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The response of botanic gardens to climate change

During the last 30 years or so, botanic gardens have modernized their outlook and their fundamental role to become increasingly active in the conservation of plant diversity. As a response to the biodiversity crisis as envisaged during the last two decades a considerable number of gardens have developed programmes of research, horticulture and environmental education particularly dealing with the conservation of rare and threatened species. Indeed, botanic gardens now have much to offer the conservation world not only as the principal centres for *ex situ* conservation but also as supporting institutions for the conservation of plants *in situ*. Many gardens have developed not only living collections but also important germplasm banks or seed banks for the long-term storage of threatened plants as an insurance policy against extinction.

With the development of BGCI, Botanic Gardens Conservation International, the world's botanic gardens have also become a major voice for plant conservation in the international forum. This has been demonstrated by the lead taken by botanic gardens in the development of *The Gran Canaria Declaration calling for a Global Program for Plant Conservation* (BGCI, 2000) which resulted in the *Global Strategy for Plant Conservation* (CBD, 2003). *The Global Strategy* proposed a number of conservation targets to be achieved by the year 2010. Many of which have direct relevance for botanic gardens and in many countries gardens have made a major effort to progress towards these objectives. However, there is concern that now, in the middle period for achieving the targets, a new challenge has to be faced, climate change, that was not originally a major element of the *Global Strategy*.

This new, most alarming threat to plant conservation, global climate change or more popularly "global warming" has come on to the scene since the *Global Strategy* was developed over five years ago. The world is changing and probably more quickly than at any time in human history and the most disruptive and perhaps least predictable alteration concerns the potentially disastrous effects of a rapidly changing global climate. There has been major governmental activity and alarm over the probable consequences of climate change. For instance, the *Stern Review on the Economics of Climate Change* for the British Government has really helped to focus on the need to take urgent, immediate measures (Stern, 2006). However, when the *Global Strategy* was originally developed, climate change was an issue to be resolved and reversed by the control of greenhouse gas emissions and the major emphasis was on the Kyoto Accord under which governments would take the necessary measures to limit their emissions. Over the past two or three years, however, the real extent of the problem is beginning to be understood and the fact that the weak measures that came out of Kyoto are not sufficient to prevent changes which potentially will be devastating for plant diversity and biological diversity in general. The Kyoto measures are, indeed, even if they were fully implemented, not sufficient to reverse climate change. The new challenge is, therefore, about how the *Global Strategy* and national strategies are taken forward for plant conservation in the face of such potentially devastating change.

Left: Gran Canaria Group of international experts who formulated a second *Gran Canaria Declaration on Climate Change and Plant Conservation* in Las Palmas de Gran Canaria, April, 2006

The most recent models based on a temperature rise of 2-3°C over the next 100 years suggest that up to 50% of the 400,000 or so higher plant species will be threatened with extinction. Furthermore, a recent study of six biodiversity-rich regions of the world covering 20% of the land area indicates that up to 37% of all species in these regions will be extinct by 2050 including for example up to 40% of South Africa's Proteaceae (Thomas *et al*., 2004). Models by Carlos Nobre from Brazil suggest that the wet tropical forests of the Amazon Basin will all but disappear with huge losses of biodiversity (2004). In Africa, Lovett and his fellow researchers predict that the tropical forests of west and central Africa will be seriously affected and that between 50 and 80% of species will have their range severely reduced, many to the point of extinction (Lovett *et al*., 2005; McClean *et al*., 2006). A recent report on the effects of climate change on the tropical rainforests of northern Queensland, Australia states that "the impact on biodiversity is likely to be very serious and could be catastrophic under some scenarios" (Krockenberger *et al*., 2004). It goes on to say that "Research, based on current models, shows that many species of animals and plants are at highly increased risk of extinction as a result of climate change, even under the least extreme of scenarios". Even a 1°C rise in temperature will cause a decline of 50% of the taxa in the area occupied by the highland rainforests of Queensland. The Queensland report goes on to make a very important and relevant statement for botanic gardens with respect to the conservation of biodiversity under such circumstances, "consideration of climate change may show that *ex situ* is the only realistic tool for some of the most at-risk species….". Some examples of the predicted impacts of climate change at the species level are shown in Box 1.

