build on the two and half billion years of evolution in the oceans by finding and using genes for dealing with potential problems that we will encounter in the next 50 years, such as eutrophication of waterways and the oceans.

Q4. Dan Etherington, founder of a social enterprise called Kokonut Pacific: *The floods in Pakistan have highlighted a critical issue regarding food security and climate change: resilience. Many of the most productive semi-subsistence smallholder irrigated farming systems are in large river deltas, but these deltas are particularly vulnerable to sudden change. The issue of food security cannot ignore the question of resilience. Speakers have drawn attention to population growth from 6.9 billion to 9 billion, but sudden changes such as those that occurred in Pakistan have left two million people in absolute crises and 20 million severely disturbed. If the same thing happens to Bangladesh we have a very, very grave situation. How does the panel view this?*

Meryl Williams: We do seem to be confronting larger and larger crisis as the decades go, in part because more people and more infrastructure is being affected by the various crises. This year extreme events such as the Pakistan floods, the fires in Russia and high temperatures in the Northern Hemisphere are leading people to say 'This looks to be more than coincidence'. Maybe we need to start now to identify what places are vulnerable and get into better planning. When an event as extreme as that in Pakistan occurs, effective response is very difficult. China has been better able to cope with some disastrous events, but I'm sure that country is rethinking how it is going to cope in future with major catastrophes. A risk assessment planning process is really needed.

Gabrielle Persley: Following some of these catastrophic events—be they climatic or due to civil strife—the international community has been able to respond fairly quickly. In Rwanda, for example, it was possible to reintroduce local varieties of beans after the civil disasters there. Part of the planning processes is to not only to understand what might happen but also have a plan of how to respond fairly quickly.

Q. Peter Stoutjesdijk, ABARE–BRS: *TJ, you talked about benefits that might accrue if we could secure nitrogen from new sources. How is the quest to transfer the capacity for nitrogen fixation from legumes to other crops going?*

T.J. Higgins: Gene technology is great at deploying a small number of genes, whereas fixing nitrogen from the atmosphere involves several hundred genes. The addition of nitrogen fixation through the use of bacterial symbionts to say, wheat, is a very big technical ask. A better option is to increase our use of legumes as part of our sustainable crop rotation system. The other is just a dream too far.

Q5. Pennie Scott, Healthy Soils Australia: *As I am a social scientist, I have been delighted to hear reference to spiritual and cultural values. One of the first descriptions of a new taxonomy I'd love to see is the description of an ecological community—we have very many descriptions and ideas of what that is, but no common definition. It appears that it's quite difficult to provide a holistic description of what we are talking about with biodiversity and providing continuous high-quality supplies of food to nourish everybody on* *the planet. I suggest that rather than just increasing crop yields and moving those yields and products around the globe, we can enable people to grow more food on a much more local basis using traditional knowledge of biodiversity inherent in communities. This would be an enabling, enriching and resilient way to provide some solutions to what we all think of as a global issue.*

James Moody: The ecological community might even see how it fits in the world's food system. The other question is about local production.

Hugh Possingham: I brought up the issue of cultural services, and showed several graphs of the trade-offs. The Millennium Assessment included assessment at both global and local scales. We found that the relative importance of different value categories changes with scale. Cultural, spiritual and aesthetic values become increasingly important at local scales—that's where those choices are being made. In contrast, commodities trade at a global scale. The scale of the context in which decisions are made and managed is a key issue. To what extent are we going to invest in developing some of these global commodities, increasing food yields, putting more nutrients in them, and to what extent should we develop whole systems locally, based on traditional knowledge and biodiversity? One of the scenarios I mentioned briefly this morning was what we call the adaptable mosaic. That's exactly the kind of solution the questioner proposes—developing local production systems that may not have necessarily have the biggest yields but may have major implications for other dimensions of human wellbeing that go beyond food security. That's the other issue that we don't want to lose sight of. It is easy to focus on just access to food or on nutrition—but good livelihoods for people go well beyond that, for example in freedom of choice and other dimensions that are fundamental and are not necessarily being addressed now by agricultural policy.

Emile Frison: I wish to link the issue of resilience with that of local production. If we focus on addressing the poverty that I mentioned, you have to start asking the question of what people do want. Want is a people problem and requires a participatory research approach and recognition of local diversity. You realise that there is much less emphasis on the major staples and that much greater diversity is used, which also affects resilience. In the more diverse systems you don't put all your eggs in the same basket; this also applies to resilience of the production system. By starting with traditional knowledge and marrying that with scientific knowledge, diverse systems that satisfy varied needs including the cultural dimension can be devised or improved. This is again something that has been totally under-researched and under-invested in, and which should receive more attention in future.

Gabrielle Persley: I offer comment on food security and local production in East Africa during the recent global food price crisis. In an analysis of what happened, it became evident that the effects of the crisis were not uniform; indeed countries which were less dependent on imported food survived much better. In Uganda, for example, in which a large proportion of the population were eating locally produced food—a wide variety of bananas for example—there was much less pressure on food prices, particularly for poor people, than in Kenya which was dependant on a lot of imported maize. This has now had a policy effect on decision-makers, who've seen the actual value of much more local production of indigenous foods rather than being too dependent on imported grains.

Hugh Possingham: A related but broad issue is that of decentralisation: I mean a connection with nature. We don't like vast monocultures, where the cotton fields go far into the distance, but they exist in western Queensland and 98% of the people who live in Brisbane have never seen them and they don't want to go and see them. They are completely disassociated from the way their food, fodder and fibre is produced. Few would know how to grow a plant any more, and that number is declining rapidly. So ultimately are Australian cities, which are incredibly centralised already. People are looking at computers. They're not going to the garden and they have no idea what a cow is. Ultimately the only solution to that, probably, is decentralisation. Australian governments haven't said that word for probably 25 years, and you would be called a communist if you did. Victoria had a decentralisation policy for a while and they put a railway system around the state, so rural centres worked. The Queensland Premier is acutely aware of these issues, and believes that Queensland just can't continue filling the south-eastern corner with people. We need to get rural communities growing and spreading to provide opportunities for people to become much more attached to their local places than is possible in the vast suburban deserts of Brisbane. But that requires real leadership by a government, state or federal, and incentives to get people decentralised.

Q6. Tony Fisher, Crawford Foundation and Honorary Fellow at CSIRO: *I actually like large cornfields and wheat fields. I think they're ascetically quite pleasing. I suppose I belong to the techno garden group. I want to take issue with Bob McMullen who said we have a difficult choice between the short-term benefits of intensified agriculture and the long-term costs. I think we've heard too many negative views about modern agriculture. Most of the world's food is produced in mechanised monocultures—not just in the developed world but also in the developing world. In China, in Asia, South Asia and South America. Only Sub-Saharan Africa hasn't moved in that direction and they're in big trouble. We are not going to turn that around. This is the agriculture that has saved at least a billion hectares from the plough. We need to be realistic about where we direct our research dollars. Do we seek out these fancy new soil, healthy cropping systems of all these new 30 000 edible plants that haven't been researched much? Or do we continue to put heavy emphasis on our existing systems and our 6 to 8 or 10 staples? I think we can make those existing systems even more sustainable than they are. They're quite diverse at the genetic level in the crops—that's what really counts—and they can be made more sustainable and many of them are quite sustainable. We need to be careful that we don't 'throw out the baby with the bath water' and go overboard chasing many of these other fancy notions that we've heard about today.*

Emile Frison: No 'one size fits all'; it is true that large areas of industrial agriculture will not be turned into the diverse systems that are seen in many smallholder farms in Africa—but we are missing out on the potential of better tapping the interactions between different species. In China, five million hectares of intense intercropping are being used to find better ways of mobilising phosphorous from the soil to maximise the benefits of interactions between cereals and legumes in nitrogen fixation, whereby the cereal stimulates greater nitrogen fixation by the legume, than if the legume is grown alone. Such synergies can lower inputs to intensified agriculture. Models based only on high inputs are short-term, unsustainable solutions. We have to tap the power of interactions between different components of the system. In addition, there are big differences between Australia and most countries in Africa. In Uganda, for example, 70% or more of the population is still in agriculture and a common farm size is half a hectare. Do we want to push Uganda towards Australia's position, with 2% of the population in agriculture?

James Moody: There has also been discussion about scale and biodiversity … Lindsay, what are your thoughts about that?

Lindsay Sly: We cannot dismiss the microbial scale. From a microbiological point of view, we have seen degradation of our agricultural soils to the point where many are almost a simple matrix to which we have to supply considerable inputs. That's fine while we can afford those inputs, but with restrictions on nitrogen application and declining petrochemical and phosphorous resources we might need microbes to mobilise phosphorous or to fix the nitrogen. Thus there is certainly a need to investigate ways of improving soil health and the role of micro-organisms, as well as getting more organic matter back into soils.

Q7. Richard Everington, Kokonut Pacific: *Can you comment on the nutrient density of food and its improvement? I can see that the key domesticated six–ten species of plants that we derive 90% or more of our energy from are going to remain with us, but what are the opportunities among vegetables, where there is a lot more biodiversity?*

Emile Frison: I will be giving some examples about that tomorrow. In East Africa traditionally more than 200 species of leafy vegetables were used—some cultivated, many picked from the wild. These show differences in nutrient (especially micronutrient—vitamin A or iron or zinc) content of ten- to a hundred-fold compared with what used to be the most common green vegetable, cabbage. This contrast has been a characteristic of most of the improved species. Nutrient density of species that have undergone a lot of genetic improvement has not been taken into consideration at all, and they have been bred only for yield and energy efficiency. A lot of the genes responsible for nutrient density may have been discarded. No vegetable is likely to satisfy all needs, and so trying to make a miracle single crop that has it all is unrealistic—it is better to tap into diversity again.

Gabrielle Persley: Amongst the most nutrient dense-foods are those sourced from animals. There was a reason why mothers always told their children to drink a glass of milk. One has to look at a balanced diet, and that's part of the developing Africa–Australia partnership in which nutrition is a high priority. It includes not only things like the African vegetables—which indeed are important sources of micronutrients—but also increasing consumption of animal-sourced foods. Just small increases from very low levels can have a very high impact, particularly on mothers and children.

Q8. Sadanandan Nambiar, Honorary Fellow at CSIRO: *Most of us would probably appreciate that it makes sense that food is produced at the local, sub-regional or regional level, in the right quantity and with the right nutrients. That's a nice model. I want to comment, however, on the popular comparison of so-called 'monocultural industrial food production' with the agriculture based on 'local , traditional knowledge'. If you look at world experience, there is no question that the local knowledge model has a high dose of romanticism. It was quite clear in my work in plantation forestry that the traditional forestry model does not necessarily serve poor people very well at all. Those societies worldwide that have come out of poverty and become able to feed themselves have succeeded largely because they adopted 'modern technology', however wrong its applications may have been sometimes. So can we actually bring welfare, wellbeing and good health to those people if they remain dependent only on local knowledge and tradition? There are many instances in which it has resulted in perpetual poverty.*

India's food supply and nutrition has been mentioned. My question is about food production as much as forestry. If you look at India's green revolution and the under-nutrition of many Indian people, it is not proven that this can be alleviated by going back to traditional knowledge and practice. This is a risk that we must be aware of. It is easy to brand modernisation as a form of colonial domination. We need to be very cautious when assessing the new-found virtues of 'traditional ways', and unintentionally perpetuate the idea that modernisation is wrong.

Unidentified panel member: One reason I raised the issue of local people and local knowledge is that in some cases of increased colonisation in rural systems there have been positive impacts on poverty, but in many cases people in rural areas have been marginalised. As you observed in forestry cases, often people have not benefited. The challenge is to engage rural indigenous people in a more participative way, to understand first of all what their needs are regarding food security and their spiritual needs; these vary a lot between different countries because different countries have different values.

I worked in the Pacific where some people wouldn't have a bar of having a logging company on their land; they didn't need that money. In Indonesia cultural values may be different and often there is deforestation. There is no solution that fits all circumstances, but we need to create space for local needs. However, unless there are more democratic systems in place, I don't think that is going to happen. That again was one of my reasons for focussing on decentralisation and democracy—we can't work just at the project level; sometimes it is necessary to be more systemic. There's no easy solution, but I am positive we can get there.

Emile Frison: It's not about opposing romantic traditional knowledge with modern technology. I was really talking about a marriage of traditional knowledge that has values and an intrinsic understanding of some of the ecological process (though not necessarily in a scientific way) with sharp scientific knowledge. It's not about being romantic about the past, but looking to go beyond a purely technological approach that has not been addressing the issues of poverty. The world hasn't solved the poverty issue; economically (as measured by GDP) we have improved in some cases by a factor of six, but in India, which has enjoyed the success of the green revolution, 50% of the children today are malnourished. Where is the progress? We have to see how modern science, which is absolutely necessary, can embrace other neglected dimensions like traditional knowledge.

