SIBBALDIA GUEST ESSAY

Professor Vernon Heywood, Emeritus Professor of Botany at the University of Reading, has had a long and distinguished career in plant taxonomy and systematics and has trained generations of students who now occupy senior positions in many parts of the world. He is a graduate of the Universities of Edinburgh (BSc, DSc), where he was taught botany at the Royal Botanic Garden Edinburgh under Professor Sir William Wright Smith, and Cambridge (PhD). His publications include the best-selling *Flowering Plants of the World* and its successor, *Flowering Plant Families of the World*, and *Principles of Angiosperm Taxonomy* co-authored with Peter Davis which for decades was the leading text in the field. In addition he has worked extensively on biodiversity and conservation issues in many parts of the world, particularly in the Mediterranean, Indian sub-continent and the Neo-tropics. He was senior consultant to the UK Overseas Development Administration (ODA/DFIC) on the building and equipment of a new National Herbarium in Dhaka, Bangladesh and a staff training and development programme.

During the past 20 years he has been especially concerned with developing strategies for the conservation of germplasm of wild species of economic importance, including the wild relatives of crop plants and medicinal and aromatic plants. He has been closely involved with botanic gardens throughout his career and was the founder director of the Botanic Gardens Conservation Secretariat (later Botanic Gardens Conservation International). During a period at IUCN, as Chief Scientist, he was responsible for developing a plant conservation programme and directed projects on centres of plant diversity, extinction rates in tropical forests, species reactions to global change, medicinal plant conservation and wild relatives of crop species. He co-ordinated and edited the UNEP Global Biodiversity Assessment, involving the collaboration of hundreds of scientists. He has served as a consultant for numerous agencies such as the World Bank Inspection Panel, UNDP, UNEP, FAO and Biodiversity International, and has advised governments, ministries, universities and NGOs in many parts of the world, including Bangladesh, Costa Rica, France, Greece, Guatemala, Honduras, India, Indonesia, Italy, Jamaica, Lebanon, Mexico, Morocco, Nicaragua, Spain, Sri Lanka and Venezuela on conservation and biodiversity issues and on botanic garden development. He has published over 65 books and is the author of 400 papers in scientific journals.

BOTANIC GARDENS AND GENETIC CONSERVATION

Vernon Heywood[1]

In his seminal paper ‘Genetic conservation: our evolutionary responsibility’ Sir Otto Frankel referred to the ‘hurricane of change’ to which our natural and cultural heritage was exposed (Frankel, 1974), a description which applies with even more force some 35 years later in the face of global and, in particular, climate change.

[1]Vernon Heywood is Emeritus Professor in the School of Biological Sciences, University of Reading.
Address: School of Biological Sciences, University of Reading, Whiteknights, Reading RG6 6AS, UK.
Email: v.h.heywood@reading.ac.uk/vhheywood@btinternet.com

Frankel's concern was with the conservation of the genetic estate – the genetic endowment of our biological heritage – and along with other pioneers of the genetic resources movement such as E. Bennett, J. Harlan, J.G. Hawkes, J. Creech and M. Swaminathan, advocated urgent action for the collection and preservation of genetic resources of the crop varieties of traditional agriculture. Wild species (as opposed to domesticates) were regarded as of little economic importance and to be conserved only by organized protection within natural communities. Frankel did however acknowledge that the wild relatives of crops were important potential genetic resources but were generally not nearly as exposed to risks of extinction as the varieties (primitive landraces) of traditional agriculture.

The subsequent development of the genetic resources sector and the large-scale collection of landraces and crop varieties and their storage in national, regional and international gene banks and Consultative Group on International Agricultural Research (CGIAR) crop centres was one of the outstanding successes of the agricultural conservation movement. The focus was very much on *ex situ* conservation and protocols and seed storage techniques. The Food and Agriculture Organisation (FAO) Commission of Plant Genetic Resources was established in 1983 to deal with issues related to plant genetic resources. The establishment of the International Board for Plant Genetic Resources (IBPGR), initially within FAO and later independent (subsequently to become International Plant Genetics Resources Institute (IPGRI) and then Biodiversity International), provided a major institutional focus[2]. The International Treaty on Plant Genetic Resources for Food and Agriculture was adopted in November 2001. Today, there are some 1300 seed banks housing some 6.5 million accessions. A detailed account of *ex situ* conservation of plant genetic resources is given by Hawkes *et al.* (2000).