Thus, faced with climate change and the prospect of mass extinction of biodiversity, it is necessary to see plants not only as essential components of ecosystems but also as the most important natural resources for the future of mankind. It is necessary to face up to the major problems of conserving ecosystems in a changing environment and, at the same time make sure that the individual components of the ecosystems are not lost, that is the species. There are no ecosystems without species! Therefore, botanic gardens need to be very concerned with creating reserve collections *ex situ* as an insurance policy for facing the effects and the impacts, on local human communities of drastic environmental change and the depletion of their currently available plant resources (Bramwell, 2006).

The challenge for botanic gardens is: how do they contribute to this species-based insurance policy in the coming years and after 2010 when the *Global Strategy* achievements will be reviewed? The *Global Strategy* gives many of the guidelines needed but in the light of the new challenge of climate change the members of the Gran Canaria Group of international experts who produced the first *Gran Canaria Declaration* leading to the *Global Strategy* have formulated a second *Gran Canaria Declaration on Climate Change and Plant Conservation* and are currently engaged in preparing an action plan to facilitate the adaptation of current plant conservation policies to meet this challenge (BGCI & Cabildo de Gran Canaria, 2006). BGCI surveyed its member gardens on their response to climate change for this meeting and the main results are given in Box 2.

The first major step is to redefine the priorities. Current thinking on endangered species is anchored to the assignment of IUCN Red List Categories. Thus the principles for assessing the conservation status and extinction risk for species are based on past and current areas of distribution and on the fluctuation of numbers of individuals and populations. With climate change, however, plants will be faced with a whole new series of threats and current concepts of what are threatened species and how they are defined will need to be completely reconsidered and revised! Without doubt botanic gardens will have a major role in adapting both science and living collections to the new climate change situation. They form a unique international network of over 2500 plant-orientated institutions throughout most countries of the world and they have amongst their numbers some of the world's leading plant research centres, for example the Royal Botanic Gardens, Kew, UK (RBG), the Botanic Gardens Trust, Sydney, Australia and Missouri Botanical Gardens, USA.

Box 1. Some examples of the predicted impacts of climate change at the species level

A European research group developed a model called "EUROMOVE" which used climate data from 1990 to 2050 as compiled from the IMAGE 2 model, and determined climate envelopes for about 1400 plant species by multiple logistic regression analysis. The climate envelopes were applied to the projected climate to obtain predictions about plant diversity and distributions by 2050. The results indicated that the species show differing responses to the forecasted climate change. For some species, their total area will increase while for other species their area will decline. Some examples include:

- *Scleranthus perennis* (Perennial Knawel), a perennial herbaceous plant of the carnation family with a European distribution will potentially undergo dramatic area reductions, with only 59% of its current distribution area remaining. The species will remain only in the centre of Central Europe, and will disappear from large parts of its distribution area in western Europe and western Russia. Its northern distribution area will slightly expand, mainly in the southern part of Finland.
- *Botrychium lunaria* (Common Moonwort), a Dutch red list species with an Atlantic and northern distribution is predicted to decrease dramatically by 2050 and it is calculated to remain in only less than half of its current area (47%). Hardly any new areas become suitable by 2050, and *Botrychium lunaria* will retreat into western Scandinavia, Iceland, Scotland, and the Alps.
- *Parietaria judaica* is a Mediterranean species growing on walls along the Atlantic and Mediterranean. Its climatically suitable area will remain largely unchanged (93%); calculations predict a potential increase of its current area (128%), primarily extending eastward into Germany and Denmark. *Parietaria judaica* is predicted to disappear from southern Portugal and Spain.

Bakkenes, M., Alkemade, J.R.M., Ihle, F., Leemans, R. and Latour, J. B., 2002. Assessing effects of forecasted climate change on the diversity and distribution of European higher plants for 2050. *Global Change Biology* **8**: 390-407.