James Moody: Hugh, is there somewhere a solution that incorporates development and poverty reduction as well as biodiversity and food security, with ecosystems services?

Hugh Possingham: Some interesting papers have recently been submitted to *Nature* and *Science* about the relationships between poverty alleviation, biodiversity and conservation. And the jury is out. If you can get people over particular humps, perhaps they all become rabid greenies. Industrial agriculture has been a big part of getting people over the short-term food supply hump, and they have started to conserve biodiversity—but there may be no causal relationship. It's a correlation in history. Although some of the countries which have moved have big middle classes, it's not completely clear that they will be as green as us, nor that we are as green as I'd like us to be. This is a global experiment with no replication.

Q9. Albert Rovira, The Crawford Fund: *I would like to defend broad-acre farming systems. When I was in CSIRO, I worked with a sugar industry that was burning every bit of organic matter between crops. That industry has completely changed now to 'green-stick' farming—retaining all residues and building up the soil with organic matter. The CSIRO found a dramatic increase in the number and variety of earthworms in those soils. Further south there has been a revolution in cereal growing with the retention of stubble and direct drilling; again there has been a buildup of organic matter and biodiversity in the micro-organisms in the soil. We should not condemn monoculture if it is managed correctly.*

Q10. Sadanandan Nambiar: *My previous question was about food production as much as forestry. If you look at India's green revolution and the under-nutrition of many Indian people, it is not proven that this can be alleviated by going back to traditional knowledge and practice. This is a risk that we must be aware of. It is easy to regard modernisation as a form of colonial idealism. We need to be very cautious when assessing new-found virtues of traditional ways, and avoid any idea that modernisation is wrong.*

James Moody: This is all about progress, not moving backwards.

Q11. Jill Gready, Australian National University: *I will bring together a number of threads in this discussion and offer another perspective. Assumptions have been made in all the discussions that the social structure and the population distribution in developing countries in 2050 will be something like it is now. Without giving away too many of my esteemed sources, there was an article in the magazine of the Weekend Australian a couple of weeks ago that speculated that by 2050 most people in developing countries, as they became more prosperous, will have moved to the cities to create a much more urbanised world. This is happening in China now. With only a relatively small proportion of people in the countryside producing food, there may then be large areas of crop in monoculture or something similar. This seems very likely in areas of Asia, although Africa may be different.*

James Moody: I'm reminded of the comment that 2009 was the first year in which there were more people living in urban than in rural environments, and the projection of current trends is that the 50% will become 80% by 2050.

Q12. Tom Nicholas, Healthy Soils Australia: *Industrial agriculture as we have known it is dead. Innovative farmers are using biology and understanding of how plants and animals interact to drive holistic production systems that are environmentally sound and creating biodiversity. They are attaining high production of nutritionally dense, high quality food. We need only small amounts of nitrogen and phosphorus at the right place at the right time. We don't have to reinvent the wheel.*

Panel overview

James Moody: Panel, we have a whole range of issues from monoculture to urbanisation to the death of industrial agriculture and what we can learn from microbiology. I invite your comment.

Gabrielle Persley: I'll respond on the urbanisation of Africa. It's true the trend across many countries of Africa is of people moving to the cities. Regretfully they don't move because they're doing well, they move because they're poor, they can't get employment on farms and the productivity of the farms is too low to be able to support all the families. So there are two development issues:

First, how should we cope with the problem of the increasingly urbanised populations of large cities? If Hugh thinks of Brisbane as an urban desert landscape, he should visit Nairobi, where challenges include infrastructure, clean water and reliable power. Secondly, there is a variety of approaches to agricultural development across Africa. Over coming decades some countries, where there is sufficient land and fairly small rural populations, will develop broad-acre agriculture. Others—the majority—will seek to intensify crop and livestock systems by a combination of local knowledge and improved technology. We must be open to using all available knowledge, whether it is indigenous knowledge, GM technology or new ways to use microbial biodiversity.

Emile Frison: There is no point in keeping barriers between romantic traditional knowledge and industrial agriculture. Similarly the debate regarding GMO is often unnecessarily sterile. We have to make the best of all forms of knowledge, and especially go beyond the disciplinary borders that have had too much prominence in the past. We should marry agricultural science with ecology and other supporting knowledge from areas such as evolution and taxonomy.

James Moody: Meryl, your ideas around world food systems seem to have anticipated a lot of the questions that we just had.

Meryl Williams: I agree that all systems have a role. We need a large amount of industrial agriculture—whether we like it or not—because most people will be living in cities, as the lady from ANU pointed out. Also, fewer and fewer people anywhere in the world—even in developing countries—are now connected with agriculture. So there is a need for much greater reaching out and re-education. Many of us of the older generation here had parents or grandparents who were on the farm; some may even have come from the farm themselves—but these days most people, including a lot of politicians, don't have that connection within the memory of living relatives. The system is a complete mystery. So educating people about how food is produced in all of its ways is very important.

Just as we've had some defence of the extremes of both large-scale industrial operations and production based on traditional knowledge, urbanisation can be defended. It's not necessarily a terrible evil. It's one of the more efficient ways of coping with the large populations that we've got, and particularly with the ones we will have by the time population peaks. Waste treatment, health services and education can't be delivered to great numbers of people unless they are living close together. Urbanisation has to be done well and a lot of things have to be worked out, but it is not necessarily an evil. It has to be embraced positively because we really do need efficiency.

Unidentified panel member: The issue of urbanisation is not simple. You could be weakening the strong by moving people unless there are governance systems that ensure that new arrivals have jobs. People who are carrying machetes and hoes for farming would probably love to make more money by making toys sitting in Nairobi if they could, but that is not the case. They may move only to be dependent on others, with the result that the economy doesn't grow and people do not make more money.

Life abhors vacuums. For example, pastoral systems in arid lands are being destroyed not because the indigenous knowledge system has not worked but because it was not replaced by appropriate policies. People had animals that were productive and indigenous governance systems that were sustainable, but if those systems are dismantled without balances the entire environment may be destroyed and the result blamed, inappropriately, on failure of the indigenous systems. Likewise in small-holder systems, when changes are imposed without any extension system being in place to inform the people of correct culture and husbandry, there is no knowledge system to replace what they knew. People treat the farm as a mine, for example by removing all crop residues and manure. What do you expect? Yields decline instead of increasing. We need to be holistic rather than simplistic.

Hugh Possingham: If I was a politician or a senior bureaucrat, what would I want to know from these discussions? Is urbanisation good or bad, is intensive agriculture going to undermine agricultural productivity? I think it's going to be always around.

I'd want to know the consequence of policy decisions. At the moment we make full projections on economic issues to assist policy decisions. We may have good forward projections on things like food supply, but maybe not enough about food durability.

Who has seen a forward projection of the consequences of agriculture policy for biodiversity? There is only continual speculation.

All we know is that we are losing it at 1000 times the current background rate. Only a couple of people in CSIRO have actually made forward projections about biodiversity. That's why policy makers never care about it. Has anybody seen some forward projections about agricultural policy and human happiness? Until ecologists and biodiversity people and social scientists can build the models to make forward projections, they will not be at the table. This is a big challenge; the systems are complicated and the variables hard to measure. But ultimately the solution to the policy management puzzle is being able to build credible forward projections of things that are very difficult to understand and measure, above and beyond GDP that has driven global policy for far too long.

James Moody: That really points to both a multidisciplinary approach and also to the question that TJ posed: what are some positive views at the end of all this?

Cristián Samper: This will really be a closing comment. The emergence of agriculture marked one of the major transitions in human evolution. If it hadn't been for that development our society wouldn't be what it is today. Agriculture was a solution but now is also a huge part of the problem. We've seen the development of different kinds of extractive systems, production systems, on land and in the sea. We need to recognise virtues of both intensive agricultural systems and traditional systems. One size will definitely not fit all. We do need to explore trade-offs. Too many decisions have been narrowly based on just one or two parameters, omitting issues like ecosystem services and social dimensions. The world is not homogeneous; different societies have different values and different choices. We need to respect that.

Food security must be viewed in the context of human wellbeing. It is not only about having nutrition or food or health, it is also about empowering people to make the right choices and to give them the freedom of choice to do that, including of food production. This will start building those bridges across disciplines.

T.J. Higgins: I will finish by paraphrasing the anthropologist Richard Leakey when he said that 'you have to be well fed to be a conservationist'. My point today was that if the former can be provided the latter will follow. Food security has been our mantra, but it is clear from this conference that we need to extend that to say 'food security **and** ecological security' will build a resilient society over the next half century.

Emile Frison: The theme of this meeting is food security, but the real objective that we have in mind is to allow a healthy human development in all its dimensions, with health including broader wellbeing dimensions. This will require outreach beyond both sectoral and disciplinary boundaries.

James Moody: Hugh, you posed the question whether we can have our biodiversity and eat too. I would like to ask you that question.

Hugh Possingham: I think we can, but not the way the current policy world is structured. It's too antagonised by different sectoral interests. Part of the green movement pushes a very narrow line. Everybody's got to broaden out their understanding and to see the forward projections of different issues. We should all come from the same informed base; unfortunately at the moment we have lots of information about the economy and jobless rates, but we're not getting information about the consequences of decisions on biodiversity for human wellbeing. The Millennium Assessment attempted this, but it didn't make a ripple in Australia. Things done in 2005 have to be brought out, revisited and people have to be clear of the consequences. What were those forward projections? Until everybody is informed about these things various sectors just keep arguing about their narrow interests.

Unidentified panel member: The conceptual framework the Millennium Assessment was useful, but the real value was in the local assessments. So here is a challenge: have Australia do its own Millennium Assessment.

James Moody: Good idea. Meryl?

Meryl Williams: I think it's a very good idea. I wasn't in Australia at the time the Millennium Assessment came out. The extent of local attention would have been influenced by the number of Australians involved and their roles in the system, and whether they brought things to the attention of or got support from local agencies. It's a very good idea and if the IPBES process[1] gets going it will provide the next opportunity to do it.

I want to discuss how the diverse needs of different countries can be effectively addressed. ACIAR plans its work at the country level, offering knowledge and skills in selected areas of agricultural expertise in talks with national and local agency partners as to what their needs are. It then puts assistance packages together. The sets of projects for each country differ remarkably because each is based on what a country needs.

This is a process that addresses Cristián's concern for action at local and regional levels—levels at which things happen. At this meeting and at the other Crawford Fund conferences in the last few years we have been very well informed of the blockbuster global pictures that have come out from various assessment studies, and papers in *Science* and *Nature* and so. Sometimes the inevitable simplification in these broad accounts is not ideal: it can be too simple. For example, the marine one shown this morning [page 44 …] will be considerably changed next month when the Millennium Ecosystem Assessment puts its picture of marine biodiversity out. It is very useful to have work at both local and global levels.

[1] http://www.iucn.org/about/work/programmes/ecosystem_management/ipbes/

James Moody: I think ACIAR's approach has had huge impact. Gabrielle, you get the last word. What are some solutions?

Gabrielle Persley: Though we have a great deal of information and knowledge on the table, not much has been said about setting priorities and who will pay. A message to take out of this conference is that we need more work on what a global agenda might be in some areas. An example that is working fairly well and that has an international framework is the conservation of agricultural crop biodiversity. Some other areas such as livestock, fisheries and microbes don't have that sort of helpful international structure.

A second area is lessons learned about successful approaches to conserving biodiversity in specific countries. Switzerland springs to mind, where incentives are provided to farmers to actually conserve biodiversity in their local environment, with both cultural and economic results. As Meryl said, lessons from the local scale may come together to produce an overall strategy. This can make a more compelling case for both public- and private-sector investors who will actually contribute to conserve biodiversity.

James Moody: We've heard a lot of different thoughts on very complex issues. The intersection of biodiversity and agriculture reaches further I and many others had thought—it reaches into productivity health; food security, climate, environment, population, wellbeing, ecology and development, to name just a few.

Agricultural Biodiversity for Nutrition and Health

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The number of chronically hungry people currently hovers just below the one billion mark, according to FAO. That figure, however, hides an even greater problem. Roughly two billion people, most of them women and young children, suffer malnutrition associated with a lack of micronutrients and vitamins. Furthermore, so-called diseases of affluence, such as type-2 diabetes, cardiovascular disease, obesity and cancers are increasing most rapidly in developing countries. The underlying reason for both of these observations is that diets have become simpler. The prevailing highly medicalised view of micronutrient deficiency sees only supplements and biofortification as effective treatments. Neither approach, however, often does not reach the poorest sectors of society where they are most needed. Similarly, while developed country governments exhort citizens to eat a greater diversity of fruit and vegetables for their health, such policies do not appear to be common in developing countries. Agricultural biodiversity offers an alternative approach to malnutrition and health, with additional important benefits for productivity, environmental sustainability and human and economic development. Examples will be presented of research to make greater use of agricultural biodiversity to increase dietary diversity, often using local diversity and addressing agronomic, social, marketing and other constraints. Much current agricultural research for development is focused on increasing major nutrients, such as protein and carbohydrate, at the expense of micronutrients. It will be argued that better nutrition and health would be just one outcome of more research into the wider use of agricultural biodiversity.