Actions to conserve *ex situ* samples of wild species with no known agricultural, forestry or other economic importance have in comparison seemed tentative and faltering, at least until recently, yet the first seed bank specifically dedicated to wild species was that established in 1966 by César Gómez Campo at the Polytechnic University of Madrid, at a time when only a handful of major seed banks existed in the world such as those of the USDA at Fort Collins, the Research Institute (now the Vavilov Institute) of Plant Industry in Leningrad (today St.Petersburg), and the Gatersleben gene bank (today the Leibniz-Institut für Pflanzengenetik und Kulturpflanzenforschung IPK). Its purpose was initially to create an active collection of accessions of seeds of the family Cruciferae and in 1973 it initiated a project of *ex situ* conservation of endemic plant species of the Iberian Peninsula and Macaronesia.

There are several reasons for this neglect. One reason is that the very notion of *ex situ* conservation has been strongly resisted by many in the conservation community, largely on the grounds that it could detract from efforts on *in situ* conservation and might even persuade governments that the latter was not necessary if seeds of endan-

[2]Subsequently the mandate of the Commission was broadened in 1995 and it was then renamed the Commission on Genetic Resources for Food and Agriculture (CGRFA).

gered species could be maintained in a seed bank. And although the disadvantages of *ex situ* conservation as compared with maintaining living populations in the field (*in situ*) are well known, some authors cast considerable doubt on the effectiveness of the *ex situ* approach. For example, Hamilton (1994) argues that *ex situ* collections "may be ineffective at preserving genetic diversity and the evolutionary potential of populations for adaptive or neutral evolution. Treating the collection of genetic variation for seed banks as simply a problem in efficient sampling of neutral, allelic genetic polymorphism is a limited view of the types and organization of genetic variation present in wild plant species". These and related issues are also discussed by Schoen & Brown (2001). While accepting that there are, of course, serious technical and scientific drawbacks to *ex situ* conservation, it still remains a vital component of a comprehensive biodiversity conservation policy and is likely to increase in importance as doubts about the long-term viability of protected areas are beginning to surface and the demand for material for reintroduction and restoration programmes increases. Having said that, we need to be cautious in looking to the agricultural gene bank sector as a model to follow or adapt. In fact, Schoen & Brown (2001) query the apparent success of agricultural seed banking as justification for extending the approach to wild species, noting that the raison d'être for the former is the provision of a readily available source of genetic diversity for crop improvement and related concerns which is only true for a limited number of wild species, although perhaps appreciably more than they suggest (cf. Heywood 2003, 2007).

As a result of these various factors, investment of effort in making and maintaining *ex situ* collections of wild species was actively discouraged, at least until recently. But perhaps the most important reason is the lack of any body or organization with a relevant mandate. This raises an issue that has so far not been adequately explored: which institutions or organizations are charged with the responsibility for *ex situ* conservation of wild species? Although this may seem a naïve question, it is as difficult to answer as the more general question, which institutions are mandated to undertake biodiversity conservation in general? While institutions such as herbaria and museums were established historically to respond to the growing demands for taxonomy, no such provision has been made for biodiversity conservation and although the Convention on Biological Diversity (CBD) talks about capacity building, it does not specify what and it is assumed that the countries will take the necessary steps. The fact is that for wild biodiversity conservation, the only widely adopted facility adopted by most countries is a system of protected areas, and apart from a number of gene banks for wild species, we have few dedicated conservation centres or institutions, whether for *ex situ* or *in situ*. Those that do exist are the exception, such as the French network of Conservatoires Botaniques Nationaux or the American Center for Plant Conservation (essentially a network of existing botanic gardens), the Institute of Biodiversity Conservation (IBC), Ethiopia (although mainly focused on agricultural and other economically important plants), the South African National Biodiversity Institute (SANBI) and a number of university departments or centres. What we do have of course, is ministries or agencies which largely charge other

bodies to carry out the actual work and a growing number of conservation biologists who are mostly based in universities. The situation for *in situ* conservation of targeted species is even more acute than that for *ex situ* conservation as discussed by Heywood & Dulloo (2006) in a global review. All too often we put forward strategies without making the necessary provision of infrastructure (or finance) to implement them.

