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New Challenges to Promote Botany's Practice Using Botanic Gardens: The Case Study of the Lisbon Botanic Garden

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Abstract

Botanic Gardens are living plant museums, where plants have been arranged according to previous research and discovery in order to be used as a display for public appreciation and learning. Thus, more than ever, they can serve to improve the practice of botany, being able: (i) to drive the continuous exchange of ideas using the 'old and new' botany approach; (ii) to show the importance of the plant world in alleviating regional and global changes; (iii) to expand forward-thinking in science promotion. The Global Strategy of Plant Conservation (GSPC) has promoted global action in environment conservation and study. From the beginning, it has been adopted by Botanic Gardens Conservation International (BGCI) to function as a *leitmotiv* for botanic gardens best practice. In the present century, a new endeavour is required to facilitate the appeal of botany to younger generations. Links between taxonomic knowledge, molecular studies, information and communication technologies, and social sciences are urgently needed. Lisbon Botanic Garden has been working on these challenges for the past six years.

1.1 Introduction

Plants have a key role in ecosystem balance and, thus, are vital for environmental sustainability. Besides that ecological value, plants represent an economic and cultural value for humans, since they give us food, feed for animals, fibres and pharmaceutical products. It is not surprising that the World Health Organization (WHO) has estimated that up to 80% of the world's human population depend on plants (or plant products) for their primary health care (Bodeker *et al.*, 2003), while playing an expanding role in its development. Although the value of plants is fully recognized, no effective action is taken to prevent the continuous decline in plant diversity and, consequently, in ecosystem services provided by them. In addition, climate change is altering the habitat of plants,

with unknown consequences (Thuiller *et al.*, 2005; Blackmore *et al.*, 2011; Merritt and Dixon, 2011).

In spite of this impending crisis, public concern with biodiversity remains limited. Although many people feel that biodiversity is a heritage that should be preserved as fully as possible, the awareness tends to be centred on a few 'charismatic' species and ecosystems. But biodiversity also includes thousands of less conspicuous species and less spectacular ecosystems. Thus, we need to better inform society about plants' significance and the importance of biodiversity for humanity.

Within the core missions of botanic gardens, educating people about the role of biodiversity and the need for plant conservation represent important issues with which to engage broader audiences (www.bgci.org). Botanic gardens are the modern-day arks; they

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have received economically significant plants from the colonies and developing scientific programmes for the planting and cultivation of medicinal herbs. In the 16th century, the first botanic gardens provided plants for medical research (Rinker, 2002). From the 17th to the 19th centuries, botanic gardens functioned as displays of colonial diversity, as well as taxonomic inventories contributing to the knowledge of tropical plant diversity (BGCI, 2014). During the 20th century, botanic gardens were transformed into specialized research centres (BGCI, 2014), particularly focused on the global loss of biodiversity and, thus, included scientific research on plant conservation and public education (BGCI, 2012).

Today, there are few nations in the world without botanic gardens. Besides conserving *ex situ* biodiversity, botanic gardens develop research on plant systematics, using ecological, evolutionary and phylogenetic approaches. Before the implementation of conservation measures, either *in situ* or *ex situ*, we need to identify, recognize and study plant species' ecology. Plant conservation is an important issue for botanic gardens, particularly after the adoption of the Global Strategy for Plant Conservation (GSPC) (CBD, 2002). This strategy was launched in 2002 by the Convention on Biological Diversity (CBD) that 'marked an important advance in raising awareness of the threats faced by plants worldwide, as well as providing, for the first time, a coherent framework for policy and action needed to halt the loss of plant diversity' (CBD, 2002). In spite of the successes brought by this convention, it was not enough to mobilize effective actions for diminishing plant biodiversity loss. New achievements should be reached by 2020, according to the CBD revision in 2011 (Sharrock, 2011).

For the success of GSPC, botanic gardens need to strength their scientific contribution, as well as their influence in government policies. This requires a better development and coordination of tasks within and among botanic gardens to underpin conservation actions according to GSPC's targets. Only with this renewed challenge botanic gardens can underline their social role. This raises four critical questions, which we review in this chapter:

- Can botanic gardens pave the way for plant learning?
- What kind of strategic mechanisms do botanic gardens need to develop?

- How important is the role of science promoters and communication services to further raise botanic gardens' social relevance?
- How important are the activities offered by botanic gardens' education services to increase public awareness of plant diversity loss and the need for conservation?

Firstly, we are focusing on the unique opportunity botanic gardens have to play a key-role in plant education through complementing academic programmes at either graduate or postgraduate level. We then consider the strategic approaches that botanic gardens have developed and the role they need to play, through systematic research and conservation assessments. Thirdly, we examine the role of science promotion and communication as a fundamental area to raise awareness for plant diversity and conservation. Finally, we consider new methods offered by education services to contribute to capacity building and training in plant science and conservation. We provide examples of each of these, based on the experiences of the Lisbon Botanic Garden (LBG).

The Lisbon Botanic Garden (LBG) is a 136-year-old institution, belonging now to the National Museum of Natural History and Science, as part of the University of Lisbon. It is a scientific garden, classified as a national heritage monument in 2010 and a member of the World Monuments Watch since 2011. It was developed during the 19th century (1873–1878), when scientific and cultural progress was emerging in Portugal. The Lisbon Botanic Garden (LBG) has always been recognized as an idyllic spot within the centre of Lisbon, particularly by foreign tourists, probably following the beautiful and romantic words expressed by Thomas Mann, in his novel *Confessions of Felix Krull* (Mann, 1955). Over four hectares, this botanic garden features an important and diverse living collection, where the Portuguese colonial memory is imprinted. Being part of the University of Lisbon, taxonomic expertise has been preserved to support adequate conservation policies as well as to maintain scientific collections. Plant conservation and sustainable use of resources are at the core of all scientific activity. The environmental consequences of the loss of biodiversity and the role of humankind on this global problem have been presented to the LBG public, benefiting from researchers' scientific knowledge and optimized through the launch of an education department and the development of a strategic plan of communication.