EMILE FRISON is Director General of Bioversity International, the world's largest international research organisation dedicated solely to the conservation and use of agricultural biodiversity. He has spent most of his career in international agricultural research for development, starting at the International Institute for Tropical Agriculture (IITA) in Nigeria in 1979. A plant pathologist by training, Dr Frison recently lead Bioversity, its stakeholders and partners in the formulation of a new strategic vision in which nutrition and agricultural biodiversity will play an important role in the overall goal of reducing hunger and poverty in a sustainable manner. He also leads the CGIAR system-wide Genetic Resources Programme and is a member of the CGIAR Genetic Resources Policy Committee, and of the Board of Directors of Ecoagriculture Partners.

Introduction

True food security is more than just calories and protein, the *quantity* of food produced. It is also about *quality*. People must have access to a diverse, balanced and preferred diet that includes adequate micronutrients and other essential components if they are to be considered food and nutrition secure.

These missing micronutrients constitute the problem of hidden hunger, which is still not sufficiently on the radar when talking about food security, and which affects roughly one person out of three. More than two billion people, mostly women and young children, suffer from various micronutrient deficiencies, which is not only directly debilitating but which also undermines the full development of the next generation. About 60% of child deaths worldwide are linked to poor nutrition, and the impact of poor childhood nutrition is felt throughout peoples' lives and in the offspring of undernourished mothers.

There is another side to malnutrition, which results in a situation that is often described as the double burden of malnutrition. This is the rapid growth in non-communicable diseases such as type-2 diabetes, obesity, cancers and cardiovascular diseases. These used to be referred to as diseases of affluence but increasingly they are affecting mostly poor people in developing countries; 80% of deaths associated with chronic ill-health and disease occur today in low- or middle-income countries and not in the industrialised countries. In the western Pacific, 70% of deaths are now caused by non-communicable diseases, which have overtaken by far all the infectious diseases combined. In Kiribati, for example, the rate of obesity in the population increased four-fold between 1981 and 2006, the latest date for which data are available.[1] More than four out of five adults in the population are overweight. The problems are not restricted to the present generation, as both underweight and overweight mothers have children that are themselves predisposed to nutritional and health of various kinds. Underweight children, for example, not only have problems in development; they may in turn, given access to sufficient food, tend to become overweight when they themselves are adults. (See, for example, Delisle 2008) The effect of poor nutrition thus transcends the generations.

Overall, the root causes of malnutrition—manifested both as underweight and overweight—are linked to what has been called the nutrition transition, a shift from diverse and nutritionally-complex diets to simplified diets based on a narrow range of foods that have often been treated to some sort of industrial processing. Almost everywhere around the world, the number of different food species that are used in diets, especially of the poorest people, has been greatly reduced: they eat the cheapest food available (Hawkes 2006).

Biodiversity provides options

How can we address this issue? In the original strategies for tackling micronutrient deficiencies the World Health Organization and other actors in the nutrition community stressed that a food-based approach using more diverse diets was the long-term sustainable solution. More recently the dominant approaches have been more medically oriented, based on delivering specific nutrients through supplements or biofortified staples, but it is becoming clear that the pendulum is now starting to swing back to diversity in the diet (Mozaffarian and Ludwig 2010). The use of diversified agriculture to deliver those diverse diets also has other benefits and it is important to keep in mind that besides providing opportunities for better nutrition and health, agriculture based on greater diversity can provide greater resilience, adaptability and stability in production. In addition, of course, it provides opportunities for income generation (Frison *et al.* 2006; Johns and Eyzaguirre 2006).

Agricultural biodiversity refers to various levels that matter to farmers. Farmers use different ecosystems and different species of plants, animals and fish. In addition to these two levels of diversity, the organisms themselves have genetic diversity that is reflected in different varieties and breeds and in the differences among individuals within populations. Furthermore, agricultural biodiversity refers not only to species that are directly used for production but also to those species that support production in the agro-ecosystem, like soil microbes and pollinating insects.

Poor food, good food, successful projects

There are many examples of the increased consumption of oils, fats and refined sugars over the past few decades (Beare-Rogers *et al.* 1998). In Senegal, for instance, the energy derived from fats and oils in the diet increased 2.5 times over a period of 25 years. Worldwide there has been a reduction in use of and access to traditional and indigenous food. Many poor people, for example in Africa, used to rely to a large extent for their micronutrients and vitamins on small quantities of food harvested from the wild. This contribution has become less significant especially as people move into the cities. The cheapest food available in urban areas is usually a form of processed major cereal, sometimes brought into countries as food aid, and often fried with sugar or salt; this food is energy rich but nutrient poor. It satisfies immediate hunger, while the impact of poor nutrition is delayed. In addition social pressures, including images of backwardness associated with traditional food, have been significant. All these various factors and others have to be tackled simultaneously in efforts to use dietary diversity to tackle malnutrition.

[1] These and other statistics are derived from the World Health Organization's Global InfoBase, http://www.who.int/ncd_surveillance/infobase/en/

Bioversity implemented a project in Kenya, in cooperation with Family Concern (an NGO) and Uchumi Supermarkets, to reintroduce traditional African green leafy vegetables (Gotor and Irungu 2010). Traditionally, Kenyans ate more than 200 different species of traditional leafy vegetables, and these may have 10 or even 100 times more micronutrients, such as iron, calcium and beta-carotene, than the cabbage and kale available in Nairobi markets. By improving seed supply (training farmers to specialise in seed production) and agronomy, training producers to present cleaner, high-quality produce, and consumer education (with leaflets and public events), sales increased from 30 to 400 tons per month over three years and incomes of producers rose 2–20-fold. Demand in the city now far exceeds supply and further opportunities remain.

Small-holder farmers in Africa cannot live on the produce of half a hectare if they focus on a stable crop like rice or maize or even a root crop. Bioversity is now following up the impact of the Kenyan project by comparing data from villages where production and consumption have been promoted by several different kinds of intervention with those from similar villages where there have been no interventions. An obvious early observation was that during the serious Kenyan drought of 2008 and 2009, when the maize crop failed almost completely in that part of the country, farmers growing these vegetables were better off than those that were not (P. Maundu, *pers. comm.* 2010). The study also includes assessments of peoples' health, and there are preliminary indications of lower levels of anaemia in the populations that are producing and consuming traditional African leafy vegetables.

To further popularise these traditional foods, the project has been working with chefs of the most famous restaurants in Nairobi to prepare new recipes, and the vegetables have been served in the canteen of Kenya's parliament. In a clear indications that changes in attitude and behaviour can be achieved, people have begun to take pride in their traditional food systems, instead of shunning them as backward and primitive. We should not accept that we cannot do anything about food preferences: education and improved choice make it possible to really change food habits.

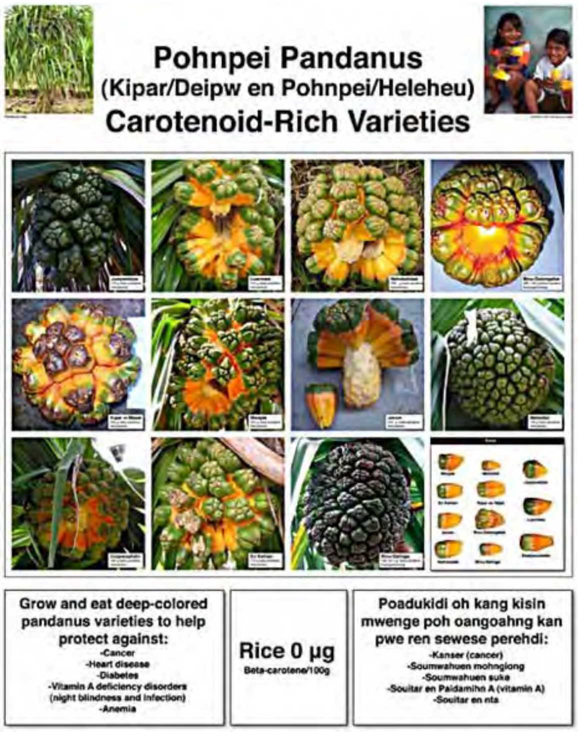
Of course African leafy vegetables are not transposable everywhere in the world, and that is not the intention of such research. However, the approaches and methodology are transposable, and these are a global public good. Bioversity has undertaken similar research with small millets in southern India with the M.S. Swaminathan Research Foundation (Bala Ravi *et al.* 2010; Shanthakumar *et al.* 2010; Vijayalakshmi *et al*. 2010; Yenagi *et al*. 2010) and with Andean grains such as amaranth and quinoa in Bolivia, with the farmers' group called PROINPA (Rojas *et al.* 2009.) In both, as in Africa, the projects work along the whole chain from production to transformation to consumption, involving local entrepreneurs to add value and making use of species that are well adapted to the environment in which they are grown.

Action in the Pacific

The Pacific is a high priority for the donor agencies in Australia. Some projects in this region have already started to look at local diversity and the contribution it can make to addressing vitamin deficiencies. (See, for example, Englberger *et al*. 2005). Vitamin A is particularly important, and in Pohnpei (one of the four states in the Federated States of Micronesia) the use of some varieties of pandanus, which are rich in beta-carotene, has been encouraged in order to provide necessary supplies of pro-vitamin A (Fig. 1). Several Pacific varieties of banana also have very high levels of this compound—a variety called Karat has a higher level of beta-carotene than the yellow-fleshed sweet potato that is often advertised (Englberger *et al.* 2006). This research, too, has global implications. For example plantains, or cooking bananas, are a major staple in Cameroon and elsewhere in West Africa. Bioversity and partners have been scouring collections of plantain diversity in search of high beta-carotene varieties in the preliminary steps of a project that will work to lessen vitamin A deficiency there (Davey *et al.* 2009).

Action in Russia

Bioversity is also working with colleagues in Russia and Luxembourg on the Pavlovsk collection of more than 5700 different fruit varieties. The collection dates back to 1926, when the great Russian plant explorer and scientist Nikolai Vavilov was one of the most important and influential scientists in the Soviet Union. Recently, the collection at Pavlovsk has been threatened by housing developers who would like to send in the bulldozers to take out the entire collection. Our



Children need about 600 µg β-carotene per day; adults need about 800 µg per day; more if breastfeeding

Pandanus fruit:

- four species; more than 180 varieties
- 14–1000 µg β-carotene per 100 g fruit

Figure 1. Some pandanus are a rich source of pro-vitamin A

collaborative project is analysing the nutritional properties of some of the fruits and vegetables in the Vavilov Research Institute's collection. The research is intended to inform a food-based approach to problems of malnutrition, taking a broad approach while at the same time focussing on local biodiversity so that when appropriate species or varieties may be introduced from other areas. This holds most promise for sustainably addressing the problem. And while the project began before the current threat to the collection materialised, the preliminary results, showing very high levels of anti-oxidants in some varieties, underscore the need to preserve such collections for their long-term value.

Conclusion

As mentioned earlier, the first strategies proposed by global advocates to respond to malnutrition focused on the dietary diversity encompassed in food-based approaches, although these were subsequently overtaken by more simplistic and inherently unsustainable solutions that focused on supplying individual specific micronutrients that were lacking. Increasingly of late the nutrition community is once again recognising the need to move back to a food-based approach. Bioversity's key objectives and contribution to this effort are to enhance food and nutrition security and thereby the health and livelihoods of poor people, ensuring traditional resiliency of food and ecosystems by using a broader range of diversity.

There is plenty of evidence, much of it anecdotal in nature, that this is the right approach. At Bioversity we have been building a broad range of partnerships that include researchers at national and international levels, and governments and government agencies, bringing agricultural and health departments together. We are building a solid base of evidence, and demonstrations of what really works on the ground, to inform policy-makers and convince large investors like the World Bank to support this food-based approach to malnutrition. In the end it is as important to obtain policy changes at the national level as it is to create the conditions and knowledge that will permit farmers and their customers to enjoy all the many benefits of the more diverse diets that agricultural diversity can deliver.

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The Importance of Biological Collections for Biosecurity and Biodiversity

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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.