The mandate for *ex situ* conservation certainly exists in the Convention on Biological Diversity: Article (9) on *ex situ* conservation requires countries to adopt measures for the *ex situ* conservation of components of biological diversity, preferably in their country of origin and to establish and maintain facilities for the *ex situ* conservation of plants, animals and micro-organisms, again preferably in their country of origin. But it also states quite unequivocally that the Parties to the Convention shall use *ex situ* techniques "as far as possible and as appropriate, and predominantly for the purpose of complementing *in situ* methods", thus making it clear that it is very much secondary to *in situ* conservation. As well as measures for *ex situ* conservation of components of biological diversity and establishment and maintenance of facilities, Article 9 also somewhat confusingly includes the adoption of "measures for the recovery and rehabilitation of threatened species and for their reintroduction into their natural habitats under appropriate conditions" which are essentially *in situ* conservation measures although *ex situ* material may be involved although not necessarily so[3].

The CBD does not restrict its requirement for *ex situ* conservation, nor for that matter for *in situ* conservation, to threatened species only, unlike the Global Strategy for Plant Conservation (GSPC), but potentially it applies to all species. Also, it interprets genetic resources much more widely than had been customary until then: instead of using the term to refer to crop genetic resources i.e. in the case of plants, crop wild relatives, advanced cultivars and landraces, it defines it as "genetic material of actual or potential value", thus effectively covering any plants (or animals or microorganisms) and even herbarium material from which DNA can be extracted.

Like other conventions and treaties, the CBD expects the signatory countries to take the necessary steps to implement its recommendations and develop the infrastructure and make available or seek the necessary finance. It should be noted that the Global Environment Facility (GEF) which acts as the main funding agency for the CBD does not support *ex situ* conservation proposals.

The main UN agency whose mandate covers conservation of biological diversity is the United Nations Environment Programme (UNEP) but it does not specifically include initiatives on *ex situ* conservation or genetic resources in general although it has collaborated with FAO in a programme of conservation of forest genetic resources which contains an *ex situ* component.

While some countries have responded to the challenge by recognizing the need for *ex situ* conservation of wild plant species, not just of agricultural or forestry species,

[3]This confusion is perpetuated in Target 8 of the CBD's Global Strategy for Plant Conservation: 60 per cent of threatened plants in accessible ex situ collections … and 10 per cent of them included in recovery and restoration programmes.

actual implementation has been very patchy. I suspect this is largely due to uncertainty as to how to proceed and what institutions should be charged with implementation as discussed above.

In an earlier Guest Essay, Kingsley Dixon (2007) refers to botanic gardens being "mandated with conserving the world's flora" by reference to the GSPC but in fact there is no such mandate and the task of making and maintaining the necessary *ex situ* collections of wild species has largely fallen to botanic gardens by default. The trouble with assumed mandates is that they do not come with funding.

Of course, by their nature, botanic gardens, whatever else they engage in, are institutions that have unrivalled expertise in growing plants and hold *ex situ* collections of them. It was logical, therefore, that efforts were made to harness these skills in the interest of conservation. The notion that botanic gardens should occupy themselves with the conservation of rare and endangered species was first promulgated explicitly at the International Congress for Nature Protection held in Paris in 1923[4], with special reference to mountain gardens and at the second Congress also held there in 1931[5], which passed a resolution that rare or endemic plant species threatened with extinction should be cultivated and placed in reserve in botanic gardens. Other resolutions, referring specifically to France, were that a botanic garden should be created in each of its overseas territories where native and exotic species should be acclimatized and as a network for the conservation of endangered species.