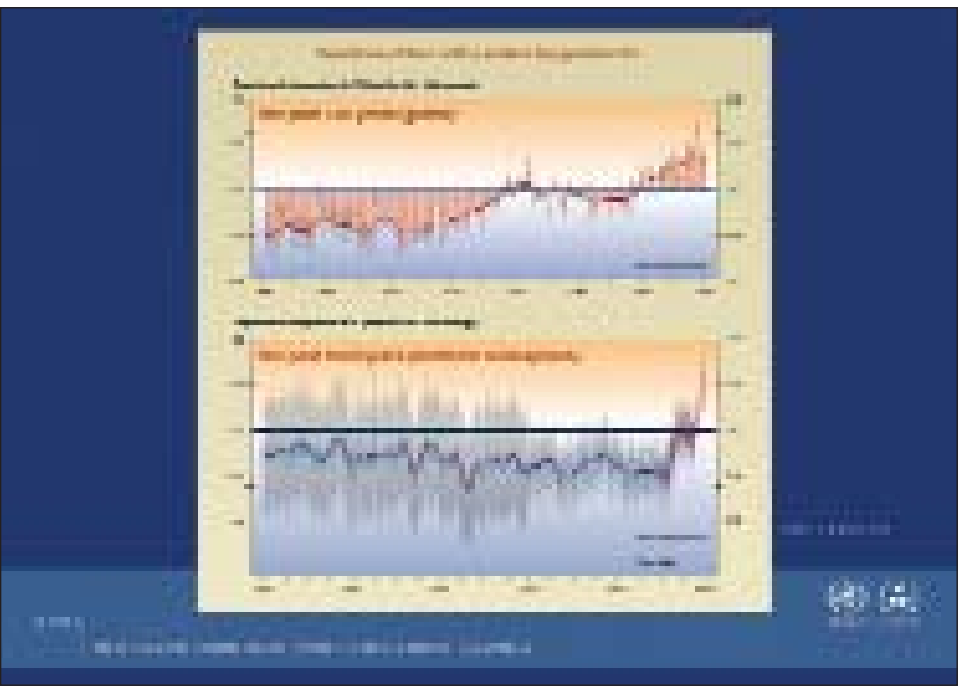
Above: *Echium wildpretii* Barcelona Botanic Garden, Spain. Canary Island endemic (Photo: BGCI)

Many other gardens are also moving very quickly towards becoming important regional and local focal points for conservation-orientated plant research. Botanic gardens are visited by several hundred million people each year making them probably the principal public interface for connecting with plant conservation and for environmental education in general.

Climate change is taking place quickly and the recent meeting of the Gran Canaria Group, leading to the second *Gran Canaria Declaration*, calls on governments to take urgent action to protect plant diversity from the threats of climate change. The group emphasized, in its discussions and report, the increasing importance of *ex situ* conservation as a means of saving vital natural resources for the future. The role of botanic gardens as centres of *ex situ* conservation was also recognized, not only as repositories for living collections but also through their historical relationship with seed storage and exchange. Many gardens round the world have developed effective seed banks for conserving germplasm of wild plant species and the establishment of more regional and local seed banks in botanic gardens is strongly advocated. Perhaps the most important one to date is RBG's Millennium Seed Bank, a major investment for the long-term future of plant diversity (see article in this issue of *BGjournal*). However, even some smaller gardens have important regional seed banks and participate in regional programmes such as the European Native Seed Conservation Network (ENSCONET) (ENSCONET, 2007). In Spain, there are good regional examples, the Andalusian seed bank at Cordoba Botanic Garden (Hernández Bermejo & Clemente Muñoz, 1996), an inter-regional network of Mediterranean Seed Banks (GENMEDOC) (GENMEDOC, 2007) and the Macaronesian Islands Regional Seed Bank (BASEMAC) at the "Viera y Clavijo" Garden on Gran Canaria with its partner centres on Madeira and on Faial in the Azores (Roca Salinas *et al*., 2004; Bramwell, 2007). If adapting to climate change is to be successful, however, current seed-bank partnerships need to be developed into a worldwide network of seed banks with the objective of conserving the seeds of wild plants on a global scale. This would be a major contribution to conservation and the custody of natural resources in the post 2010 climate change circumstances when increasing global population and reduced available natural resources will undoubtedly sooner or later precipitate a major survival crisis for large parts of humanity. The building of such a network should be one of the major objectives between now and 2010 and then beyond.