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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 vale) 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 pathways 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, Chariton 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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Sir John Crawford Memorial Address

Plant Diversity at the Turning Point

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The world aspires to sustainable healthy living for all. This ambition is challenged by accelerating global change, fuelled directly by entrenched patterns of land and water use and loss of biodiversity, combined with rising consumption and ongoing population growth. We can and must improve levels of agricultural productivity to feed the world. At the same time, the hope of a continuing 'green revolution' as future salvation focussed on a few mainstream crops seems increasingly unlikely without new land and water ethics, economics, and political and financial systems that value social and natural capital as much as present systems focus on financial goals. We are at a global turning point, comparable to that when slavery was abolished. Plant diversity has never been more important than now to help with solutions towards sustainable livelihoods. This presentation will touch upon global plant diversity patterns, ongoing scientific discovery, and strategies that have helped and will help towards humans living with and sustainably using biodiversity.

Professor Steve Hopper is a conservation biologist and the 14th Director of the Royal Botanic Gardens, Kew. He holds Visiting Professorships at the University of Reading, The University of Western Australia and at Kings Park and Botanic Garden in Perth, and is a Fellow of the Linnean Society and a Corresponding Member of the Botanical Society of America. He was awarded the Nancy T. Burbidge Memorial Medal from the Australian Systematic Botany Society in 2008 and an honorary Doctor of Science degree from the University of Western Australia in 2010. He has led the development of a collaborative forward 10 Year Breathing Planet Programme for Kew and its global partners that seeks plant diversity solutions towards sustainable living and a reasonable quality of life.

Introduction

It's been my pleasure and privilege to be the director of the Royal Botanic Gardens, Kew for four years, the first non-British-born person to hold that post. Some might say that Kew's Trustees took a bit of a risk in appointing a foreign national to the job. But we do live in a global village—every city, every country, the world has changed dramatically from when I was a university student just 30 years ago. And I hope that applying new international thinking to old vibrant organisations in rapidly changing times can be beneficial.

In this context, I would like to put some propositions to you to provoke thought that I hope will be of benefit to the theme of the conference.

Firstly, I propose that global change is evident, including global warming and the loss of biodiversity, associated with and accelerated by human action—especially unsustainable use of land and water on parts of the planet.

Secondly, we are at a turning point—at no other point in history has plant diversity been more important to people than this time.

Thirdly, it is a time to rethink. We have to deliver on a new relationship between plants and people and this will involve, in part at least, scaling up plant diversity science and using plants sustainably across mainstream human livelihoods.

Fourthly, the next decade is critical. You only have to read the literature on global warming—Lord Stern's (2006) report on the economics of climate change—to understand that no longer can we think bad things are going to happen three, four or five decades away. It's real, it's with us now and it's our responsibility to take action, not in a rushed or unthinking way, but in a measured way and with a sense of urgency.

Lastly there is a message of hope. None of the things we have to do in order to pull through the challenges the world faces are particularly new. Many of them are already being done or have been done before. But can we achieve sustainable living and livelihoods and an adequate quality of life for humanity, in a reasonably timely fashion for most people on the planet? That question obviously goes into the arenas of economics, of politics, of finance—beyond any insights I can give you as a biologist—but the ultimate take-home message is 'we are all in this together', and new partnerships and new ways of collaborating are essential. What I can offer as a practicing conservation biologist are some insights on the issues of importance if we are to live sustainably with biodiversity in the future, conserving nature's riches and better integrating their use into human livelihoods.

A definition of conservation that I find most useful focuses on intergenerational dialogue and benefit:

'conservation is … about negotiating the transition from past to future in such a way as to secure the transfer of maximum significance' (Holland and Rawles, cited in O'Neill and Holland 2000).

The authors are landscape architects who published a paper in a book dedicated to the opening of the National Botanical Gardens in Wales in 2000. The big point of debate is what is of maximum significance. Groucho Marx had an alternative view; he said, 'Why should I care about future generations? What did they ever do for me!' (http://www.grinningplanet.com/environmental-quotes/funny-environmental-quotes.htm).

Many a true word is spoken in jest. Many people may well support Groucho rather than the landscape architects. The big question for this conference is, 'Is plant diversity of significance and is it worth transferring to the future?'. The global issue in simple terms is this: while there are many examples of sustainable long-term human use of land and water, without question the practice of inappropriate human use of land and water is really why we are here tonight. This leads to environmental changes for the worse; it causes the decline of biodiversity including plant diversity. It forces people into a declining quality of life and the circle is complete (Fig. 1). People are placed in desperate circumstances where ultimately they have no choice but to continue or worsen inappropriate forms of land use and water use. The under-appreciated bit in this cycle is plant diversity.

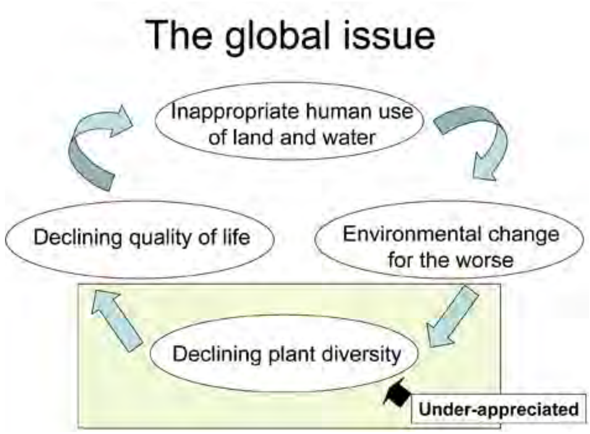

Figure 1. The global environmental issue, leading to a downward spiral towards loss of diversity and increased poverty

Reservoirs of diversity

In 2000 Norman Myers and colleagues, in a paper in *Nature*, asked the question 'Where on the planet are plant and bird species that are most threatened and most endemic (that is, confined to a region and found nowhere else, and therefore under threat) concentrated' (Myers *et al*. 2000). They identified 25 areas, but some that you might think should feature in this list didn't get mentioned—the major tropical areas, of South America including the Amazon basin, tropical Africa and Papua New Guinea and the like, simply because population density is lower in these areas (Cincotta *et al*. 2000). The degree of endemism of the plants and birds is lower and the degree of threat therefore was judged to be less than, for example, the Brazilian Cerrado, adjacent to the Amazon Basin, or parts of Australia, the south-west in particular (Hopper and Gioia 2004), and islands adjacent to Papua New Guinea.

Another global analysis identified areas where the authors judged unsustainable pastoralism and agriculture are most pronounced in crisis ecoregions (Hoekstra *et al.* 2005). Areas in Australia were recognised: the main wheat-growing regions in Victoria, New South Wales, South Australia and Western Australia.

Climate and carbon

Global warming is beyond reasonable doubt. It's ironic that while the US Congress recently voted down any move for climate change legislation, its own government scientists reported on the parlous state of the global climate (Arndt *et al*. 2010). This scientific report identified ten attributes, seven of which you would predict would go up if the planet was warming and three to go down. All ten, as modelled, conformed to the predictions in 2009.

At Kew Gardens I see evidence of plant responses to global warming every day and there's a rather interesting attribute that perhaps isn't so well known, revealed by a NASA global temperature graph (http://data.giss.nasa.gov/gistemp/graphs/) that shows separately the global temperature trends for land in the Northern and Southern Hemispheres. Warming is not as pronounced in the Southern as in the Northern Hemisphere; this difference may be influencing peoples' attitudes towards global warming. When I arrived in the UK four years ago, the major political parties were doing everything to out-green each other, arguing that they would take the best possible action against global warming. I note, however, that this issue was scarcely mentioned in the recent election of 2010. Similarly, in the recent Australian federal election, the same applied, and the little media attention there was gave as much coverage to human-induced climate change denial as it did to mainstream scientific evidence on this vital subject.

The really big question is, what's going to happen in the next decade? Recent evidence relating to climate change (e.g. van Vuuren and Riahi 2008; Velicogna 2009; Kennedy and Parker 2010; Nicholls and Cazenave 2010; Overpeck and Udall 2010; Raupach *et al.* 2010; http://www.aip.org/history/climate/xmillenia.htm) indicates that we are tracking above the line for the worst-case scenario on projected global warming put forward by the IPCC (2007). We are at higher temperatures and other indicators of global change than predicted in the worst-case scenario (Rahmstorf *et al*. 2007; Füssel 2009; Smith *et al.* 2009; Trenberth and Fasullo 2010)—a situation that the ANU's Professor Will Steffen encapsulated in a recent lecture in Sydney as 'faster change and more serious risks' (cf. Steffen *et al*. 2009). That to me is a real alarm bell, and it provokes my suggestion to you that the next decade is going to be critical. If we don't take action reasonably soon any responses in the succeeding decade will be much harder and much more costly (Stern 2006). Lord Stern concluded that if we delay two or three decades our attempts to slow down global warming, to get carbon emissions back to present day levels or lower, and to pay for damage caused by accelerating global change, will be economically challenging indeed.

Where is the carbon on the planet? Global terrestrial carbon stocks in protected lands, in national parks, nature reserves, state forests, etc. are compared with those in other forms of land ownership in Figure 2. Most of the carbon stocks are not protected in a way in which you would feel confident that we are looking after what remains of wild plant diversity, wild forest, nor after those that are planted for production purposes as well.

Counterbalances include emergence of carbon trading markets and an unprecedented recognition of the importance of plant diversity, most recently reinforced at the Convention on Biological Diversity's 10th Conference of Parties in Nagoya, Japan (Nayar 2010). Plants have a vital role in producing the oxygen that we breathe. We seek shelter and we maintain our health with the help of plants. Plants help us to get the water and food we need, and to manipulate our habitat in all sorts of ways. We have a tremendous focus on gardening and on other social and cultural activities that involve plants. Plants are obviously helping us mitigate global change, if in no other way but by accumulating carbon and removing it from the atmosphere.

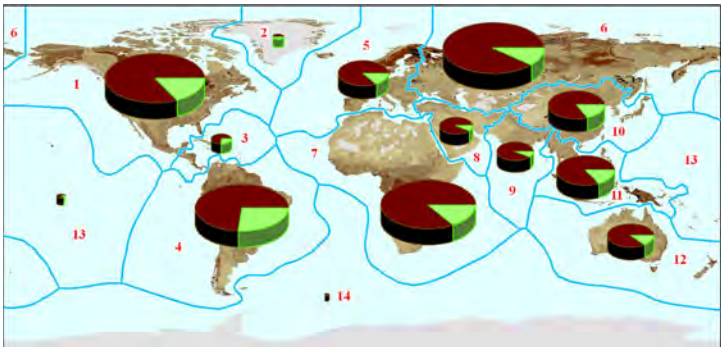

Figure 2. There is no protection for 85% of carbon on land. Carbon stock in terrestrial regions: total (*proportional pie-charts*), and stored within the protected areas network (pale green segments). Source: Campbell *et al.* 2008.

Sustaining irreplaceable resources

We are ambivalent to world plant diversity. We create and destroy; we socialise and annihilate; we love and hate; we celebrate and mourn. We behave in contrary ways to each other and towards the environment. We have some redeeming features; we also have many features that we would be less then proud of if we reflected on it for too long.

The big question for Australia is, how sustainable is our present way of life? There is some evidence of good sustainable practice in the nation, but also of major damage to the environment and society because of some mainstream approaches to use of land and water (e.g. Beeton *et al.* 2006; Gibbs 2009). A fundamental question that politicians in particular have to grapple with is, what are the critical environmental thresholds above which we shouldn't transgress? I am reminded of Goyder's Line in South Australia (Meinig 1961; Sheldrick 2005) as an example of good political decision-making that ultimately said, 'farming had gone too far': so far into arid land that it couldn't lead to sustainable agriculture, and human misery would be the primary outcome if farming pushed beyond the Line.

Many biologists—perhaps most—believe an extinction crisis fuelled by land-use conflict is looming. Recent scientifically-evidenced estimates of the fraction of plants and vertebrates under threat globally are at 20% and rising (Brummitt *et al.* 2010; Hoffmann *et al.* 2010). Deforestation, agriculture and urban expansion, mainly in tropical landscapes, underpin the heart of this decline in biodiversity. It is heartening and humbling to know that 80% of the plant food we consume globally is provided by just 12 species of plants—the cereals barley, maize, millet, rice, rye, sorghum, sugar cane and wheat, and tubers cassava, potato, sweet potato and yam (Grivetti and Ogle 2000). Yet we know that there are at least 7000 edible and partly domesticated plants (Williams and Haq 2002) and an estimated 30 000–75 000 edible wild species of plants on the planet (Myers 1997; McNeely and Schutyser 2003). Traditional western farming has expanded agriculture by moving into land occupied by biodiversity, bulldozing the wild vegetation and burning it to grow the main-stream crops. Some of the plant, animal and microbial diversity we were bulldozing and continue to bulldoze and burn may be part of our salvation in a rapidly changing world.