The first concerted attempt to involve the world's botanic gardens in the protection of species threatened with extinction was made at an international colloquium of the sub-commission of botanic gardens of the International Union of Biological Sciences (IUBS) on 'The scientific organization of botanic gardens' in 1953 (also in Paris). Amongst the themes covered was the protection of nature and living collections and it was envisaged that some botanic gardens should be transformed into 'sanctuary gardens' and that they accept responsibility in their respective regions for the inventory and monitoring of the localities of rare plants and eventually their preservation. This foreshadowed at an international level the creation of IABG and at a national level the creation of the network of Conservatoires Botaniques Nationaux in France charged with precisely the responsibilities just outlined. In 1953, the International Association of Botanic Gardens (IABG) originated as the sub-commission of the IUBS, which held a colloquium on 'The scientific organization of botanic gardens' in Paris 4–6 June 1953, at which it was resolved to establish a section within the International Union for the Protection of Nature [later IUCN] to work out the role of botanic gardens in the protection of plants and plant communities. IABG in turn at its Plenary Session held in Moscow in 1975 "recognized that numerous botanic gardens of the world, united under the auspices of IABG represent a powerful force, which is capable of rendering effective assistance in the conservation of plant life in all continents". Little effective

[4]1er Congrès International pour la Protection de la Nature, Paris (1923).
[5]2ème Congrès International pour la Protection de la Nature, Paris (1931).

action was taken and it was not until the late 1970s that the potential role of botanic gardens in species conservation began to be implemented to some degree: in the 1980s the Center for Plant Conservation in the United States (see below) and the IUCN Botanic Gardens Conservation Secretariat, later to become the independent Botanic Gardens Conservation International (BGCI) were founded and conservation became a major focus of many gardens.

My involvement in setting up BGCI was based on the conviction that the botanic garden community represented the sleeping giant of plant conservation and in drafting the Botanic Gardens Conservation Strategy indicated the main ways in which this new role for botanic gardens could be implemented in those gardens that wished to participate. The achievements of the botanic garden estate towards such a goal in the past 25 years have certainly been quite remarkable and need not be rehearsed here. But before accepting that botanic gardens should automatically assume the mantle of custodian of the world's *ex situ* plant conservation collections, we need to examine the actual capacity of botanic gardens to undertake such a role and before we can do that, assess the size of the task and the costs involved.

THE CALCULUS OF *EX SITU* CONSERVATION

The number of species for which *ex situ* conservation is an appropriate option is very difficult to calculate. Even if we were to restrict it to threatened species, as in Target 8 of the Global Strategy for Plant Conservation, we are faced with two problems. On the one hand, we do not know how many species are currently threatened as national assessments are incomplete in many countries and the only global assessment available is the IUCN Red List (IUCN, 2008) which seriously underestimates the actual numbers. Based on a figure of 298,506 species, global assessments have been made for only three per cent of species and even that sample is unrepresentative and biased (Brummitt *et al.*, 2008). On the other hand, the effects of climate change will lead to more species becoming threatened and also change the threatened status of some of those that have currently been assessed. The best we can do is make an educated guess as to the number of species threatened today by extrapolation from known samples and then factor in an allowance for global change over, say, the next 50 years. For example, Newton & Oldfield (2008) summarize the results of ten recent assessments of different groups of trees, covering more than 2,500 species, and estimate that a mean of 42% were classified as threatened. Using various lines of evidence, Maunder *et al.* (2004) come up with a figure of about 30% of the world's flora threatened with extinction which translates to between 90,0000 and 126,000 taxa[6]. Applying such figures to the recommendation of Target 8 of the GSPC that 60% of threatened species be maintained in accessible *ex situ* collections would give us a figure of 54,000 to 75,600 which is well in excess of current capacity or even aspirations.

[6]The range reflecting differing estimates as to the total number of plants known.

FROM THE SEEDS OF EXCHANGE TO THE SEEDS OF CONSERVATION

Botanic gardens have been involved in the collection and exchange of seed and other propagules with other gardens since the late 17th century and this led to the development of the Seed List (*Index Seminum*) system which effectively created a worldwide network of botanic gardens and other scientific institutions. The purpose of such seed exchange was not to do with conservation but rather the introduction of new plants into cultivation and the building up of diverse plant collections in botanic gardens. Much has been written about the merits and failings of the seed list system (Aplin *et al.*, 2007; Clemente Muñoz, 1994; Heywood, 1964a; 1964b; 1987; Howard *et al.*, 1964; Thompson, 1970; Yeo & King, 1965) and will not be discussed further here. A growing number of gardens began to devote efforts to building up accessions of wild species of conservation interest and including seed of such species in their Seed Lists.