The above four key questions are behind the mission of Botanic Gardens Conservation International (BGCI), a global network derived from the International Union for Conservation of Nature (IUCN) in support of botanic gardens, and particularly focused on connecting people with nature and finding solutions for sustainable livelihoods. A primary concern of BGCI has been to provide a means for botanic gardens in all parts of the globe to share information and new advances to benefit conservation and education (Wyse Jackson and Sutherland, 2000). After the Earth Summit in Rio de Janeiro 1992, the Plant Conservation Report in 2009 and the adoption of the Global Strategy for Plant Conservation (GSPC), BGCI has explored different ways to engage botanic gardens with the various objectives and targets of the GSPC. Therefore, plant diversity learning, conservation policies and education practices are interrelated keywords, encompassing the mission of botanic gardens all over the world.

1.2 Botanic Gardens and Plant Learning

For the public visiting botanic gardens, there is a natural attraction rather than a need to understand the plant collections. This is because the majority of visitors do not have motivation to learn *per se* while visiting these institutions; rather, to enjoy the garden as a place of peace and relaxation (Darwin Edwards, 2000). Motivation for visiting may also be affected by other factors: namely, the existence of entrance fees for the majority of botanic gardens, the availability of free-access green urban areas and the association of the outdoors more with physical activity than enjoyment of nature. Moreover, many people living in urban areas are experiencing a growing disconnection from nature. Richard Louv, in his 2005 book, *Last Child in the Woods*, calls attention to this problem, referring to the ‘nature-deficit disorder’, or our lack of relationship to the environment, which is increasingly noticeable in children. Besides this, most people find animals much more interesting than plants. This is what James Wandersee, of Louisiana State University, and Elizabeth Schussler, of the Ruth Patrick Science Education Center, called ‘plant blindness’ (Wandersee and Schussler, 1999; Wandersee and Schussler, 2001): the inability of people to recognize the importance of plants in the

biosphere and to appreciate the aesthetic and unique biological features of these life forms (Wandersee and Schussler, 1999).

Botanic gardens can be important as a ‘cure’ for such blindness and nature-deficit disorder, through their role in plant learning and informal education to increase the knowledge of plant biology (Wandersee and Schussler, 2001; Powledge, 2011). They can serve this mission through informal education aimed at schools, hands-on activities, open days and guided tours for the general public. Moreover, botanic gardens offer research programmes to attract university students to plant biology, systematics and taxonomy, since they house botanical reference collections such as herbaria.

However, while taxonomy flourished in the 18th century, the era of exploration, expedition and identification, at the end of the 19th century it went out of fashion (Granjou *et al.*, 2014). In the 20th century, with the increase of laboratory work and technological advances that allowed the rise of new biochemical and molecular approaches, taxonomists have been regarded as consultants or mere collectors of living things rather than as researchers (Sluys, 2013). Today, however, with apprehensions about biodiversity and ecosystem services, taxonomy may be viewed as a crucially relevant scientific field with new opportunities (Mallet and Willmott, 2003; Tautz *et al.*, 2003).

In the 21st century, botanic gardens are able to complement the work developed at universities and colleges, paving the way for plant learning, including the traditional taxonomic approaches but also encompassing systematics, with phylogenetic reconstruction.

Besides displaying plant collections, LBG was created to promote botany learning within the University of Lisbon, a connection that still exists today. Science research in LBG is mainly focused on studying the ecology and taxonomy of vascular and non-vascular flora towards *in situ* and *ex situ* conservation. Plant collections in the garden (> 1500 species) as well as in the herbarium (> 250,000 exsiccates) serve various fields of botanic research. In recent years, two different learning approaches were developed in LBG in relation to students from the university: plant learning for biology students or a source of inspiration for fine art students (Martins-Loução *et al.*, 2014b).

Botanic gardens, particularly those with a strong research activity, have always collaborated with

colleges, universities or other science centres. Some of them offer specialized courses or postgraduate programmes, particularly in the UK or USA. Similar to many others (Smith, 2008), LBG promotes botanic garden and academy networks at national and international level through project collaborations, joint fieldwork and training programmes. Training ranges from informal instruction in the field to laboratory practices on plant identification in a straight collaboration with the University of Lisbon's Faculty of Sciences. From 2002 to 2008 more than 200 people received education in plant taxonomy and Mediterranean vegetation. Former graduate students were the drivers of such training courses, giving rise, recently, to the establishment of an online database of Portuguese flora (www.flora-on.pt), which fulfils the first target of GSPC (CBD, 2002; CBD, 2012).

Following the GSPC and the mission statement of BGCI (www.bgci.org), LBG re-stated its mission: contributing to understanding and documenting plant diversity (objective I), conserving plant diversity (objective II) and promoting education and awareness about plant diversity (objective IV) (Martins-Loução *et al.*, 2010; Martins-Loução *et al.*, 2014b). The taxonomists and curators who worked on plant collections, either in the garden or the herbaria, were encouraged to strengthen research interactions to attract more postgraduate students. It has been a challenge to move students from the sophisticated and high technology laboratory at the university campus to the old collections-based facilities of the garden. A positive relationship between well-known research teams and students' interest was observed. This was particularly relevant for the non-vascular flora group that was, and still is, very well established and involved in a number of inventories and biomonitoring studies based on bryophytes (Sérgio *et al.*, 2007). The Portuguese bryoflora comprises about 40% of European species and almost 65% of all Iberian bryophytes. These organisms are identified as one of the oldest groups of plants, with great ecological importance, fundamental for ecosystem biodiversity maintenance (Sérgio *et al.*, 2000; Luís *et al.*, 2012) and serving as bioindicators of environmental quality and climate change (Figueira *et al.*, 2009; Sérgio *et al.*, 2014). *The Checklist of Bryophytes of Portugal* includes all the bryoflora of mainland Portugal and was published in the *Atlas and Red Data Book of Threatened Bryophytes of Portugal* (Sérgio *et al.*, 2013). These publications were possible due to the