Perhaps it would be useful to highlight examples of the wild edible plants that I know well, from south-western Australia. The Noongar Aboriginals there have four staples producing carbohydrates (Fig. 3):

- Youlk, *Platysace deflexa*, which has a large, sweet, potato-like tuber, and is being trialled now for agricultural crop production. It is in the same family as the carrots (Woodall *et al.* 2009)

Figure 3. Noongar Aboriginal carbohydrate staples from south-western Australia. Photos: youlk—G.S. Woodall; warrine and yanjit—S.D. Hopper; mean—K.W. Dixon

- Yanjit, *Typha* bullrushes, consumed right across Australia by Aboriginal people
- Warrine, *Dioscorea hastifolia*, an edible native yam
- Mean (pronounced mee-an), *Haemodorum spicatum*, the bush onion in the kangaroo paw family. It's full of oxalic acid and rather hot to the taste, but was a major staple for the Meananger or Mineng people centred around Albany (Woodall *et al*. 2009).

We often lose sight of the fact that hundreds of millions of people rely on wild or under-utilised plants such as these as supplements to a diet made up largely of the 12 mainstream crops. If we continue to move into increasingly marginal agricultural land and reduce the populations of these wild or under-utilised crops, we reduce significantly many peoples' risk management options, when the mainstream crop fails, and starvation is the result. We surely have to find a balance now, deciding how much land is left for biodiversity, how much land is restored and repaired for biodiversity, and focus our attention on the land that is very productive and sustainably farmed with mainstream crops to feed the population of the future and of today.

A fifth of global carbon emissions are still caused by deforestation and burning—more than are caused by the world's transport system (Fig. 4). Globally we are still hooked on the notion of expanding into new lands, more and more marginal, through bulldozing and burning. When will the clearing of wild vegetation stop? When will we devise ways of getting the best out of the agriculturally productive land and getting the best out of the marginal lands that are rich in biodiversity? A paradigm shift is required.

Accelerating scientific research and problem-solving

We also have an extraordinary learning curve. Up-scaling the science of climate change and biodiversity is absolutely essential. Apart from understanding implications of ongoing clearing, biodiversity inventory is significantly incomplete. Even less is known about the influence of climate on biodiversity, and our biodiversity predictive tools are embryonic. The fossil record does indicate very clearly that turnover of biodiversity has happened in the past—so why don't we just let it continue to happen now? The fundamental fact is that the rate of turnover, of extinction, has accelerated by orders of magnitude with human impact on the environment, and we have some responsibility to deal with the consequences for biodiversity because of the acceleration. Those consequences are already evident.

At Kew Gardens, I see examples of the consequences every day. London is going through some of its coldest winters and its driest summers in decades; select plants in Kew are stressed out, some have died. Geographical range changes are documented for butterflies and moths in the UK (Conrad *et al*. 2006; Menendez *et al*. 2006), and for many birds (e.g. Araújo and Rahbek 2006). Dates of flowering season are changing (Robbirt *et al*. 2010): we have a record going back 60 years of the date of first flowering of a hundred of the plants in Kew Gardens; on average they've moved forward two weeks over that 60-year period (Pain 2000; Hepper 2003). There are new invasives. Oak processionary moth—*Thaumetopoea processionea*—is now a potential cause of human health problems (Gottschling and Meyer 2006**)** and significant devastation to oaks in west London. It is a Mediterranean moth whose caterpillars have hairs that in the worst cases cause anaphylactic shock in people. And there are new diseases as well.

An extinction cascade is forecast—so where is biodiversity richest? Not only in the tropics; a real surprise has been the floristically rich regions of mediterranean climate around the world including that in Australia (Hopper and Gioia 2004).

Do we know what's out there in terms of biodi-

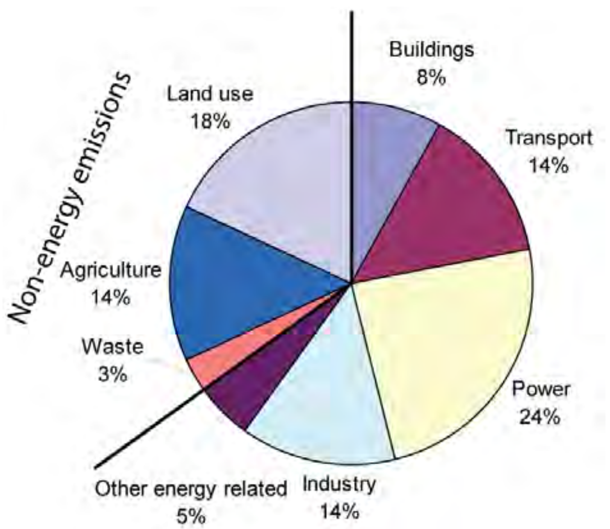

Figure 4. A fifth of carbon emissions is due to ongoing deforestation ('land use', lilac); total emissions in 2000 were 42 Gt CO_2e (Stern 2006). Crown Copyright 2006.

versity? Perhaps for birds, for mammals a little less so, as we get more sophisticated in our application of DNA. In the case of plants we still don't know how many plant species there are on the planet; we are naming about 2000 new species of plants each year and another 2000 are reclassified, largely due to DNA sequence analysis (Fig. 5). An example from 1994 was the Australian wollemi pine *Wollemia nobilis*. An extraordinary case, the pineosaur as it is now called was discovered alive in a small gully just north-west of Sydney, but known from similar fossils of Cretaceous age more than 70 million years old. It has been able to easily grow this year through the worst winter that London has had for some time, with four snows (Fig. 6). It's just one example of the tolerance of plants to climatic change. We should not assume that the present distributional range reflects the future distributional range of organisms at all; there is evolutionary history and individual tolerance and plasticity to climatic extremes to take account of.

DNA sequencing is exciting the biological world and introducing new rigour into our understanding of biodiversity. Through collaboration between Kew, Missouri Botanical Gardens, New York Botanical Garden and some other leading gardens, by the end of this year we will have the first global check list of plant species since Linneaus published his list of an estimated 5000 species of plants in 1753, but new species are being described all the time. They range from the smallest of little annuals to rainforest trees 40 metres high and examples like the wollemi pine.

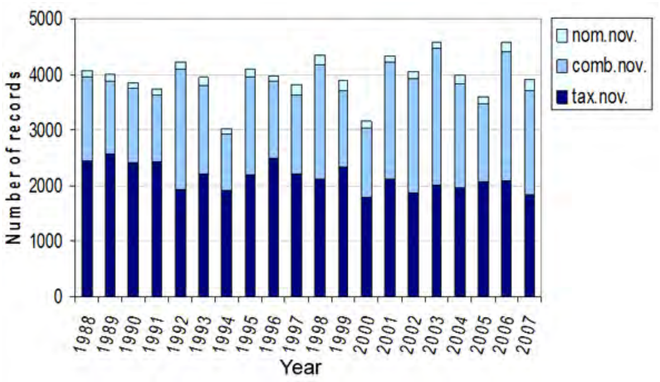

Figure 5. Ongoing taxonomic synthesis—over 2000 new vascular plant species are described per annum globally ('tax nov' above) and another 2000 reclassified. Data from Index Kewensis and International Plant Name Index, Royal Botanic Gardens Kew: www.ipni.org/stats.html.

Figure 6. The wollemi pine (*Wollemia nobilis*) discovered in a sheltered deep canyon in warm temperate rainforest north-west of Sydney in 1994. This plant is growing at the Royal Botanic Gardens, Kew, London, in light snow in 2009, demonstrating the plasticity of some plants in the face of climate change, and the need for caution in inferring future distributions based on present occurrence. Photo: S.D. Hopper

Food and environmental security

Why does this all matter? Food security is the obvious example of why it is important; coffee provides a case study. An expert working at Kew on coffee, Dr Aaron Davies, heads up a team of international collaborators who are still finding new species directly related to commercial coffee. At least 25 million farming families worldwide are dependent on coffee production. A dozen or more new species of coffee were described in 2008, including one discovered in Madagascar (*Coffea ambongensis*) with a 'bean' several times heavier than the arabica bean (Davis and Rakotonasolo 2008). Despite their importance as crop wild relatives, 70% of coffee species are in danger of extinction due to habitat loss and climate change.

The mongongo nut (*Schinziophyton rautanenii*) that occurs in semi-arid sub-Saharan Africa is another example. It's quite a beautiful nut to eat—highly nutritious; a dietary staple these days still of the San bushmen in the Kalahari, and with little need for irrigation or fertiliser. Unfortunately people have destroyed the wild habitat of the mongongo nut in Mozambique and planted orchards of cashew, mango and citrus that need both irrigation and fertiliser and largely serve a volatile export market. Many such farms (machambas) have been abandoned, but some hopeful work is underway on restoring farms in miombo wood-land for poverty alleviation using a better informed mix of crops (Palmer and Silber 2009). So, in relation to mongongo, this is an example of a tree traditionally used to supplement commercial crops in bad seasons and who's habitat is slowly being eroded. Now people are interested in growing the tree, but it has been difficult to germinate until scientists at the Millennium Seed Bank at Kew focused on the question—we can now achieve 80% germination routinely.

Mangroves provide another example of the need to have a good understanding of biodiversity—one of the few cases published in the scientific literature of a significant failure of international aid and poor communication between biologists and people implementing a biodiversity restoration program. In a 20-year project in the Philippines, 44 000 hectares of mangrove habitat was planted up with 440 million propagules of mangrove at a cost US$17.6 million—but up to 90% of the seedlings died (Samson and Rollon 2008). This failure was simply because the people who were planting hadn't been trained to identify different species of mangroves: they were putting mangroves that usually grow in seagrass beds into mud flats and vice versa. As we move towards more integration of mainstream and minor crops, the necessity for good taxonomy, good field identification aids and good technical knowledge will accelerate enormously.

Another example: in the wheat belt and gold fields of Western Australia, people had observed for a hundred years that the salmon gum (*Eucalyptus salmonophloia*), the biggest tree, seemed to grow on the most fertile productive land but also on the edge of salt lakes. Over the past century, more and more salt has been coming to the surface of soils in that region, and it is estimated that 30% of the productive land will become useless unless we can rectify the rising ground water (Caccetta *et al*. 2010). Salmon gums were planted in salinising land—but they just died. A colleague and I discovered in the 1980s, however, that there are two species of salmon gum, with quite different juvenile leaves: one is tolerant of salt and now called the salt salmon gum (*Eucalyptus salicola*), and the other is the normal salmon gum (*E. salmonophloia*—Brooker 1988). This is another example where rehabilitation efforts have been hindered until enhanced by good systematics (van der Moezel *et al.* 1991). Water management is an issue that's going to be globally even more significant in the future; we can't afford failed projects.

Why does biodiversity matter? I'm a biologist; I just love the bush and getting out and observing plants, animals and landscapes, and working with people in the countryside. I never under-estimate emotional attachment to the landscape and biodiversity as a motivator for people. If they really enjoy the pleasures of what the bush offers, they'll do extraordinary things, economically irrational things. I've emphasised the importance of plants, and the urgency of according them more attention. There is also a fundamental values issue that is the human condition 'writ large'. Gandhi said the 'Earth provides enough to satisfy every man's need, but not every man's greed.' That is a fundamental dilemma that we all face. Each and every one of us in our daily lives will need to adjust our expectations and some environmentally unsustainable behaviours into the future. Most importantly of all we must give hope, in particular, to young people.

Plans at Kew

I want to describe what we've been thinking about at Kew; how we might change our business. Lord Stern made the proposition in 2006 that no walk of life, no line of business could be business-as-usual if we are to deal with the global problems we face. That's a significant challenge. We took it seriously in relation to the botanic gardens community, and have developed a forward ten-year programme at Kew based around seven strategies (Fig. 7).

The first three are about retaining the earth's major remaining wild biodiversity:

- We are focused on accelerating the rate of scientific discovery, description and communication about the identification of plants and fungi. This has to happen if we are to take the urgency seriously.
- We can apply the wonders of geographical information systems, of new computer technologies, to map plant diversity and help work out where the priority areas on the planet are most in need of attention.
- And we can work with partners who are of a mind to achieve better conservation on the ground by setting up new protected areas, and through integrated farming approaches that inject biodiversity into farming.