Today botanic gardens are the main centres that hold *ex situ* collections of wild species, both as living collections and as seed in seed banks. The number of botanic gardens with seed banks is over 200[7] (BGCI, 1998), ranging from small numbers of accessions stored in a domestic or commercial deep freezer to large-scale custom-built facilities. Several European botanic gardens have developed or house significant seed banks. That at the Jardín Botánico de Córdoba, Spain is the Germplasm Bank of the Environmental Agency of Andalucía (Banco de Germoplasma Vegetal Andaluz de la Consejería andaluza de Medio Ambiente) and stores more than 7,000 accessions or propagules, mainly seeds, of more than 1,500 different species of Andalusian plants and about 500 other Iberian endemic species. The Millennium Seed Bank of the Royal Botanic Gardens Kew at Wakehurst Place (UK) is in a category of its own and is the largest seed bank in the world dedicated to wild plants. It plans to collect and conserve 10% of the world's seed-bearing flora, principally from arid zones by 2010 and to collect and conserve seeds of the entire UK native seed-bearing flora by 2010. The whole project is expected to cost approximately £80 million. In the United States, at Rancho Santa Ana, a garden dedicated exclusively to California's native plants, the Fletcher Jones Education Center for the Preservation of Biodiversity complex includes cold storage for seeds, climate-controlled growth chambers that facilitate germination studies and graduate program research, seed processing equipment and ample laboratory space. It is a member of the Center for Plant Conservation (CPC) whose National Collection of Endangered Plants contains seeds, cuttings and other plants for more than 700 of the USA's most imperilled native plants held at the 33 institutions (mainly botanic gardens and arboreta) that participate in the Center.

Even if botanic gardens focus primarily on the *ex situ* conservation of rare and seriously endangered species, as has been customary in recent years, this will still represent a huge, if not overwhelming, challenge. In preparing the Botanic Gardens Conservation Strategy, I suggested that, based on an estimated total number of 25,000

[7]For a survey of botanic garden seed banks in 1995 see Laliberté (1997).

candidate species, if 250 botanic gardens participated in a programme of *ex situ* conservation, each would have to accept responsibility for an average of 100 species and if duplicate collections were allowed for, this would rise to 200–300 species each. These figures are substantially higher than the average of 18 threatened species that the partners of the Center for Plant Conservation manage. Maunder *et al.* (2004) provide a useful discussion of this topic in their book on *ex situ* conservation of wild species and if we accept their estimate that the total number of threatened species is in the range of 90,000 to 126,000, this would give an average requirement for each of the 250 gardens to conserve *ex situ* stock of 360 to 504 species without allowance for duplicates. Taken at face value, this would need either the involvement of a much larger number of the world's c. 2,500 botanic gardens or the creation of hundreds more botanic gardens with seed banks (at present there are c. 200) and other *ex situ* facilities, or a combination of both. As is well known, the present distribution of botanic gardens is heavily biased towards temperate regions such as Europe and North America so that it is not just the number of gardens involved in *ex situ* conservation that needs to be increased but their location that needs to be rebalanced.

If looked at in terms of seed storage alone, the *ex situ* requirement would be equivalent to three to four additional Millennium Seed Banks *and* a vast increase in the number of seed banks and infrastructure in the partner countries, although in practice additional botanic gardens or *ex situ* cultivation facilities would be needed for those species with recalcitrant seed[8]. If future climatic scenarios are factored in, even these figures will not be sufficient[9].

The above calculations are very rough and ready but give an idea of the probable scale of operations needed for *ex situ* storage in seed banks or field gene banks. Unlike the Target 8 on *ex situ* conservation and Maunder *et al.* (2004), I have deliberately excluded recovery and restoration programmes as these are essentially *in situ* although they may include *ex situ* components and not only are they highly complex and costly but involve a wide range of stakeholders and require the deployment of conservation specialists that most botanic gardens do not have available.

Barthlott *et al.* (2000) on the other hand, offer a more sceptical perspective:

> *"Even if half of the world's 1775 gardens could be recruited today for a serious ex-situ conservation effort, each of them would have to cultivate around 40 species that are officially endangered. However, in order to qualify as a serious ex-situ conservation effort, this would have to be done in a very elaborate manner. As a result, ex-situ conservation of a significant part of plant diversity is no longer considered feasible. Therefore, there is a consensus that ex-situ*

[8]Linington *et al*., (2003) also address this issue in the light of Target 8 of the GSPC and give estimates of the likely costs involved.