In a future world where vegetation and whole ecosystems will be changing and will generally be depleted by climate change, such a global reserve of germplasm of wild plants will be vital for human adaptation through restoration, reintroduction and even for the total replacement of lost ecosystems. Germplasm banks will also be a source of plants and genetic diversity for the development of new crops and for the adaptation of old ones, for medicinal plants, green energy sources and other uses. If, as currently predicted, large numbers of species do become extinct in the wild then the world's seed banks, will become the only source to humankind of those species and their germplasm in the future.

There are schools of thought that consider that in some situations, the migration of plants will mitigate the effects of climate change. However, both the time scale for migration and factors such as natural barriers,



Left: Variations of the Earth's surface temperature for the past 140 years (global) and the past 1000 years (Northern Hemisphere) Source: Intergovernmental Panel on Climate Change (see page 36)

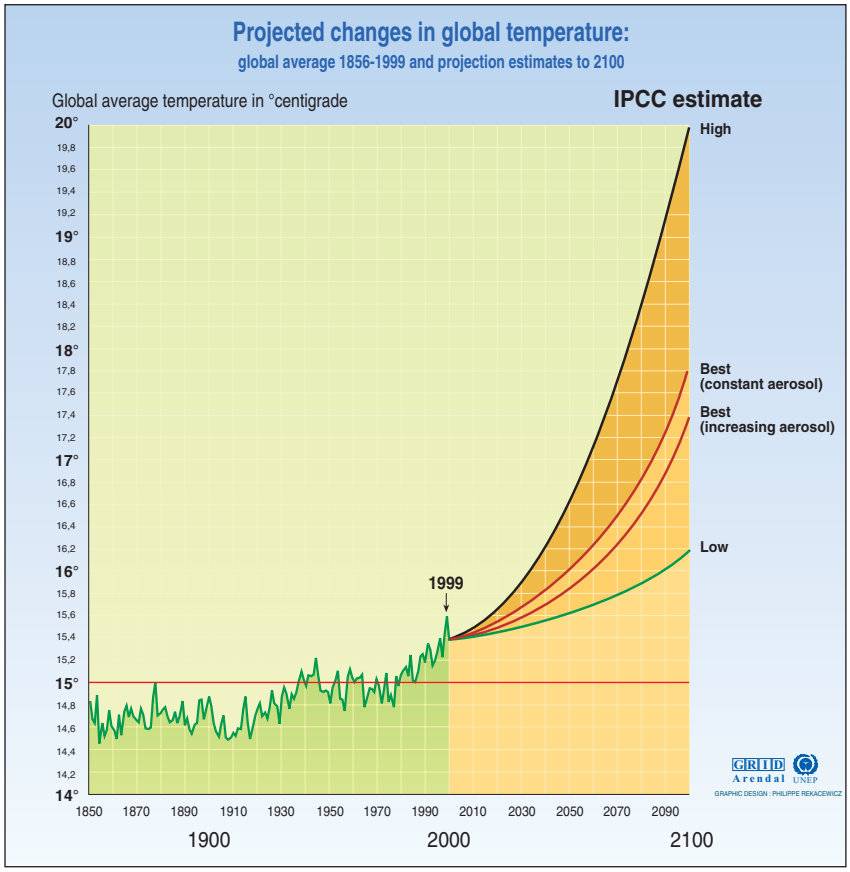
Right: Seed capsules in the seed bank of the Jardín Botánico "Viera y Clavijo" – an insurance policy for the future (Photo: BGCI)

Far right: Botanic gardens, the main interface between plants and the public (Photo: David Bramwell)

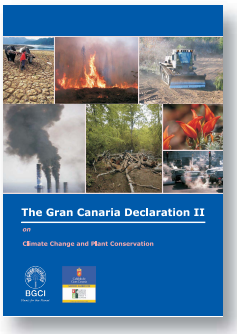
dispersal mechanisms, absence of pollinators, absence of available area for colonization, sea level rise as well as man-made barriers such as agricultural zones and urban sprawl as poor people migrate to the cities will put severe limitations on both the natural movement of plant communities and on the creation of major migratory corridors. The movement of seed and living plants through seed banks and botanic gardens has the potential however, to become one of the most important man-made "migratory corridors" for the re-establishment of plant communities in the future (termed an *assisted migration* process by the author). In many cases it will probably be the only way of moving even the most basic set of species for any community restoration and as a source of natural resources for adaptation to new circumstances. Certainly the experience and skills that botanic gardens staff have acquired over several centuries of growing both native and exotic plant species will be of vital importance if assisted migrations are to succeed.