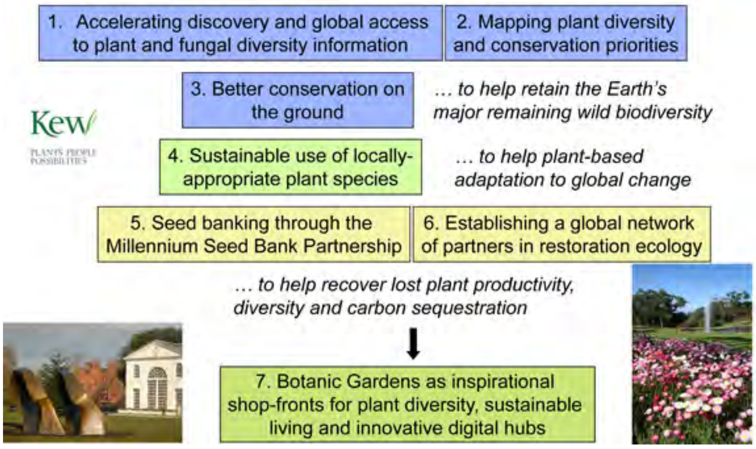

Figure 7. How botanic gardens might make a step change in scientific plant-based solutions to global environmental challenges: Kew's Breathing Planet Programme with global partners. Photos of RBG Kew, London, and Kings Park and Botanic Garden, Perth: S.D. Hopper

Then:

- We have to make greater informed use of 'locally appropriate' plant species. We are in a world of globalisation where the tendency has been to focus on the major crop species and a limited range of diversity for food production. In some places it's the best thing you can do, in other places it's the worst possible thing you could do. A sense of place is absolutely important, there is no 'one size fits all'. Agricultural scientists worked that out a long time ago. You have to tailor human endeavour, food production and living to local circumstances and use local biodiversity where and when appropriate; plants can assist adaptation to global change if we use them sustainably and intelligently.
- Seed banking is a fundamental strategy; the Millennium Seed Bank, an initiative of Kew in the year 2000, now has 54 countries as partners with 100 organisations. It achieved its objective in October last year of securing, in the country of origin and backed up by an extra collection in the Millennium Seed Bank south of London, 10% of the world's wild plant species, on time and below budget. Sir David Attenborough has described this as an ambitious and successful global conservation program. Seed banking is a fundamental, critical insurance policy.
- If we are going to put biodiversity back into some landscapes, or to grow new crops as climate changes, we have to have the germplasm well stored in international standard facilities and dispersed to the people who really need it and who have the right technical information. Australia has a challenge with agricultural germplasm, but Australia has been one of the major participants in the Millennium Seed Bank. Every state and territory now has a seed bank for wild plant species with well-trained staff and perhaps there's scope for collaboration between the agricultural and biodiversity sectors.
- Establishing a global network of partners in restoration ecology to facilitate the use of seed banks and other botanic garden resources in the urgent repair and re-establishment of damaged native vegetation.
- And finally a challenge for botanic gardens is to use their unique opportunity as mainly urban visitor attractions to convey some of the positive things each of us can do to help deliver a more sustainable future. Botanic gardens throughout the world, under the auspices of the Global Strategy for Plant Conservation (UNEP 2002), are applying a similar approach, tailored to local circumstances (e.g. Council of Heads of Australian Botanic Gardens 2008).

I want to leave with you messages of hope. Sustainable cities can be designed and maintained. Clean skies are something we enjoy. A hundred years ago any photo of London skies would have been fundamentally different to those today, and the same applies to many cities. Botanic gardens around the world are gardens of hope. If they have the right policy and the right public support they can achieve an enormous amount, as has happened already with the Millennium Seed Bank Partnership, and we are motivated to play our part in that regard. Seed banking, seeds of hope, are fundamental; there is an exciting nexus looming between mainstream agricultural crop seed banks and biodiversity seed banks because of the emerging priority of wild relatives of crops.

South Korea last year pledged $38.1 billion towards a major green program generating a million jobs including river cleaning, dealing with water shortages and reforestation. The Guiana government has formed a partnership with the Norwegian government to protect rainforests under a deal that will reward the Guianan government according to the carbon credits it accumulates. Guiana had gone out to the market-place and asked if anybody in the world wanted to support it in moving people who are destroying rainforests—because it's the only livelihood they have had—and offer sustainable livelihoods outside the rainforests.

I recommend Ian Lowe's book, *A Big Fix—Radical Solutions for Australia's Environmental Crisis*, as it includes a discourse on what makes a sustainable society. The requirements are not new, and have been achieved in varying combinations somewhere around the world in the past. We should rethink agriculture and biodiversity. High-quality agricultural land is largely sequestered. Our big challenge is to get the best possible out of that land to feed the world. Conventional cropping is a major contributor to both climate change and biodiversity loss—a new model has to come. What should we do? Adapting conventional crops is absolutely fundamental. Broadening the plant biodiversity used for crops, using inter-cropping and under-utilised crops, is going to be much more significant in the future, as is giving back to nature and restoring biodiverse carbon sinks on marginal lands. Seed banking I've emphasised. We have to focus on research. Many of the challenges in the future are unprecedented; the notion that we know enough and just need to get on and do it is bereft and short term. We have to conserve local knowledge in particular if we are to conserve biodiversity.

Conclusion

We are at a great historical moment comparable to that when slavery was abolished. Comments in the UK parliamentary records at that time mirror those made today by climate change skeptics … the end of the economic regime as we now know it; the end of the way we operate. And yet people took the moral decision not to proceed with slavery, and the world survived and prospered in a new way.

We are in a similar situation now in that the way we are living has detrimental effects on the environment and causes irreplaceable loss of biodiversity. We have to move into a triple-bottom-line accounting system where natural capital and social capital are valued as much as financial capital.

Plant biodiversity does underpin human existence and livelihoods, and yet we continue to destroy wild plant diversity at an alarming rate, with one in five plant species recently estimated to be under threat of extinction. We are at a turning point for plant biodiversity of unprecedented importance to people in a rapidly changing world. We do have a steep learning curve. We mustn't forget investment in science. Targeted plant diversity science in botanic gardens and elsewhere offers solutions to global problems and an important message of hope—not all, but some solutions. We can feed the world through sustainable use of biodiversity. But will we?

Acknowledgements

I am grateful to The Crawford Fund for the invitation to deliver the 2010 Crawford Address. Professor Pauline Ladiges of The University of Melbourne was instrumental in suggesting this proposal to the Fund. Cathy Reade and Alan Brown arranged for a transcript of the address to be provided to me, without which this paper would not have been completed. Dr Rhian Smith assisted in securing permissions for use of some figures included herein. Christine Barker provided Index Kewensis and IPNI new species statistics for Figure 5.

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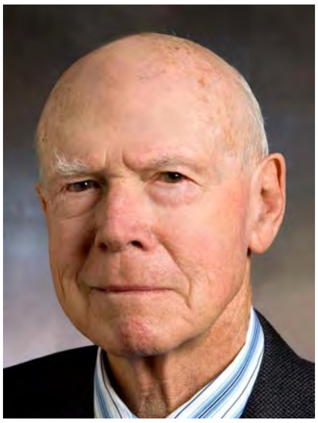

Sir John Crawford

JIM INGRAM AO

This year is the one-hundredth anniversary of the birth of Sir John Crawford, after whom the Crawford Fund is named. Neil Andrew and Denis Blight believed that tonight's dinner provided an appropriate occasion for Sir John's achievements to be remembered. I am honoured to do so. I worked with Sir John for many years, first in negotiations with the EEC in 1960 on the Common Agricultural Policy. Our collaboration was very close during my years with the overseas aid agency, culminating in the establishment of ACIAR in 1982.

Sir John was a truly great Australian. His achievements, I believe, compare favourably with those of his better known contemporaries, for example 'Nugget' Coombs. It is disappointing that a full-scale biography has not been commissioned[1].

What is so extraordinary about Sir John is that he was a visionary; a visionary committed to realising his vision, something seemingly in short supply in today's Australia. At the same time he had an acute sense of what was practical, what was achievable. His lifetime interest was the development of public policy, policy rooted in an understanding of long-run political and economic trends. Among his diverse successes were the harnessing of agricultural economics to the development of policy for Australian food and fibre production; the conception and implementation of Australian overseas trade policy; as a builder of institutions; as an academic and university administrator; as a manager of government departments; and as a trusted adviser to successive governments.

Given my own background it is perhaps not surprising that I see Sir John's greatest achievements as being in the international sphere, among them the conclusion of the 1957 Trade agreement with Japan and implementation of the Green Revolution in India[2].

The approach that Sir John brought to the Japanese negotiations was in line with his brilliant, prescient essay published in 1938. In it Sir John challenged every major assumption upon which our approach to world affairs was then based. He argued that to attempt to thwart Japan's industrialisation would lead to conflict and war. Thus he was critical of Australian support for UK trade policy toward Japan through the 1930s. He gave weight to the fact that already one-quarter of our

JAMES (JIM) INGRAM is a former diplomat who was Chief Executive of the United Nations World Food Program (WFP) for ten years from 1982. In 1992 Brown University granted him the Feinstein World Hunger Award and in 2000 WFP made him one of its two inaugural 'Food for Life' awardees. Jim was Director General of Australia's international development assistance agency (now AusAID) from 1977 to 1982. He worked closely with Sir John Crawford, promoting science and technology in the aid program, including the establishment of the Australian Centre for International Agricultural Research. In retirement Jim has been a member of the Board of the International Food Policy Research Institute, and chair of the Crawford Fund and of the Fund's 2008 Task Force on the world food crisis. His book, *Bread and Stones: Leadership and the Struggle to Reform the United Nations World Food Programme,* was published in 2007.

[1] For those interested in an overview of Sir John's work see: Evans, LT. and Miller, J.D.B. 1987. *Policy and Practice, Essays in Honour of Sir John Crawford*. Pergamon Press, Sydney.

[2] For information on relations with Japan and India, see especially the essays by Peter Drysdale and W. David Hopper on which I have drawn.

trade was with the Pacific. He was the first to describe the 'Far East' as the 'Near North'. He was sceptical, even at that date, of Australian confidence that we could rely for our security on what were later described as 'great and powerful friends'.

It says much for the courage of the Menzies government that it would contemplate, let alone conclude, an agreement which among other important steps extended most-favoured-nation tariff treatment to Japan, the still despised and hated enemy. Much business opinion was also strongly opposed. Sir John had as well to convince the Japanese that, given our past record, we were sincere in advancing generous proposals. The process of persuasion and negotiation took three years. That treaty laid the foundations for future agricultural-based prosperity. At the time farm products were 80% of total exports and production was increasing. We were as dependent on agriculture, especially wool, in 1957 as we are on minerals today.

That Sir John succeeded owed everything to his far-sightedness, patience, persistence and powers of persuasion.

Modest, quietly spoken, physically unimposing, Sir John was easily underestimated. In fact he had a formidable will and considerable self confidence. All who knew him have testified to his brilliant chairing of small groups. Somehow he gained the result he wanted without alienating those who may have initially favoured a different course. Never losing sight of his goals, he was ready to build on small advances. His judgement was not distorted by vanity or self-indulgence or arrogance. Never pompous, never ruffled, he did not 'put down' anyone. The result was that he engendered great respect and loyalty. He was also a superb judge of talent and gathered around him in each of his endeavours associates of the highest ability.

Sir John was a superb diplomat. His skills with the Japanese were repeated with the Indian government. Over time he persuaded it to provide the resources that enabled the Green Revolution to be taken up, just in time as it happened, to avoid ever more devastating famines. For over ten years Sir John, on behalf of the World Bank, visited India annually to review and thus help to keep on track and adjust as necessary the agricultural revolution under way. To this day his contribution is acclaimed in India.

Sir John developed a considerable and lasting respect for the top officials of the World Bank. It was through his long association with the Bank that he became so deeply involved with the Consultative Group for International Agricultural Research (CGIAR). The CGIAR was, and is, in essence a consortium to coordinate the work of, and secure funding for, an expanding number of international agricultural research institutes. From its inception the CGIAR was assisted by a Technical Advisory Committee (TAC) which, for many years, was chaired by Sir John to great acclaim from all involved—government and other donors, centre directors and scientists from among the world's best.

Under his leadership many new institutes were created. In Sir John's view it was essential to widen the range of disciplines to be addressed if food production, especially in developing countries, was to accelerate. One such was the International Livestock Centre for Africa, ILCA, created in 1974. Sir John was the first chairman of its governing board. The late Professor Derek Tribe was a member of ILCA's Board of Trustees at that time and he and Sir John developed a lasting respect and affection for one another. Tribe created the Crawford Fund in 1988 to honour the name of Sir John by promoting in Australia knowledge of, and funding for, the CGIAR centres. This annual conference is one way the Fund continues to do so.

Sir John was not a natural scientist but through his leadership of the CGIAR he was alive to all the scientific disciplines promotion of which is essential to achieve ecologically sustainable food production. Thus he played a leading role in fathering one of the most vital, but less widely known CGIAR institutes, today's Bioversity International. Its work bears directly on that of this evening's distinguished speaker, Professor Stephen Hopper, Director of the Royal Botanic Gardens, Kew.