scientific knowledge of Portuguese bryophytes as well as the maintenance of herbaria collections, from the first ones in the 19th century to the most recent studies, adopting criteria and categories proposed by the IUCN. To increase the scientific impact, and responding to student demand, this non-vascular plant group at LBG has enlarged its focus of plant systematics to include phylogenetic studies and modelling approaches (Draper *et al.*, 2003; Sérgio *et al.*, 2007; Stech *et al.*, 2011; Martins *et al.*, 2012; Sérgio *et al.*, 2014). Both fieldwork and herbaria collections have been the bases of all these works showcasing plant taxonomists and LBG at international level. Besides bryophytes, lichen and fungi collections have been enlarged and studied either from a taxonomic or systematic perspective, contributing to the knowledge of the biology of those organisms and the development of conservation strategies (Melo *et al.*, 2006; Carvalho, 2012; Ryvarden and Melo, 2014). Traditional aspects of botanic gardens research in plant taxonomy and biosystematics continue to underpin much work in biodiversity, and they remain major botanic garden priorities (Wyse Jackson and Sutherland, 2000). However, the continuation of these studies depends on funding and, unfortunately, taxonomic studies are normally underfunded in Portugal as well as in Europe and USA (Mallet and Willmott 2003; Granjou *et al.*, 2014).

The Mediterranean region is important for the diversity of crops and their wild relatives (Kell *et al.*, 2008), as well as an area of plant diversity (Myers *et al.*, 2000). The development of species checklists and inventories is, thus, seen as a first step to effective conservation (CBD, 2002; CBD, 2012), as well as habitat characterization (Rosselló-Graell, 2003; Vieira *et al.*, 2004; Stofer *et al.*, 2006). A checklist allows the characterization of a country's rich resources and, thus, needs data to be organized in a logical and retrievable way (Prendergast, 1995). Non-organized taxonomic data, as well as dispersed biological literature, are major obstructions to the production of complete national inventories. Additional information on native and cultivated status, ethnobotanical uses, national and global distribution, *in situ* and *ex situ* conservation status, threat assessment, and legislation is sparse and difficult to access (Magos Brehm *et al.*, 2008b). However, in Portugal, the development of the crop wild relatives (CWR) and wild harvested plants (WHP) inventory (Magos Brehm *et al.*, 2008a) together with the evaluation of inter- and intra-population genetic diversity of some

endemic threatened plant species (Magos Brehm *et al.*, 2012) was possible, due to a collaborative PhD programme between LBG and Birmingham University (Magos Brehm, 2009). The connection to herbaria collections present at LBG, good plant identification skills of the student and the facilities of molecular laboratories and CWR knowledge background at Birmingham University were crucial for the development of such a programme, launching a collaboration that outlined the PhD thesis. The inventory database includes a detailed evaluation of the current utilization of CWR (Magos Brehm *et al.*, 2008b). But the most important implication of this kind of work is that Portugal have produced baseline data about the taxa present and their actual and potential value, to be further used as a conservation tool to complement the setting of conservation priorities (Magos Brehm *et al.*, 2008a; Brehm *et al.*, 2010; Magos Brehm *et al.*, 2012). The establishment of conservation priorities among species is also an important tool in the implementation of any conservation strategy, since financial resources are generally limited (Brehm *et al.*, 2010).

Similarly to what has been seen in many other botanic gardens during the past 30 years (Maunder, 2008), LBG has become key to documenting plant diversity and promoting plant conservation, becoming an important Portuguese player in the United Nations' Global Strategy for Plant Conservation (Martins-Loução *et al.*, 2010; Martins-Loução *et al.*, 2014a). The institutional dependence of LBG on the University of Lisbon is, thus, found to be strategically important for the ongoing role of the botanic garden on plant learning. LBG with its herbaria and seed bank collections are the repositories of vast amounts of taxonomic and botanical diversity information. Apart from the collections, the research developed in LBG with its partner institutions, within and outside the country, as well as the complementary formation classes within the garden give an important and complete taxonomic knowledge to graduate and postgraduate students.

1.3 Strategies to Implement Conservation Policies

Because of biodiversity loss and the rapid disappearance of natural ecosystems and their species, botanic gardens, arboretums and other facilities bear a heavier responsibility for preserving plant genetic resources. Botanic gardens may use this

conservation mission as a flag to attract new researchers and students, but also to appeal for new sources of financial support. This means that while the basis of conservation can be taught in universities, botanic gardens must draw attention to their practical role and publicize their work through *in situ* and *ex situ* conservation programmes.

Consistent with the claim for the development of a global programme on conservation of useful plants and traditional knowledge (Barve *et al.*, 2013), the scientific community needs to create a concerted effort focused on the loss of basic knowledge about plants and their uses, especially at the local and regional level. The second phase of GSPC implementation for the period 2011 to 2020 (CBD, 2012) is therefore necessary to minimize the loss of diversity and threatened plant-based ecosystems worldwide, as well as to safeguard tens of thousands of plant species close to extinction. For botanic gardens, GSPC is a catalyst for working together at all levels – local, national, regional and global – in order to understand, conserve and promote the sustainable use of plant diversity while promoting awareness (CBD, 2012). At the Iberian level, Associação Ibero Macaronesica de Jardins Botânicos (the Ibero-Macaronesian Association, that includes Portugal, Spain and Cape Verde, www.jbotanicos.org), has held several meetings to explore the ways in which botanic gardens can engage with the various objectives and targets of the Strategy. This Association has played an important role in the dissemination of research projects and educational activities through an annual online journal, *El/O Botánico* (www.elbotanico.org).