[9]In the light of climate change and the ever-increasing impact of human activities, the Millennium Seed Bank intends to accelerate its activities to secure in safe storage 25% of the world's plant species by 2020 (Millennium Seed Bank Project, 2009)

conservation makes sense only in special cases and should be considered merely a supportive measure to further in-situ conservation."

In drawing attention to these issues in no way do I wish to detract from the significant role of botanic gardens in the *ex situ* conservation of wild species and the quite remarkable progress they have made so far in some parts of the world, but even if one puts aside such vital questions as the adequacy of sampling and maintenance of the material and long-term sustainability (Laliberté, 1997; Heywood, 1999; Schoen & Brown, 2001), it is quite clear that the present botanic garden estate is not at present capable of handling the task of *ex situ* management of wild species on the scale that is required if it is to be adopted as a major strategy. In view of the very limited facilities, finance and staffing of many botanic gardens, it is probably unrealistic to believe that botanic gardens alone will be able to take on such a massive and highly expensive responsibility and it is not necessarily appropriate that they do. And if the present structure of botanic gardens systems cannot cope, then what other solutions can be proposed?

THE NEED FOR AN INTERNATIONAL MECHANISM?

The large scale *ex situ* conservation of plant diversity is a vast enterprise and not one that botanic gardens can or should attempt to undertake on their own. It would have to be organized and implemented not just by botanic gardens through IABG and BGCI but by a consortium of international conservation and biodiversity agencies and organizations such as CGIAR, UNEP, FAO, Biodiversity International, IUCN and the CBD. IABG and BGCI could be charged with responsibility for particular aspects of policy development, and regional and national associations would have a major part to play as implementing agencies along with existing agricultural and horticultural gene banks and any new facilities that need to be developed. I have suggested (Heywood, 2002) that some form of inter-governmental co-ordinating authority or at least mechanism for wild species germplasm policy should be established, comparable in some ways to the CGIAR (although with a broader remit covering *in situ* as well as *ex situ* conservation and management), that would establish a detailed policy on logistics, sampling, accessions, storage and other technical matters and determine priority species or groups of species on an international, regional and national basis. A similar proposal has been made by Laliberté (1997) who proposed that:

"BGCI, IPGRI and FAO should be involved in the establishment of a global network of plant genetic resources which would include the accessions of botanical institutions. This survey can be used to prepare a draft strategy for the development of an International Botanic Garden Seed Bank Network, including a list of long-term data requirements and a forum for the exchange of ideas and information and to help create new institutional links with the crop genetic resource sector."

We need to explore how far existing agricultural and horticultural gene banks can increase their involvement in the conservation of wild species (already many contain accessions of crop wild relatives) and botanic gardens should work more closely with the plant genetic resources sector[10]. For example, some of the participants in the American Center for Plant Conservation use the National Center for Genetic Resources Preservation, a USDA facility in Fort Collins, Colorado for seed storage. In South Africa, seed of wild species collected by SANBI is stored at the National Plant Genetic Resources Centre in Roodeplaat near Pretoria and in parallel at the Millennium Seed Bank, Kew; the aim is to have 40% of the native flora represented in the National Botanic Gardens. The Millennium Seed Bank at Wakehurst Place, Royal Botanic Gardens Kew, which aims to develop a global seed conservation network capable of safeguarding wild plant species is an example of how large-scale cooperation might work. Its network comprises c. 20 partner countries and over 40 partner institutions. Already, some steps have been taken at a regional level, notably in Europe and at a national level as in the USA, to move towards a co-ordinating mechanism. A number of regional initiatives exist, such as ENSCONET – The European Native Seed Conservation Network[11], GENMEDOC, an inter-regional network of West Mediterranean seed banks[12], and a few national *ex situ* networks such as REDBAG (Red Española de Bancos de Germoplasma de Plantas Silvestres), the Spanish network of germplasm banks of wild plant species.