I'm quite certain that Sir John would share Professor Hopper's vision of a world at a turning point. As Professor Hopper argues, maintenance of plant diversity has become essential if food production is to expand sustainably while adequately nourishing the earth's burgeoning population. Professor Hopper, an Australian by the way, is uniquely qualified to explain why that is so. In addition to his primary role at Kew he holds many others including visiting professorships and fellowships.

Professor Hopper is a very welcome contributor to this conference.[1]

[1] The presentation is included here, commencing on page 92.

APPENDIX 1

Delegate List
The Crawford Fund International Conference 2010

(EXCLUDING THOSE NOMINATING PRIVACY)

Last name	First name	Organisation
ADAMS	Mark	University of Sydney
AGRAWAL	Animesh	The John Curtin School of Medical Research
AHAMMAD	Helal	ABARE-BRS
ALEXANDER	Kim	CSIRO
ANDERSON	Felicity	Murray Catchment Management Authority
ANDERSON	John	The Crawford Fund
ANDREW AO FTSE	Neil	The Crawford Fund
ANGUS	John	CSIRO Plant Industry
ASHCROFT	Vincent	AusAID
ATKINSON AO	Sallyanne	The Crawford Fund
AUSTIN	Nick	ACIAR
BACKHOUSE HARRIS	Briony	Department of Agriculture Fisheries and Forestry
BALDWIN	Madeleine	Department of Agriculture Fisheries and Forestry
BASFORD	Kaye	The University of Queensland
BATTERHAM AO	Robin	The Crawford Fund
BAXTER	Les	ACIAR
BAXTER	Peter	AusAID
BECKMANN	Roger	Dept of Parliamentary Services
BLIGHT	Denis	The Crawford Fund
BRADLEY-CROSS	Natasha	Australian Business Volunteers
BRAIDOTTI	Gio	Coretext
BROWN	Alan	The Crawford Fund
BROWN	Anthony H D	CSIRO Plant Industry
BUI	Elisabeth	CSIRO Land and Water
BULL	Melissa	Student
BURNS	Craig	RIRDC
CARMICHAEL	Andrew	CLM Pty Ltd
CARRASCO	Jean-Bernard	AusAID
CARTER	Julie	CSIRO
CHANDLER	Sonja Sonja	Chandler
CHESWORTH	Samuel	University of Sydney
CLARK	Megan	CSIRO
CLARKE	Rachel	ABARE-BRS
CLEMENTS	Bob	N/A
COFFEY	Shaun	Industrial Research Limited
CONSIDINE	Margaret	Dept of Environment Water Heritage and the Arts
COOK	David	CSIRO
COUGHLAN	Kep	The Crawford Fund
COWAN	Sara	Department of Agriculture Fisheries and Forestry
CRASWELL	Alison	Crawford Fund
CRASWELL	Eric	The Crawford Fund
CRIBB	Alex	Family of Julian Cribb
CRIBB	Jasmine	Family of Julian Cribb
CRIBB	Julian	Julian Cribb & Associates

Last name	First name	Organisation
CRIBB	Olivia	Family of Julian Cribb
CUMMINS	Jay	Rural Solutions SA
D'OCCHIO	Michael	The University of Queensland
DALE	James	Centre for Tropical Crops and Biocommodities Queensland
DALY	Joanne	CSIRO
DALZIELL	Rosamund	Australian National University
DAWSON	Victoria	University of Sydney
DENNEY	Ian	Animal Health Australia
DIXON	John	ACIAR
DRENTH	Andre	The University of Queensland
ECKER	Saan	The Australian National University
EDGAR	Robert	The Crawford Fund Victorian Committee
EDMEADES	Chris	CABI
EK	Kai Lin	Sydney University
ENRIGHT	Terry	The Crawford Fund
ETHERINGTON	Dan	Kokonut Pacific Pty Ltd
ETHERINGTON	Richard	Kokonut Pacific Pty Ltd
FALVEY	Lindsay	Universities of Melbourne and Cambridge
FINKEL	Elizabeth	AAAS Science Magazine
FISCHER	Tony	The Crawford Fund
FISCHER AC	Tim	Australian Ambassador to the Holy Sea
FOTIA	Marijke	Austraining International
FOX	Paul	ACIAR
FRASER	Greg	PHA
FRENCH	Simon	Department of Agriculture Fisheries and Forestry
FRISON	Emile	Bioversity International
GABB	Skye	
GARNETT	Helen	The Crawford Fund
GODDARD	Jenny	Grains Research and Development Corporation
GOULD	Simon	Outcomes Australia
GRANT	Allen	Department of Agriculture Fisheries and Forestry
GRAY	Doug	ACIAR
GREADY	Jill	The Australian National University
GREGSON	Tony	The Crawford Fund
GRENOT	Kate	Rural R&D Council
GUDDE	Jane	Industry & Investment NSW
GUY	David	ANU Enterprise Pty Ltd
GYLES	Mandy	Australian Centre for International Agricultural Research (ACIAR)
HANJRA	Munir	Charles Sturt University International Centre of Water for Food
HARCH	Bronwyn	CSIRO
HARDCASTLE	Susan	Department of Agriculture Fisheries and Forestry
HARTLEY	Margaret	The Crawford Fund
HAWKER	David	Member for Wannon
HAYES	Ted	The Crawford Fund
HEALY	Roseanne	RIRDC
HEARN	Simon	ACIAR
HEATH	Tim	The University of Adelaide

Last name	First name	Organisation
HENTY	Sam	CSIRO Plant Industry
HENZELL	Ted	
HICKEY	Georgina	ACIAR
HICKEY	Lee	The University of Queensland
HIGGINS	TJ	CSIRO
HIRSCH	Mikael	Department of Agriculture Fisheries and Forestry
HOPPER	Stephen	Royal Botanics Garden Kew
HORNE	Peter	ACIAR
HORVAT	Peter	Fisheries R&D Corporation
HOSSAIN	Zamir	Department of Agriculture Fisheries and Forestry
HULME	Therese	Industry & Investment NSW
HYDE	Nicole	Charles Sturt University
INALL	Neil	NSW Crawford Committee
INGLETON	Sally	360 Degree Films Pty Ltd
INGRAM	Jim	World Food Program
JACKSON	Norton	Energy Exploration Ltd
JACKSON	Phil	The Crawford Fund
JEHNE	Claus	Retired
JEHNE	Walter	Healthy Soils Australia
JEPHCOTT	Thomas	University of Sydney
JOYCE	Robin	
KANNAPPAN	Babu	The Australian National University
KEATING	Brian	CSIRO's Sustainable Agriculture Flagship
KENEALLY	Kerry	The Crawford Fund
KERIN	John	The Crawford Fund
KLEYN	Gary	Future Directions International
KLEYN	Harry	Wungong Holdings
KNIGHT	Megan	Industry and Investment NSW
KNIGHT	Michelle	Fenner School ANU
KRAUS	Stefan	Australian Department of the Environment Water Heritage and the Arts
LA SALLE	John	CSIRO
LATUKEFU	Alopi	AusAID
LAWN	Robert	James Cook University
LAWRENCE	Janet	The Crawford Fund
LAWRENCE	Louise	CSIRO Ecosystem Sciences
LEO	Audrey	The University of Melbourne
LEWIS	Bill	AIAST
LIBRANDO	Tessie	Family of Julian Cribb
LIN	William	University of Sydney
LLOYD	Bruce	The Crawford Fund
LOCKHART	Erin	University of Sydney
LONG	Rowena	The University of Western Australia School of Plant Biology
LOPEZ	Patricia	Timothy G. Reeves and Associates P/L
LOUCOS	Karen	University of Sydney
LOVETT	John	CRC NCB
LUKACS	Zoltan	GRDC
LUM	Keng – Yeang	CABI Southeast and East Asia

Last name	First name	Organisation
MACFADYEN	Sarina	CSIRO
MAMUN	Ezaz	Biosecurity Australia
MAYBERRY	Dianne	The University of Queensland
MCCLUSKEY	Su	Council of Rural Research and Development Corporations
MCCOMB	Arthur	Murdoch University
MCCOMB	Jen	The Crawford Fund
MCCORMICK	Bill	Dept of Parliamentary Services
MCCUSKER	Alison	IBPGR
MCKINNON	Ian	The Crawford Fund
MCKINNON	Lachlan	CropLife Australia
MCLACHLAN	Karina	Dept of Environment Water Heritage and the Arts
MCLOUGHLIN	Sam	University of Sydney
MCMULLAN MP	The Hon. Bob	Parliamentary Secretary for International Development Assistance
MEADLEY	Bernard	CropLife Australia
MEIRELLES BETANCUR	Tamara Daniela	The Australian National University
METCALFE	Andrew	Department of Immigration and Citizenship
MOODY	James	CSIRO
MOORE	Joseph	Charles Sturt University
MULLER	Felicity	ACIAR
MWAI	Okeyo	International Livestock Research Institute
NAMBIAR	Sadanandan	CSIRO Ecosystem Sciences
NAUMANN	Ian	Department of Agriculture Fisheries and Forestry
NELSON	Sam	National Farmers Federation
NICHOLAS	Tom	Healthy Soils Australia
NINNES	Peter	ICRISAT
O'CONNELL	Connall	Department of Agriculture Fisheries and Forestry
OGILVY	Sue	The Mulloon Institute
OLIVER	Janice	Rural R&D Council
PAGE	Warren	ACIAR
PATIL	Raj	Department of Agriculture Fisheries and Forestry
PATRICK	Sarah	Australian Business Volunteers (ABV)
PAULSEN	Kylie	Grains Research and Development Corporation
PEROTTI	Enrico	Department of Agriculture Fisheries and Forestry
PERRETT	Keith	Grains Research and Development Corporation
PERSLEY	Gabrielle	Doyle Foundation
PINE	Rhys	University of Sydney
POLAK SCOWCROFT	Caroline	University of Manitoba
POSSINGHAM	Hugh	Australian Research Council Federation
POWER	Catherine	University of Sydney
PRATLEY	Jim	Charles Sturt University
QING ZHANG	Li	University of Sydney
RADCLIFFE AM	John	The Crawford Fund
RADEMAKERS	Linda	World Vision Australia
RAE	Mel	Agriculture Resource Management
RAMIREZ	Pablo	Student
RANSOM	Lois	Department of Agriculture Fisheries and Forestry

Last name	First name	Organisation
READE	Cathy	The Crawford Fund
READING	Peter	GRDC
REDDEN	Bob	Department of Primary Industries Victoria
REEVES	Timothy	Grains Research and Development Corporation
RIHI DARA	Maxi Julians	Crawford School of Economics and Government
ROVIRA	Albert	The Crawford Fund
RUSH	Becky	Department of Environment Water Heritage and the Arts
RYAN	Michael	DAFF
SAMPER	Christian	Smithsonian Institution
SAYERS	Keith	ALP - International Affairs Policy Committee
SCHNEIDER GUILHON	Larissa	The University of Canberra
SCOTT	Pennie	Healthy Soils Australia
SCOTT-ORR	Helen	Member NSW Crawford Fund Committee
SECOMB	Stephanie	The Australian National University
SHEALES	Terry	ABARE-BRS Department of Agriculture Fisheries and Forestry
SHEARER	David	ACIAR
SIMS	Benjamin	Crawford School
SLACK-SMITH	Dick	The Crawford Fund
SLY	Lindsay	University of Queensland
SMITH	Andrew	University of Adelaide
SMITH	Hilary	Latitude Forest Services
SMITH	Millicent	University of Sydney
SMITH	Patrick	CSIRO
SOSNA	Daria	University of Sydney
SPARKES	Jessica	ABARE-BRS Department of Agriculture Fisheries and Forestry
STALLARD	Sebastian	University of Sydney
STANDEN	Bruce	The Crawford Fund
STAPLEY	Ben	CropLife International
STOUTJESDIJK	Peter	ABARE-BRS
SUMMERELL	Brett	Royal Botanic Gardens and Domain Trust
SWIFT	Roger	The University of Queensland
TACCONI	Luca	Environment Management and Development Program, Crawford School ANU
TARZIA	Marguerite	Dept of Parliamentary Services
TELFER	Joshua	Rural Solutions SA
TEMPLETON	Deborah	ACIAR
TEN HAVE	José	ABARE-BRS
TERVET	Lucy	Austraining International
TRUEMAN	Holly	Catalyst ABC Science
VAN OOSTENDE	Marchien	The Crawford Fund
VELARDE	Sandra	ANU
WALKER	Rachel	University of Sydney
WATSON	Chris	
WATSON	Laura	Landmark
WHITTY	Thomas	CropLife Australia
WILLIAMS	Meryl	ACIAR
WILLS	Ron	The University of Newcastle
WIMBORNE	Sara	University of Sydney

Last name	First name	Organisation
WINDSOR	Peter	University of Sydney
WITTEVEEN	Micheal	Family of Julian Cribb
WOLF	Nicholas	AusAID
WRIGHT	Lisa	ACIAR
ZILLMAN	John William	The University of Melbourne
ZSOGON	Agustin	The Australian National University

2010 International Development Conference
BIODIVERSITY AND WORLD FOOD SECURITY
Nourishing the Planet and Its People
Parliament House, Canberra
30, 31 August and 1 September

Media Coverage

The following is a chronological listing of the key media coverage from the conference, with links to the report where available.