When we think in terms of conservation, it is important to face the fact that a great number of European plant species are vulnerable and at risk of extinction due to climate change (Thuiller *et al.*, 2005). Moreover, changes observed in the use of land, as well as other environmental threats, such as nitrogen deposition, may alter competitive interactions in plant communities, yielding novel patterns of dominance and ecosystem function (Cruz *et al.*, 2010; Dias *et al.*, 2013; Branquinho *et al.*, 2014). For plant species with orthodox seeds (seeds that tolerate a decrease in moisture content), seed banks provide the most practical method for preserving large amounts of genetic material in a small space. The ultimate goal is seed preservation for several centuries, or perhaps even millennia (Gómez-Campo, 2006). Botanic gardens with seed

banks and/or seed conservation expertise have a significant contribution to GSPC (objective II). The LBG seed bank (> 3600 seeds) represents an important and effective asset (Draper *et al.*, 2007; Clemente *et al.*, 2011; Clemente *et al.*, 2012; Clemente and Martins-Loução, 2013) with already more than 55% of threatened Portuguese flora represented. In a decade, the LBG seed bank increased the number of taxa and threatened endemic species banked in *ex situ* conservation (Clemente and Martins-Loução, 2013), contributing to target 8 of GSPC: the *ex situ* conservation of 75% of threatened flora in each country by 2020. Besides this conservation effort, the expertise of curators has also served in habitat restoration (Clemente *et al.*, 2004; Draper *et al.*, 2004; Draper *et al.*, 2007; Marques *et al.*, 2007a; Oliveira *et al.*, 2012; Oliveira *et al.*, 2013; Pinto *et al.*, 2013), extension of plant collections outside the LBG (Magos Brehm and Martins-Loução, 2011) and *in situ* conservation (Draper *et al.*, 2003; Rosselló-Graell, 2003; Pinto *et al.*, 2012; Pinto *et al.*, 2013). Every year, seeds of threatened plant species are collected, as well as seeds from plants growing in threatened habitats. Help is also given to Portuguese-speaking countries with which some project collaborations have been established (e.g. collaboration with Mozambique: Niassa Reserve). This is also a way of engaging local people while increasing the capacity for implementing the strategy (CBD, 2012).

With the increasing demands posed by needing to feed the world, it is vital that we address agricultural adaptation more comprehensively, facing the present global changes, climate and land use changes. Currently, agronomists and plant physiologists are investing in better use of crops. However, there is a need to look for new crop varieties that can be productive in the climate of the future (Howden *et al.*, 2007). Evidence has shown that more than half of the wild relatives of 29 globally important crops are not adequately conserved in seed banks (Gewin, 2013). Because of this, a programme was launched, headed by Global Crop Diversity Trust, based in Bonn, Germany, in partnership with Millennium Seed Bank at the Royal Botanic Gardens in Kew, UK, financed by the Norwegian Government, to conserve crop wild relatives (CWR). It is the largest international initiative so far established for this purpose, with a large worldwide consortium, where LBG was invited to represent Portugal.

Ex situ conservation may also serve minimization actions of impacted construction projects, since seed banking can be considered ‘warehouses’ of biological information or a ‘backup’ of genetic resources (Draper *et al.*, 2007; Gonzalez *et al.*, 2009). The LBG seed bank is able to function both as a gene bank for restoration programmes (Clemente *et al.*, 2004; Draper *et al.*, 2007; Oliveira *et al.*, 2013) and as a source of scientific expertise to support the best seed samples and germination procedures (Marques *et al.*, 2007b; Oliveira *et al.*, 2011; Oliveira *et al.*, 2012). This is possible due to its participation in a EU-funded coordination action, ENSCONET, in the 6th EU framework programme (2004 to 2009). Until very recently, seed banks in Europe acted in an uncoordinated way at local or national levels, adopting different working standards. As a result of this EU-funded action, which for the first time unified all key facilities for European native seeds, much has changed over the last five years. Today, native seed research facilities in Europe have defined high-level, common working standards, for collecting, cleaning, checking quality and viability (ENSCONET, 2009a, b).

Apart from seed conservation, associated knowledge on plant biology and propagation found in seed banks and botanic gardens are invaluable for those who need to implement conservation practices (Smith, 2008). As suggested by Maxted (Maxted *et al.*, 1997) there is a need for a multiple-tier approach to conservation and, ultimately, to prioritization measures. This means that for a correct characterization of a plant species conservation status, a good knowledge about the ecology and genetic variability of species is required. Also, the Convention on Biological Diversity (CBD) (CBD, 1992), the GSPC (CBD, 2002; CBD, 2012), the European Plant Conservation Strategy (EPCS) (2002) and the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) (FAO, 2001) address the need for conserving the genetic diversity of plants, either wild species, crops or the wild relatives of crops. This means that a species-targeted conservation strategy should, whenever possible, include information on the genetic diversity of the target taxa to maximize the intra-specific diversity and potentially useful genes conserved (Magos Brehm *et al.*, 2012). This kind of approach can be used to avoid founder effects, determine effective population size and avoid outbreeding or inbreeding depression, any one of which can influence a reintroduction programme (Smith, 2008).