The recommendations from the workshop on Gene Banks and Botanic Gardens at the Fifth International Botanic Gardens Conservation Congress held in Cape Town, South Africa, will, if implemented, make a major contribution to such a policy. The Action Plan for Botanic Gardens in the European Union and some of the recommendations made at EuroGard 2000 are important contributions to this objective and protocols for *ex situ* conservation for all groups of vascular plants, cryptogamic plants and fungi have been produced. But despite these and other initiatives, the *ex situ* conservation of wild species is still largely uncoordinated in many parts of the world and a global strategy is required. The first task for such a strategy will be a critical review of *ex situ* needs and capacity, including an assessment of the need for new *ex situ* facilities – seed banks, botanic gardens and perhaps new kinds of facilities for growing and maintaining *ex situ* collections.

TOWARDS AN UNCERTAIN FUTURE

In a period of rapidly changing climatic conditions and uncertainty, a massive acceleration of our efforts to conserve plant diversity is needed to equip us as far as possible for the uncertain future that we face. This will include both *ex situ* and *in situ* approaches and cover both wild and agricultural germplasm. A vast increase in *ex situ* collections

[10]Perhaps an indication of this is the fact that none of the contributors to Guerrant *et al*. *Ex situ plant conservation* (2004) cites Hawkes *et al*. *Plant Genetic Resources* (2000). On the other hand the latter devote several pages to considering the role of botanic gardens in *ex situ* conservation.
[11]http://www.ensconet.eu/
[12]http://www.genmedoc.org/eng/progetto/presentazione.htm

will be needed over the coming years to meet the demands of a variety of users and to complement our protected area systems and other *in situ* approaches. Botanic gardens will continue to have a major role to play in this as well as having an increasing involvement in recovery and restoration projects. We should be under no illusions as to the size and complexity of the task: it is well beyond the present capacity of the botanic garden estate and a global system and mechanism is needed for collecting, maintaining and deploying *ex situ* accessions of wild species. This will involve both seed banks and living conservation collections in botanic gardens and other germplasm banks and will require new capacity which will have to be carefully planned to achieve this goal. Even so, there are no guarantees and we will need to be flexible in our approaches and develop ever more cooperation between the various agencies involved.

REFERENCES

APLIN, D.M., LININGTON, S. & RAMMELOO, J. (2007). Are indices seminum really worth the effort? *Sibbaldia* 5: 93–107.

BARTHLOTT, W., von den DRIESCH, M., IBISCH, P.L., LOBIN, W. & RAUER, G. (2000). *Botanic Gardens and Diversity*. Federal Agency for Nature Conservation, Bonn.

BGCI (1998). Seed Banks. Available at: http://www.bgci.org/resources/Seedbanks/ (Accessed: June 2009)

BÖCHER,T.W. & HJERTING, J.P. (1964). Utilization of Seeds from Botanical Gardens in Biosystematic Studies. *Taxon* 13: 95–98.

BRUMMITT, N., BACHMAN, S.P. & MOAT, J. (2008). Applications of the IUCN Red List: towards a global barometer for plant diversity. *Endangered Species Research* 6: 127–135.

CLEMENTE MUÑOZ, M. (1994). Los *Indices Seminum* de los Jardines Botánicos de la Asociación Ibero-Macaronésica. *Amaranto* 4: 14–21.

CLEMENTE MUÑOZ, M. & HERNANDEZ BERMEJO, J.E. (1990). Seed exchange experience of a germplasm bank in the Mediterranean area, pp. 115–117. In: HERNÁNDEZ BERMEJO, J.E., CLEMENTE MUÑOZ, M. & HEYWOOD, V. (Eds.) *Conservation Techniques in Botanic Gardens*. Koeltz, Koeningstein.

DIXON, K. (2007). The science-living collections continuum in botanic gardens. *Sibbaldia* 5: 5–14.

FRANKEL, O.H. (1974). Genetic conservation: our evolutionary responsibility. *Genetics* 78: 53–65.

HAWKES, J.G., MAXTED, N. & FORD-LLOYD, B.V. (2000). *The* Ex Situ *Conservation of Plant Genetic Resources*. Kluwer Academic Publishers, Dordrecht.

HAMILTON, M.G. (1994). Ex Situ Conservation of Wild Plant Species: Time to Reassess the Genetic Assumptions and Implications of Seed Banks. *Conservation Biology* 8: 39–49.

HEYWOOD, V.H. (1964a). Seed Lists and Taxonomy. *Taxon* 13: 94–95.

HEYWOOD, V.H. (1964b). List of Botanic Gardens offering spontaneous seed. *Taxon* 13: 137–142.