Date	Name	Program	URL
20/08/10	Stephen Hopper	ABC Canberra—Mornings with Alex Sloan	
24/08/10	Tony Gregson	ABC Rural Canberra	http://www.abc.net.au/rural/regions/content/201008/2991510.htm
	Tony Gregson	ABC Rural NSW	http://www.abc.net.au/rural/nsw/content/2010/08/s2992042.htm?
	Tony Gregson	ABC Rural National	http://www.abc.net.au/rural/content/2010/s2991675.htm
	Tony Gregson	ABC Rural National	http://www.abc.net.au/rural/news/content/201008/s2991705.htm?
26/08/10	Tony Gregson	ABC Rural Tasmania	http://www.abc.net.au/rural/tas/content/2010/08/s2994381.htm
	Tony Gregson	ABC Rural National	http://www.abc.net.au/rural/news/content/201008/s2994164.htm?
	Denis Blight	ABC Rural National	http://www.abc.net.au/rural/news/content/201008/s2994023.htm?
	Denis Blight	ABC Rural Canberra	http://www.abc.net.au/rural/regions/content/201008/2993694.htm
27/08/10	Tony Gregson	ABC Rural National e-newsletter	
30/08/10	Stephen Hopper	RN Bush Telegraph	http://www.abc.net.au/rural/telegraph/content/2010/s2997219.htm
	Tony Gregson	The Land, QCL, Stock Journal, Stock and Land, Farm Weekly	http://theland.farmonline.com.au/news/nationalrural/grains-and-cropping/general/crop-genetics-undervalued-gregson/1923624.aspx
	Tony Gregson	Online Opinion	http://www.onlineopinion.com.au/view.asp?article=10905
	Stephen Hopper	Canberra Weekly	
	Luca Tacconi	Radio Aus Pac Beat	http://www.radioaustralia.net.au/pacbeat/stories/201008/s2996907.htm
	Meryl Williams	Radio Australia	http://www.radioaustralia.net.au/pacbeat/stories/201008/s2996907.htm
30/08/10	Cristián Samper	ABC Canberra – Mornings with Alex Sloan	

Date	Name	Program	URL
30/08/10	Stephen Hopper	The Age/ Sydney Morning Herald—Tom Arup interview	
	Okeyo Mwai	Radio Australia Today	
	Keng Yeung Lum	Radio Australia Today	
	Stephen Hopper	ABC Rural interview with Mary Goode	
	Emile Frison	Canberra Times Opinion Piece	
31/08/10	Conference	ABC TV Nightly News and News 24	
	Emile Frison	ABC TV News Breakfast	http://www.abc.net.au/news/stories/2010/08/31/2998541.htm
	Cristián Samper	Rural Press - Matt Cawood iv	
	Emile Frison	News Radio Africa Program	
	Okeyo Mwai	News Radio Africa Program	
	Conference	Canberra Times 'Fridge Door'	
	Cristián Samper	National Commercial Rural News (2UE/3LO/6PR etc)	
	Conference	ABC 3pm News Brisbane, ABC Capricornia (Rockhampton), ABC Far North (Cairns), ABC Gold Tweed Coasts (Gold Coast), ABC North Queensland (Townsville), ABC North West Qld (Mt Isa),ABC Southern Queensland (Toowoomba), ABC Sunshine and Cooloola Coasts (Sunshine Coast), ABC Tropical North (Mackay), ABC Western Queensland (Longreach), ABC Wide Bay (Bundaberg), Radio National (Brisbane) - Clipping	
	Conference	ABC 1pm News ABC 666 Canberra (Canberra)	
1/09/10	Samper/Hopper	Canberra Times (Clipping)	
	Cristián Samper	Radio National Breakfast	http://www.abc.net.au/rn/breakfast/stories/2010/2999017.htm
	Cristián Samper	Radio Aust Bahasa	http://www.radioaustralia.net.au/indonesian/news/stories/201009/s2999121.htm
	Emile Frison	Radio Aust Pacific Beat	http://www.radioaustralia.net.au/pacbeat/stories/201009/s2999165.htm
	Emile Frison	ABC Canberra—Mornings with Alex Sloan	
	K Y Lum	Radio Australia Connect Asia	
	Cristián Samper	Radio Australia—In the loop	
2/09/10	Okeyo Mwai	ABC Rural National	http://www.abc.net.au/rural/news/content/201009/s3000470.htm
3/09/10	Meryl Williams	ABC Rural Canberra	http://www.abc.net.au/rural/act/canberra/
	Hugh Possingham	ABC Rural Canberra	http://www.abc.net.au/rural/act/canberra/
	Hugh Possingham	ABC Rural National	http://www.abc.net.au/rural/news/content/201009/s3001552.htm
	Meryl Williams	ABC Rural ACT	http://www.abc.net.au/rural/act/canberra/
	Meryl Williams	ABC Rural Regions	http://www.abc.net.au/rural/regions/content/201009/3001445.htm?

Date	Name	Program	URL
	Meryl Williams	ABC Rural NSW	http://www.abc.net.au/rural/nsw/content/2010/09/s3002017.htm
3/9/10	Meryl Williams	ABC Rural National	http://www.abc.net.au/rural/news/content/201009/s3001543.htm
4/09/10	Hopper/Samper	Canberra Times (seven-page feature article)	
5/09/10	Emile Frison	Stock & Land	http://sl.farmonline.com.au/news/nationalrural/agribusiness-and-general/general/why-simplified-food-is-damaging-our-health/1930031.aspx
		The Land	http://theland.farmonline.com.au/news/nationalrural/agribusiness-and-general/general/why-simplified-food-is-damaging-our-health/1930031.aspx
		Stock Journal	http://sj.farmonline.com.au/news/nationalrural/agribusiness-and-general/general/why-simplified-food-is-damaging-our-health/1930031.aspx
		Farm Weekly	http://fw.farmonline.com.au/news/nationalrural/agribusiness-and-general/general/why-simplified-food-is-damaging-our-health/1930031.aspx
		Queensland Country Life	http://qcl.farmonline.com.au/newssearch.aspx?cmd=run&q=frison&au=cawood&sb=rel&so=asc&sf=9&cf=&scf=
2/10/10	Aust. Collections	Radio National Science Show	http://www.abc.net.au/rn/scienceshow/stories/2010/3027412.htm
5/10/10	Aust. Collections	Radio National Australia Talks	http://www.abc.net.au/rn/australiatalks/stories/2010/3028975.htm
29/10/10	General	Maitland Mercury ‘Biodiversity, the key to life’	
18/11/10	Aust. Collections	Weekly Times	http://www.weeklytimesnow.com.au/article/2010/11/18/259881_on-farm.html

COSMOS Magazine September on Australian Collections http://www.cosmosmagazine.com/features/online/3773/australia-abandons-genetic-diversity-farming

AAAS (US) SCIENCE magazine September edition, Vol. 329 on Australian Collections

Chemistry in Australia Magazine November edition—article from Lindsay Sly paper

FOCUS Magazine November edition on ‘Biodiversity and Food Security’ including papers from Crawford Fund and a range of speakers

ISSUES Magazine December edition on ‘Biodiversity and Food Security’ including papers from Crawford Fund and a range of speakers

ABC TV Catalyst Program (forthcoming episodes) from crew attendance and interviews with Samper, Possingham, Frison

Other Crawford Fund Publications since 2005

The ATSE Crawford Fund 2005. *Healing Wounds: An Australian Perspective.* Research that rebuilds agriculture after conflicts and natural disasters. The Fund, Parkville, Vic. 14 pp.

The ATSE Crawford Fund 2005. *Report 1 January 2004 to 30 June 2005.* The Fund, Parkville, Vic. 25 pp.

Brown, A.G. (ed.) 2006. *Forests, Wood and Livelihoods: Finding a Future for All*. Record of a conference conducted by the ATSE Crawford Fund, Parliament House, Canberra, 16 August 2005. The ATSE Crawford Fund, Parkville, Vic. vi + 91 pp. ISBN 1 875618 86 4

Anon. 2006. *The ATSE Crawford Fund Report 1 July 2005–30 June 2006*. The Fund, Parkville, Vic. 28 pp. http://www.crawfordfund.org/publications/pdf/annualreport2006.pdf.

Brown, A.G. (ed.) 2007. *Water for Irrigated Agriculture and the Environment: Finding a Flow for All*. Record of a conference conducted by the ATSE Crawford Fund, Parliament House, Canberra, 16 August 2006. The ATSE Crawford Fund, Parkville, Vic. vi + 72 pp. ISBN 1 875618 92 9.

Anon. 2007. *The ATSE Crawford Fund Report 1 July 2006–30 June 2007*. The Fund, Parkville, Vic. 28 pp. http://www.crawfordfund.org/publications/pdf/annualreport2007.pdf

Brown, A.G. (ed.) 2008. Biofuels, Energy and Agriculture: Powering Towards or Away from Food Security? Record of a conference conducted by the ATSE Crawford Fund, Parliament House, Canberra, 15 August 2007. The ATSE Crawford Fund, Parkville, Vic. vi + 54 pp. ISBN 1 875618 95 3

Persley, G.J. and Blight, D.G. (eds) 2008. *A Food Secure World: How Australia can Help.* Report of the Crawford Fund World Food Crisis Task Force, Australian Academy of Technological Sciences and Engineering (ATSE), Melbourne, 60 pp. ISBN 978 1 921388 00 2.

Anon. 2008. *The Crawford Fund: An Initiative of the Australian Academy of Technological Sciences and Engineering. Annual Report 1 July 2007 to 30 June 2008*. The Fund, Deakin, ACT, 36 pp. http://www.crawfordfund.org/publications/pdf/annualreport2008.pdf

Brown, A.G. (ed.) 2009. *Agriculture in a Changing Climate: The New International Research Frontier*. The ATSE Crawford Fund Fourteenth Annual Development Conference, Parliament House, Canberra, 3 September 2008. The ATSE Crawford Fund, Deakin, ACT. vi + 72 pp. ISBN 978-1-921388-01-9

Anon. 2009. *The Year in Brief July 2008–June 2009.* 8 pp. http://www.crawfordfund.org/assets/files/reports/2009_year_in_brief.pdf

Brown, A.G. (ed.) 2010.*World Food Security: Can Private Sector R&D Feed the Poor?* The Crawford Fund Fifteenth Annual Development Conference, Parliament House, Canberra, 27–28 October 2009. The Crawford Fund, Deakin, ACT. viii + 116 pp. ISBN 978 1 921388 08 8

Gupta, V.V.S.R., Ryder, M. and Radcliffe, J. (eds) 2010. *The Rovira Rhizosphere Symposium*. Celebrating 50 years of rhizosphere research. A festschrift in honour of Albert Rovira AO FTSE, Friday 15 August 2008. SARDI Plant Research Centre, Adelaide. The Crawford Fund, Deakin, ACT. viii + 136 pp. ISBN 978 1 921388 07 1

The Crawford Fund newsletter, *Highlights*, is available from the Fund's website (http://www.crawfordfund.org/resources/highlights.html) or in printed form. In 2010, two issues were published.

The three publications below discuss the global setting for international agricultural research. The website of the Cooperative Group for International Agricultural Research (CGIAR) (http://www.cgiar.org/) provides other information.

Alston, J.M., Pardey, P.G. and Taylor, M.J. (eds) 2001. *Agricultural Science Policy: Changing Global Agendas*. John Hopkins University Press, Baltimore, 285 pp. ISBN 0 8018 6603 0

Pardey, P.G., Alston, J.M. and Piggott, R.R. (eds) 2006. *Agricultural R&D in the Developing World: Too Little, Too Late?* International Food Policy Research Institute, Washington DC. Available for download from http://www.ifpri.org/pubs/books/oc51.asp

World Bank 2007. *World Development Report 2008: Agriculture for Development*. World Bank, Washington, DC. xviii + 365 pp. http://econ.worldbank.org ISBN: 9780821368077

The Crawford Fund facilitated an award-winning one-hour TV documentary, *Seed Hunter* (1988) that follows Australian scientist Dr Ken Street on a quest through Central Asia to find rare genes that may save our food from the looming threat of climate change. More details are at http://www.seedhunter.com/.

Global food supply and demand is reviewed by:

Cribb, J. 2010. *The Coming Famine: The Global Food Crisis and What We Can Do to Avoid It.* CSIRO Publishing, Melbourne. xii + 248 pp

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