Thus, apart from plant systematics, molecular biology has found application in botanic gardens research directed towards conservation. Molecular biology lab facilities were developed at LBG in 2008. Before that, international collaborations and networks both with other museum departments and international partners were the best strategy found to update the skills present at LBG seed bank. Besides seed banking, it was also possible to start an endemic Portuguese plant DNA collection that has been growing slowly (Clemente *et al.*, 2012). DNA barcoding is presently an important tool in conservation strategies and, interestingly, many of the plant group researchers are based in botanic gardens (Cbol *et al.*, 2009). DNA barcoding is currently an important tool in biodiversity assessment for both animal and plant communities. This is because it either provides insights into the process of species definition or helps in the identification of unknown specimens (Cbol *et al.*, 2009). However, in plants, DNA barcoding has been challenging and its success varies among plant lineages. Though sequencing nrITS from environmental or floristic-pooled samples is now almost routine, the great difficulty is to obtain sequence data from numerous unlinked single-copy nuclear markers. Only this can allow high-resolution species discrimination to cope with closely related species assemblages (Cbol *et al.*, 2009). The collaboration with Royal Botanic Gardens, in Kew, UK, and Canary Botanic Gardens, Viera y Clavijo, in Las Palmas, Spain, has been crucial for the development of this expertise. The work done in a group of closely related species of *Caryophyllaceae* and sympatric hybridizing orchids enabled LBG with experience of sequencing several different types of markers to discriminate species (Cotrim *et al.*, 2010).

At present, the research community must pay attention to the development of locally adapted varieties, either wild or wild relatives of crops (CWR) as well as its evolutionary mechanisms. The biodiversity stored in gene banks may fuel advances in plant breeding, as the genetic sequence data provides a genomic ‘parts list’ that can help to decipher mechanisms that enable plants to adapt to myriad environments (McCouch *et al.*, 2013). Banking of seeds is a good asset but seed banking is not the major focus of conservation strategies. According to the GSPC’s objective II (CBD, 2012), plant diversity conservation includes ecological regions or vegetation types (targets 4 and 5) as well as productive lands (target 6). These must be secured

through an effective management and/or restoration for conserving plants and their genetic diversity, besides *in situ* (target 7) and *ex situ* (target 8) conservation. Particular attention is also paid to the genetic diversity of crops, including their wild relatives (target 9), and management plans to prevent new biological invasions (target 10). This means that conservation entails safeguarding of species diversity, both *in situ* and *ex situ*, ecological systems and evolutionary processes in nature. It is, thus, a complex ‘mission’ that should be an integral *raison d’être* for botanic gardens.

Before the development of any conservation strategy, it is important to understand the ecology, adaptation and speciation mechanisms of plants (Marques, 2010; Serrano *et al.*, 2014b). Four factors can be pointed out to influence plant evolutionary interplays (Marques, 2010) as well as endemism or rarity (H.C. Serrano, Ecology of the rare endemic *Plantago*: understanding the limiting factors towards its conservation. Lisbon, Portugal, 2015, ULisboa PhD thesis): demographic (e.g. gene flow, dispersal, competition), plant/animal (e.g. pollination, predation), edaphic (e.g. nutrient availability, presence of toxic elements) and bioclimatic factors (e.g. drought, cold stress). Following the indications of GSPC, LBG is focused on studying threatened Portuguese or Iberian endemic species through best conservation strategies. Multidisciplinary works have been developed to further understand the threats of Portuguese endemic species, namely, *Narcissus cavanillesii*, *Plantago almogravensis* and *Ononis hackelii* (Marques, 2010; Pinto *et al.*, 2012; Rosselló-Graell *et al.*, 2003; H.C. Serrano, Ecology of the rare endemic *Plantago*: understanding the limiting factors towards its conservation. Lisbon, Portugal, 2015, ULisboa PhD thesis). The work on *Narcissus* was developed in collaboration with Real Jardín Botánico, in Madrid, Spain, and intended to understand in what way breeding systems could be a threat to the endemic *N. cavanillesii* (Marques, 2010; Marques *et al.*, 2010), particularly after the recognition of *N. x perezlarae*, a hybrid of *N. cavanillesii* x *N. serotinus*, as a new taxon for Portugal (Marques *et al.*, 2005). Results based on reproductive biology, molecular studies and demographical monitoring suggest that hybridization does not represent a threat to the survival of parental species (Marques, 2010; Marques *et al.*, 2011; Marques *et al.*, 2012a, b) and its outcomes are mostly dependent on pre- rather than early post-zygotic isolation mechanisms (Marques *et al.*, 2007a; Marques *et al.*,

2012a). On the contrary, *N. cavanillesii* seems to benefit from occurring in sympatric populations, probably due to an increase in pollination success (Marques *et al.*, 2012a). From a conservation perspective and facing the threat status of *N. cavanillesii*, the results of these studies suggest that conservation efforts should be focused on preserving habitats and their interactions or restoring communities in the case of any disturbance (Draper *et al.*, 2004; Rosselló-Graell *et al.*, 2007; Marques, 2010). All these results attribute an important role to hybridization as an evolutionary mechanism, especially because it can lead to an increase in genetic diversity (Rieseberg, 1997). Nevertheless, the possible outcomes may be different according to the provenance of their parents (Tauleigne Gomes and Lefèbvre, 2005; Tauleigne Gomes and Lefèbvre, 2008).

This *in situ* conservation perspective, focused on preserving habitats rather than being species-specific, may not be generalized. For each threatened species it is important to understand its ecologic limiting factors that may have been driving the species to a rarity status near extinction, before the development of conservation guidelines. In the case of *Plantago almogravensis*, an endemic and rare Portuguese species, the plant lost part of its genetic variability (H.C. Serrano, Ecology of the rare endemic *Plantago*: understanding the limiting factors towards its conservation. Lisbon, Portugal, 2015, unpublished thesis) in favour of the site-adapted traits. This represents increased tolerance to aluminium (Al) (Serrano *et al.*, 2011), associated to Al hyper accumulation (Branquinho *et al.*, 2007) and development of nanism habit (H.C. Serrano, Ecology of the rare endemic *Plantago*: understanding the limiting factors towards its conservation. Lisbon, Portugal, 2015, ULisboa PhD thesis). This rare plant species found its ecological niche, outside its optimal performance site, due to trade-offs with environmental constraints (Serrano *et al.*, 2014a). The expansion of this species outside its present habitat has been proved to be a good strategy in the enlargement of its distribution area (Pinto *et al.*, 2013).