A second area in which botanic gardens can play a major role is in the local monitoring of the effects of climate change. Many gardens have, over the years, accumulated a considerable amount of information about their local or regional floras. This information will become increasingly valuable as the local effects of rising temperatures are observed and, if possible protective measures initiated. Species distribution, vegetation maps and plant community data can all play a major role in monitoring change. As more and more research potential and economic resources at universities are taken up by molecular studies and biochemistry, botanic gardens are becoming the only sources (even the last bastions) of whole plant biologists, taxonomists and field ecologists for the future. This lack of foresight by universities and research councils in the majority of developed countries can only become an acute problem in the years to come. Currently, molecular biology might seem a more exciting area for research and it doubtless has a value in the advancement of science, but its emphasis, even its hegemony to the detriment of whole-plant science, taxonomy and field ecology, will not contribute to the practical future of humanity in the face of global climate change.

However, much more accurate and refined climate change models on a local or regional scale will be needed because corrective measures for the conservation of floras and ecosystems will have to be taken at these levels. This implies that the role of botanic garden taxonomists and field botanists will become more and more important for monitoring changes in vegetation distribution, species composition in



Right: Projected Changes in global temperature: global average 1856-1999 and projection estimates to 2100 Source: Climatic Research Unit, University of East Anglia, Norwich, UK. Projections: IPCC report 95 (see page 36)



Above: Cover of *The Gran Canary Declaration II on Climate Change and Plant Conservation*

plant communities and species distribution on a local scale. This will provide better data about climatic effects on local plants and communities for modelling the future and also by functioning as a plants threat early warning system. Furthermore, botanic gardens have a wealth of data on how plants can tolerate different climatic regimes through garden records and observations and the experience of growing plants including exotics. In northern Europe tropical plants are not grown under exactly the same conditions as in their native habitats but in rather varying greenhouse conditions that mimic different climate regimes. This is especially true for temperature tolerance, rainfall (watering regimes) and atmospheric humidity so that by studying garden records and calling on the wisdom accumulated by the gardeners, an estimate can be made of the tolerance range of the species grown and of what might happen to them in their natural habitat during global climate change. Such estimates of species tolerance can contribute important hard data both to climate change modelling, ecosystem management and to the selection of specifically vulnerable species for use in monitoring climate change effects.

So where does this lead in defining the role of botanic gardens in relation to climate change? The recent realization at a political level, of the importance of the effects of global climate change on the world's economy and on biological diversity will mean that a major international effort will be made over the next 20 years or so to conserve natural resources and minimize potential biodiversity loss due to global warming. From a plants point of view the *Global Strategy* will need to be adjusted and its terms of reference extended well beyond the initial proposal of 2010. The role of botanic gardens will become increasingly important in the period after 2010 because the effects of climate change will be seen on an increasing scale. The changing nature of threats and the large numbers of endangered species including many not currently considered to be threatened will be increasingly apparent. Those gardens participating in the international network

Box 2. Climate change: the botanic garden response

BGCI undertook a survey of its members in November 2005. The following questions were asked:

- Does your institution maintain meterological or phenological records?
- Is your garden involved in any research on plants and the impact of climate change?
- Have you modified your planting schemes in response to climate change?
- Is your garden involved in any public awareness or education activities on this topic?
- Are you undertaking any steps to reduce or off-set carbon dioxide emissions?

A more recent survey (2007) has indicated that 88% of gardens responding are taking, or plan to take action related to climate change.