HEYWOOD, V.H. (1987). The role of seed lists in botanic gardens today. In: SIMMONS, J.B. *ET AL.* (Eds.) *Conservation of Threatened Plants*. Plenum Press, New York.

HEYWOOD, V.H. (1999). The role of botanic gardens in *ex situ* conservation of agrobiodiversity. In: GASS, T., FRESE, L., BEGEMANN, F. & LIPMAN, E. (Eds.) *Implementation of the Global Plan of Action in Europe – Conservation and Sustainable Utilization of Plant Genetic Resources for Food and Agriculture.* Proceedings of the European Symposium, 30 June–3 July 1988, Braunschweig, Germany. International Plant Genetic Resources Institute, Rome, pp. 102–107.

HEYWOOD, V.H. (2002). The future of botanic gardens – challenges and conflicts. In: *Jardins Botânicos. Que perspectivo para o futuro?* Actas VII Simpósio da Associação Ibero-Macaronésica de Jardins Botânicos. 24 a 26 Jilho 2002, Auditorio da Lagao Branca, Tapada da Ajuda, Lisboa, Instituto Superior de Agronomia, Lisboa, 11–21, 2002.

HEYWOOD, V. (2003). Conservation and sustainable use of wild species as sources of new ornamentals. In: DÜZYAMAN, E. & TÜZEL, Y. (Eds.) *Proceedings of the International Symposium on Sustainable Use of Plant Biodiversity to Promote New Opportunities for Horticultural Production Development*, *Acta Horticulturae* Number 598: 43–53.

HEYWOOD, V.H. (2007). The use and economic potential of wild species: an overview. Chapter 43 In: MAXTED, N., FORD-LLOYD, B. V., KELL, S. P., IRIONDO, J. M., DULLOO, M. E. & TUROK, J. (Eds.), *Crop Wild Relative Conservation and Use*. CABI, Wallingford.

HEYWOOD, V.H. & DULLOO, M.E. (2006) [2005]. In situ *Conservation of Wild Plant Species – a Critical Global Review of Good Practices*. IPGRI Technical Bulletin No. 11. FAO & IPGRI. IPGRI, Rome (2006).

HOWARD, R.A., GREEN, P.S., BAKER, H.G. & YEO, P.F. (1964). Comments on "seed lists". *Taxon* 13: 90–84.

IUCN RED LIST (2008). *The IUCN Red List of Threatened Species™2008*. Available at: http://www.iucnredlist.org/

LAGUNA, E., FERRER, P.P. & MARZO, A. (2008) Bancos de germoplasma de hábitats, una nueva propuesta para la conservación *ex situ. Conservación Vegetal* 12: 9–11.

LALIBERTÉ, B. (1997). Botanic garden seed banks/genebanks worldwide, their facilities, collections and network. *Botanic Gardens Conservation News* 2: 18–23.

LININGTON, S.H., TENNER, C. & SMITH, R.D. (2003). Seed banks: *ex situ* is not out of place. *Biologist* 50: 202–207.

MAUNDER, M., GUERRANT JR., E.O., HAVENS, K. & DIXON, K.W. (2004). Realizing the full potential of *ex situ* contributions to global plant conservation. In: GUERRANT JR. E.O., HAVENS, K. & MAUNDER, M. (Eds.) *Ex Situ Plant Conservation. Supporting species survival in the wild*. Island Press, Washington DC.

Millennium Seed Bank Project. Available at: http://www.kew.org/msbp/where/index.htm (Accessed: 9 March 2009)

NEWTON, A.C. & OLDFIELD, S. (2008). Red Listing the world's tree species: a review of recent progress. *Endangered Species Research* 6: 137–147.

SCHOEN, D.J. & BROWN, A.H.D. (2001). The conservation of wild plant species in seed banks. *BioScience* 51: 960–966.

THOMPSON, P.A. (1970). Seed banks as a means of improving the quality of seed Lists. *Taxon* 19: 59–67.

WIELAND, G. D. (1995). *Guidelines for the management of orthodox seeds*. Center for Plant Conservation, St. Louis, MO.

YEO, P. F. & KING, C. J. (1965). Methods of Seed-Exchange: An Appeal to Botanic Gardens. *Taxon* 14: 179–180.