Although there is a lot of conservation work going on in botanic gardens, conservation is rarely seen as the main priority. This is because most botanic gardens are primarily visitor attractions, from where they get important revenues (Powledge, 2011; Martins-Loução *et al.*, 2014b). However, it is the use of the conservation work that botanic gardens

develop that can charm new students and attract new projects, connecting and cooperating, at the same time, with conservation practitioners and the private sector. It is by broadening their contacts that botanic gardens can find real social relevance in this demanding contemporary world. Although GSPC is focused on conservation efforts in the country of origin, it also advises the support and development of regional efforts. This is what the Millennium Seed Bank (Royal Botanic Gardens, Kew, UK) has been doing, offering its knowledge, innovation and practices to indigenous communities, through technology transfer and information sharing. So, one of the strategies of broadening the visibility of botanic gardens is to spread their capacity building and toolkits of the best conservation practices within and outside their country of origin.

1.4 Communication in Botanic Gardens

At present, botanic gardens create new proactive ways of communication more because they need visitors to raise their revenues than because they need to be considered as scientific centres. All over the world, botanic gardens are becoming sophisticated business entities that increasingly depend upon the financial patronage of the public (Maunder, 2008). This produced a profound change both in the way curators and horticulturists see visitors and in governmental authorities viewing botanic gardens as tourist attractions. Botanic gardens very often recognize that their future depends on the way they are able to transmit the importance of their work and on the links they establish with their local community (Maunder, 2008; Powledge, 2011). This new social role was completely embraced by LBG, exploring more a subtle art to attract visitors that is based on staff skills and creativity rather than on improving garden infrastructures, which is completely dependent on financial investments (Martins-Loução *et al.*, 2014b).

LBG is located in the centre of Lisbon, and is enclosed within the walls of the National Museum of Natural History and Science and private buildings, along a deep slope facing upstream of the Tagus river. Some collections, such as palms, ficus and cycads, are the garden's hallmarks. The outstanding diversity of species from all continents, growing outside greenhouses, lends an unexpectedly tropical atmosphere to several spots in the garden. In addition, its Lisbon location allowed the development of several microclimatic niches where

flora from different bioclimatic regions live side by side in a wild environment that is very much appreciated by tourists. But there was also a need to attract Portuguese visitors to the garden. For that, different strategies have been utilized, namely, the development of new interpretation panels, new temporary exhibitions, art performances in the garden and guided visits (Gaio-Oliveira *et al.*, 2013; Martins-Loução *et al.*, 2014b). Collaborations between botanic garden curators and artists from the Beaux Art Faculty were established. Also, other projects such as the European Youth Volunteer project and the Leonardus programme brought to the garden young students with different backgrounds, who offered their expertise and creativity to establish more activities either focused on plant diversity awareness or artistic expression (Martins-Loução *et al.*, 2008; Martins-Loução *et al.*, 2014b).

The strategies used by botanic gardens to attract and communicate to the public are very important and have enlarged the type of personal resources at the garden. Besides scientists, curators or horticulturists, botanic gardens need professionals dedicated to science communication and education. These professionals are responsible for the interaction between science and society; they know how to meet the expectations of the public, how to change public behaviour towards biodiversity loss awareness and to mobilize action for a sustainable future. Communication and science promotion are important issues to be used by botanic gardens to approach the public and attract visitors (Gaio-Oliveira, personal unpublished data). There is a need to improve scientific literacy in order to increase public awareness for plant diversity and conservation. However, different findings put botanic gardens in alignment with urban gardens for public attraction: the main factors that motivate people to visit these gardens are the appreciation of the aesthetic and rare qualities of plants; interest in garden design and landscaping; admiration of the scenery; and the pleasure of being outdoors (Neves, 2009; Villagra-Islas, 2011). Still, some people have the mistaken idea that botanic gardens are passive places, where plants are identified with strange and difficult names, as was common in 19th-century museums (Rinker, 2002). But today, botanic gardens should be looked upon as global treasures in a century of ecological crisis.

In the absence of focused governmental policies, botanic gardens can play important roles, both increasing consciousness about the need for better

plant knowledge and supporting policy regulations on ecosystems conservation. A solid commitment to education and ethics should be established for botanic gardens, enabling them to enlarge their ecological leadership (Rinker, 2002; Powledge, 2011). Social interaction and scientific dissemination of knowledge for the general public ought to be key aspects of gardens visits. Besides visits, other different approaches can be used to communicate with a new public. An interesting example is the use of art. Art *per se* (e.g. art exhibitions, concerts, performances) may be considered an effective tool in attracting visitors to increase revenue, associating the arts with plant awareness (Martins-Loução *et al.*, 2014b). Since botanic garden displays are also a form of exhibition, creative and well thought out landscape design can be another powerful tool for connecting people with nature (Villagra-Islas, 2011). This approach often brings about debate over whether these activities deviate from the organizational mission related to plant conservation and engaging the public with plants. It is important to bear in mind that, taking a holistic perspective, binding science and art with creativity can promote a better public understanding for ecological values.