Summary of results

Maintenance of meteorological or phenological records and monitoring
Phenological records are being collected by botanic gardens around the world, including gardens in Europe, North America, China, Kazakhstan, Bangladesh, Indonesia, Mexico, Malaysia and Russia. Many gardens also maintain meteorological records, often going back over long periods of time. For example, Bogor Botanic Garden in Indonesia has kept records for more than 30 years as has the Botanic Garden of the Institute of Crop Botany in Bangladesh. In Austria, the University Botanic Garden, Innsbruck has kept meteorological records at its main Botanic Garden (600m) since 1995 and at the Alpine Garden (1950m) since 1994. Furthermore, the Landesmuseum Kärnten in Austria stores a series of photos of the Carinthian Alps mountain tops, which clearly shows glaciers receding. In addition, the Regional Botanic Garden of *Cadereyta* in Mexico has observed its local alpine region getting warmer and drier. For example, the cactus *Thelocactus leucacanthus* was previously reported as occurring at a maximum height of 1900m, but has recently been recorded at 2600m. Similarly, the Botanic Garden at Syktyvkar, Russia, has noted a change in tree development and life history that was previously constrained by the long period of extreme cold e.g. *Quercus robur* usually bears fruits only once every 4-5 years, but this recently occurred in both 2004 & 2005.

Research
Many examples were cited, including:

- The Argotti Gardens in Malta is involved in research on the drought resistant conifer *Tetraclinis articulata*.
- Kings Park and Botanic Garden, Australia are carrying out research on the drought tolerance of rare and threatened plants.
- The Forest Research Institute, Malaysia is assessing the carbon stocks and sequestration potential of the natural and plantation forest in Malaysia.
- Olso University Botanic Garden, Norway is predicting future plant immigrations and vegetation changes in Svalbard due to global warming.
- The Royal Botanic Gardens (RBG), Melbourne, Australia is involved with the management of weeds, biosecurity and pest management in relation to climate change - the tropical palm disease "pink rot" has made an appearance in the last two years in their gardens, growing on the indigenous *Archontophoenix* spp.
- Xishuangbanna Tropical Botanical Garden, China has carried out research on microclimate changes in the tropical rainforest fragments of the region.
- The National Botanic Garden of Wales, UK has a 3 year study of the potential evolutionary changes of *Senecio cambrensis* induced by climate change.

Modified planting schemes
Many gardens (approximately one third of respondents) reported changes in the plants they grow in their gardens, with for example, gardens now growing palms outside which could previously only be grown in greenhouses. The Diomides Botanic Garden in Greece has stopped cultivating some species requiring exposure to low temperatures and Mediterranean rather than alpine plants now thrive at the Landesmuseum Kärnten in Austria. RBG Melbourne is planning its planting and management for reduced water availability, including C4 grasses for turf while the Georgetown Botanic Gardens in Guyana stated "we have done a complete new scheme to cater for our climate change". In a related response to climate change, Oxford University Botanic Garden has extended its opening season from May 20-Oct 31 to April 1-Nov 30, in response to earlier flowering of bluebells, and later autumn colours.

Education and public awareness
About one third of respondents had education resources focused on climate change. Some gardens had static exhibits on the subject, but many undertook lectures to visiting school children, or to the general public. These gardens ranged from those in the UK (EdenProject, Oxford, Wales), to those in Georgia, USA and Bangladesh.

Reducing carbon emissions
About one third of respondents noted measures for improved efficiency, such as better boilers and reducing fossil fuel use. Some gardens noted that they used electric carts in the garden, and others suggested that their plantings contributed to offsetting carbon. Chester Zoological and Botanical Garden, UK offset carbon emissions of air travel and the Eden Project offers a reduced admission rate for public transport users.

of seed banks will be aiming at new targets for the long-term storage of seed collected from the wild and concentrating on saving plant resources for the future. The same will apply to living collections, especially in the case of species with recalcitrant seeds. These are predominant in some of the humid, tropical ecosystems which will, according to the models, be under severe threat from climate change. The future of many such species will probably depend on what botanic gardens can do for them in terms of cultivation (field gene banks) and even the possibility of assisted migration provided that new habitats are available.