However, botanic gardens improve their public relevance by proving that they can answer everyday problems. They need to show they are accredited centres on plant knowledge and conservation practices, as well as the refuge of some threatened species (Rinker, 2002). As well as this, they also need to admit that they may be indirectly responsible for the spread of invasive species (BGCI, 2012; Heywood and Sharrock, 2013). Because of this, it was crucial to launch a code of conduct (Heywood and Sharrock, 2013) and disseminate it as widely as possible. Nowadays, all botanic gardens may share information about the impacts of invasive alien species and advice on their control as it is stated in GSPC (CBD, 2012). One example was the invasion of red palm weevil (RPW), which threatened the LBG palms collection. The pest, commonly called the red palm weevil (RPW), the *Curculionidae* (Coleoptera) *Rhynchophorus ferrugineus* Olivier, was accidentally introduced into several European countries of the Mediterranean Basin, and is affecting palm trees all over the Mediterranean region (Hallet *et al.*, 1999). As a consequence of commercial exchanges of palm trees from contaminated areas of North Africa, this pest is putting at risk large collections of palms within botanic gardens.

Before pest arrival, LBG established careful monitoring in its palm collection (more than 30 species grown outside) and mapping of many others surrounding the garden. An intensive outreach programme was established to share information about the risks of current management practices (objective IV, GSPC), to raise awareness among the owners of private gardens about the danger and consequences of pest arrival, and to alert local authorities and companies to help prevent the arrival of red palm weevil in gardens (target 10, GSPC) (Pinto *et al.*, 2011). Although it did not prevent the pest arriving, this science communication programme was very useful for community engagement and alerting people about the risks of invasive species in general, either plants or animals.

Botanic gardens can therefore make social changes if they become leader institutions for research and education about the plant kingdom. But, as in many other places, science communication needs to be promoted, engaging new professionals in one of the most challenging societal issues: awareness of the need for biodiversity conservation and sustainable use of resources. Moreover, they can help botanic gardens in taking action by maintaining continuous communication with local communities. Unfortunately, in many botanic gardens, as for LBG, this type of work is often achieved through short-term funded projects. Botanic gardens need to be much more proactive and explore new ways of funding if they want to become more socially responsible. This requires a continuous understanding of community needs and very clear expression of the values, social role and responsibilities of the organization (Dodd and Jones, 2011).

1.5 Education in Botanic Gardens

Defining the level of success of public education among botanical gardens is difficult, given the diversified features of the gardens (Kneebone, 2006; Gaio-Oliveira, personal unpublished data). Dependent on their resources, either human, financial or both, all botanic gardens aim at accomplishing GSPC target 14 – promoting education on plants and awareness on human impacts in plant diversity loss.

Botanic gardens offer learning opportunities for practical and multi-sensory activities with plants. However, all these educative offers vary from garden to garden and there is, still, limited evidence of research into learning experiences. In 2003 LBG launched an education department and since 2008

more than 8000 students, every year, have visited the botanic garden to attend educational programmes and learning activities. For schools, it has been described as an ideal place for students to take part in scientific activities that have been specifically planned to fit the national curriculum.

This success brought an increasing concern about the assessment of educational activities, discussion about the best practices for reaching young students and promoting the role of botanic gardens in plant education. This is one of the concerns about GSPC indicators. More than numbers, it is crucial to assess the quality of these activities, the scientific content as well as the results (CBD, 2012). Different projects have been launched in LBG, focused on involving young children in research activities (Barata and Martins-Loução, 2009), and on understanding changing attitudes and behaviours after environmental education projects (Barata, 2014). This last study has tested the effect of psychosocial factors that may promote environmental action. Results demonstrate the potential of using botanic gardens in environmental education and suggest that associating these educational practices with psychosocial processes, such as public commitments, will promote a change in pro-environmental behaviours among teenagers. This is an important issue bearing in mind that botanic gardens are to become more proactive in social contexts.

The education provided by botanic gardens should be beyond environmental education. Thus, to increase concern about plant diversity they need to establish thoughtful relations with educational agents, either schools or universities, in order to encourage students' motivation and interest in science. While at universities the teaching of science often focuses on the accumulation of facts at botanic gardens, informal education can present the problems faced by society daily. The European Union has recommended that teachers should promote high-quality education (European Commission, 2012). Thus, improving teachers' academic and professional training, through the creation of continuous professional development (CPD) programmes and making the profession more attractive to young people, were considered vital in European recommendations (Council of the European Union, 2014).

Scientific studies from many countries suggest that both students and teachers find the engagement with the epistemology and practices of scientific inquiry very challenging (Dillon *et al.*, 2006; Barata *et al.*, 2013). Policy orientations in Europe as well

as in North America encourage teachers to use inquiry-based learning as an efficient method in trying to get science students doing the very things scientists do (Bybee, 2010; European Commission, 2013). LBG, in Portugal, was one of the partners of the INQUIRE project (SCIENCE-IN-SOCIETY-2010 no 266616) designed to reinvigorate Inquiry-Based Science Education (IBSE) in formal and ‘Learning Outside the Classroom’ (LOtC) educational systems throughout Europe. In this project, LBG functioned both as a LOtC and a science research institution. The project aimed to design a CPD programme to help teachers move from more traditional pedagogies to inquiry-based ones. It was particularly focused on teaching biodiversity and climate change and directed at teachers of 5th to the 9th grade students of basic and secondary education (Gaio-Oliveira *et al.*, 2012; Martins-Loução *et al.*, 2012). LBG results asserted that the CPD course was able to change teaching conceptions through the establishment of teachers’ learning communities of practice outside schools (Martins-Loução *et al.*, 2013). Teachers were able to evaluate and reflect on their own practice so that, at the end, they developed new approaches to apply scientific inquiry while teaching biodiversity and climate change in the context of their own classrooms (Barata *et al.*, 2013).

Educational departments of botanic gardens can, therefore, encourage the implementation of the IBSE method, both in garden activities and in teachers’ professional development programmes (Martins-Loução *et al.*, 2012). Another strategy is to help schools to use playgrounds as LOtC spaces. Botanic gardens should promote this approach in several ways; for example, by developing courses for teachers interested in improving (or creating from scratch) playground gardens in order to integrate them in the curriculum; or by developing good practice manuals that allow school communities to use the best playgrounds as LOtC areas (Gaio-Oliveira and Garcia, 2014).

Botanic gardens may also use novel technologies to introduce young people to the wonders of the plant kingdom. However, while digital technology is changing how we live and communicate, botanic gardens are still experiencing this fast paced digital age (see Roots, 2013, vol. 10, <http://www.bgci.org/education/roots/>). Nevertheless, science education can be more effective when information and communication technologies (ICT) are used, an important asset for reaching a broader audience, according to the indicators of target 14 (GSPC).

Within the EU programme, ‘Natural Europe: Natural History & Environmental Cultural Heritage in European Digital Libraries for Education’ project (CIP-ICT-PSP- 250579, www.natural-europe.eu) aimed to develop digital libraries and to produce online educational pathways based on natural history museum exhibitions, including inquiry-based activities and their assessment. The results of this study have shown that online supported guided tours have proven to offer new positive ways of exploring information and preparing visiting tours (Barata *et al.*, 2012). The results reported from this EU project emphasize the crucial role that botanic gardens may have in the preparation of inquiry-based activities, tools and materials, profiting from online resources as a driver for visits to real contexts in the garden.

Informal education in botanic gardens may, thus, complement formal education in schools, helping teachers to motivate students for science, engage them for improving their understanding and to inspire their personal involvement for creative experiences (Gano and Kinzler, 2011). In the current technological world, the use of ICT tools may benefit student’s engagement to contribute positively for science learning. The importance of plant diversity and the need for its conservation incorporated into communication, education and public awareness programmes, as it is stated in target 14 of GSPC (CBD, 2012) must be the driver of different creative initiatives within botanic gardens.

1.6 Conclusions

Even during the problems caused by a global financial crisis, botanic gardens are more than live botanical collections. Through scientific research, these are true institutions for plant education, projecting their knowledge as a continuous dialogue between taxonomy and systematics to explain evolution and phylogeography (Cbol *et al.*, 2009; Chase and Reveal, 2009; Nieto Feliner, 2014). This scientific knowledge is pivotal for a better understanding of plants, their evolution and consequent development of conservation tools. This demonstrates that the maintenance of plant science research at botanic gardens paves the way for plant education. Also, by promoting systematic research on plants, botanic gardens contribute to fundamental knowledge about how plants maintain the planet’s environmental balance and ecosystem stability.

Thus, by maintaining their status as research centres, botanic gardens may better promote plant diversity and conservation practices, support post-graduate students, or implement capacity building of professionals' as well as teachers' training workshops. Strategically, botanic gardens need to be engaged in real societal problems, such as the consequences of climate change and the established 'planet boundaries' (Rockström *et al.*, 2009) to help construct a better sustainable future. Addressing these problems will enable intervention at science centres and universities and help restrain the loss of species and ecosystems. Because of this, botanic gardens must play an important role in underpinning conservation action. However, their successes need to be better understood and better disseminated, independently of any failure to reduce the loss of biodiversity (Blackmore *et al.*, 2011). Also, strategically, botanic gardens need to demonstrate to their public how they are involved in science, conservation and educational activities (Powledge, 2011). Many botanic gardens are already doing this (e.g. new installations of Millennium Seed Bank, Royal Botanic Gardens, Kew, UK, New York Botanic Garden, USA), but most of them safeguard the laboratories and maintain hidden historical collections. Of course, herbaria and laboratories need to be preserved and clean, for the safety of materials and research experiences, but opening large windows allowing visitors to observe researchers at work, could be organized sometimes, with small investments. Another possibility is to promote open-day laboratories to make people aware of the scientific work developed behind closed doors. However, it is advisable that new exhibition spaces must be designed as showcases of the vital scientific work (Maunder, 2008).

Changes include the presence of science promoters and the implementation of a communication department or group. Botanic gardens are true plant diversity arks that, to be fully understood, need a twofold process of biological learning and social engagement. Visits to the garden bring different audiences, most of them drawn by the aesthetic value (Ballantyne *et al.*, 2008), but the act of communicating, the concept, the rationale, influences how people perceive the message (Hall *et al.*, 2014). To align the language to a broader audience, it requires understanding of perspectives and simplified contexts within the social setting to effectively contribute to a change in attitude (Hall *et al.*, 2012). This is a new and important perception for

the community. However, if botanic gardens really want to promote their social relevance, raise awareness about plants and effectively disseminate GSPC, a good collaboration with social sciences, humanities and communication professionals is needed. Besides, the strategy of plant conservation also emphasises the need to look for "indicators of quality rather than showing only numbers concerning public engagement actions" (CBD, 2012). Creative approaches, binding science with art, will also benefit message dissemination while attracting a new public to the garden.

Last, but not least, the educational services of botanic gardens need to take care with messages and the way they promote botany education. More hands-on educators should be involved in new pedagogic approaches to help children and young students learn about how plants support and improve our livelihoods. Inquiry-based approaches should be widespread as well as the recognition of botanic gardens as places of learning outside the classroom (Dillon *et al.*, 2006). In these places the students should have the opportunity to use the language of science and to increase their interest in learning, according to EU reflections (Osborne and Dillon, 2008). Establishing partnerships with university research centres and strengthening the collaboration with schools will contribute to better contents that fit scholarly curricula; diverse pedagogic offerings drive youths' enquiring minds and, at the same time, increase teachers' motivation for plant education.

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