Climate change will open up further fields for research such as reproductive biology, molecular population genetics, the ecology of colonization of new habitats but they must not be embraced to the detriment of classical taxonomy. Inventories and classification will still be needed if knowledge about biodiversity is to be learnt before it is too late. Therefore, the capacity for botanical exploration must be increased and the skills required for taxonomic revision and the description of new species developed. From a biodiversity point of view, it has been said that Linnaeus described about 9000 species. Currently, the same number are being described each year but in order to finish the catalogue, of even the most conservative estimates of the total biodiversity of the planet, 400 and 500 years will be needed. The enormity of this task should be appreciated and, in the face of a new phase of rapid mass extinction brought on by climate change, scientists should urge politicians to provide sufficient resources to attend to cataloguing and conserving biodiversity. Indeed, there should be a major UN-led programme to do this but it will be up to the scientific community to propose it perhaps through the climate change action plan for plants proposed by the Gran Canaria Group. Botanic gardens, as a major world network for plant conservation, can, if they are given sufficient resources in the period coming up to 2010 and then beyond, be important contributors to such a programme and have a major role in fulfilling the task of understanding and conserving the biological diversity of the planet in the face of climate change.

References

- BGCI, 2000. *The Gran Canary Declaration* calling for a *Global Program for Plant Conservation*. BGCI, London, UK.
- BGCI & Cabildo de Gran Canaria, 2006. T*he Gran Canary Declaration II on Climate Change and Plant Conservation*. BGCI, London, UK & Cabildo de Gran Canaria, Las Palmas de Gran Canaria, Spain.
- Bramwell, D., 2006. Los Jardines Botánicos y el reto del cambio climático. *Rincones del Atlantico* **3**: 244-249. http://www.rinconesdelatlantico.com/num3/botanicos.html accessed 25th June, 2007.
- Bramwell, D., 2007. The role of botanic gardens and seed banks in biodiversity conservation after 2010. *Ensconet Bulletin* in press.
- CBD Secretariat, 2003. *Global Strategy for Plant Conservation*. CBD Secretariat, Montreal, Canada. http://www.cbd.int/programmes/cross-cutting/plant/default.asp accessed 4th July, 2007.
- ENSCONET, 2007 http://www.ensconet.com/ accessed 25th June, 2007.
- GENMEDOC, 2007. An inter-regional network of Mediterranean seed banks. http://www.genmedoc.org/default.htm accessed 25th June, 2007.
- Hernández Bermejo, J.E. & Clemente Muñoz, M., 1996. Strategies and *ex situ* Conservation Techniques in the Cordoba Botanic Garden: the Germplasm Bank. In *Proceedings of the Third International Botanic Gardens Conservation Congress*, Hobson, C. (ed.). http://www.bgci.org/congress/congress_rio_1992/bermejo.html accessed 25th June, 2007.
- Krockenberger A.K., Kitching R.L. & Turton S.M. (eds.). 2004. *Environmental crisis, Climate Change and Terrestrial Biodiversity in Queensland*. Report 28. Rainforest CRC, James Cook University, Cairns, Australia.
- Lovett, J.C., Midgley, G.F. & Barnard, P., 2005. Climate change and ecology in Africa. *African Journal of Ecology* **43**: 167-169.
- McClean, C.J., Doswald, N., Küper, W. et al., 2006. Potential impacts of climate change on Sub-Saharan African plant priority area selection. *Diversity and Distributions* **12**: 645-655.
- Nobre, C. A., 2004. *Climate Change Scenarios and Impacts on the Biomes of South America*. WWW.aiaccproject.org/meetings/Buenos_Aires/Nobre accessed 25th June, 2007
- Roca Salinas, A., Vilches Navarrete, B., Jardim, *et al*., 2004. The Macaronesian Seed Bank (BASEMAC). A programme for rational conservation of plant diversity. In *2nd World Botanic Gardens Congress, Barcelona 2004*. http://www.bcn.es/medciencies/botanicgardens2004/abstracts/pdf_abstracts/Alicia_Roca_final.pdf accessed 25th June, 2007 http://www.bgci.org/barcelona04/postcongress/oral.html accessed 25th June, 2007
- Stern, N., 2006. The Stern Review on the Economics of Climate Change. Cabinet Office, HM Treasury, UK Government. http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/stern_review_report.cfm accessed 25th June, 2007.
- Thomas, C.D., Cameron, A., Green, R.E., *et al*., 2004. Extinction risk from climate change. *Nature* **427**:145-148. http://stephenschnieder.stanford.edu/Publications/PDF_Papers/ThomasEtAl2004.pdf, accessed 25th June, 2007.

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Right: *Lotus berthelotii* (Lobster Claw) Jardín Botánico "Viera y Clavijo" Canary Island endemic (Photo: BGCI)