The river of diversity: perspectives on the use and management of living collections in botanic gardens

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"*All is flux, nothing stands still*" Heraclitus

Abstract

Botanic gardens maintain very high levels of plant diversity in remarkably small areas. Superficially, their collections of living plants may appear static but this disguises rapid turnover of accessions, plants and plant organs. A cohort of accessions decays like a radioactive isotope. Thus, although in certain respects botanic gardens can be considered as analogous to museums, a better model is to treat them as conduits for a river of diversity, which must be sampled, recorded and studied promptly and actively if it is to leave any trace of its passage other than the consumption of financial and human resources.

Introduction

Writing about the role of botanic gardens has become compulsive. Many symposia have been arranged (e. g. *Boissiera* vol. 14 [1969], BEDINI & GARBARI 1993, BRAMWELL & al. 1987, FROGGATT & OATES 1993, HE & al. 1990, HEYWOOD & WYSE JACKSON 1991, SINGAPORE BOTANIC GARDENS 1990, and the present volume) and the literature is daunting (RAE 1995). This suggests that there is no consensus about what botanic gardens should be, but a great yearning for one. Whatever roles botanic gardens may have played in the past now seem insufficient. Directors and staff seek a new consensus that addresses current concerns: loss of biodiversity, climate change, environmental degradation, sustainable development, malnutrition and poverty, quality of life, unemployment. If it can be shown that botanic gardens have important parts to play in relation to such issues, the future for botanic gardens will be glorious; if not, they are an anachronism.

In this paper we will not attempt yet another summary or reshuffle of the kinds of activities botanic gardens undertake, which are basically four: research and development (including the exploitation of plant germplasm for pharmaceuticals, foodstuffs and so on), conservation, education and information, and amenity. These have been discussed widely (for example, in the symposia referred to above) and many examples are available to show what is possible (RAE 1995). Instead we will examine the essential nature of the living plant collections themselves.

A botanic garden may be defined, perhaps, as an area where hard work and horticultural expertise are used to achieve ultra-high plant diversity. It is the antithesis of the arable fields of W Europe and N America, in which high yields of uniform, easily harvested plants are assured by sowing highly selected strains of a single species and ruthlessly eliminating every possible competitor. The diversity maintained by botanic gardens is truly staggering. The 5000 taxa maintained on a tiny site (2 ha) by the Oxford Botanic Garden is on a par with the wild diversity of the whole of Italy, with 4800 species in an area of over 300,000 km^2. Cambridge University Botanic Garden (16 ha and *ca* 8000 species) has as many taxa as a small tropical country, such as Gabon, with an area of 270,000 km^2. The Royal Botanic Garden, Edinburgh, with the fifth largest holdings of any botanic garden (data of K. WALTER in RAE 1995), maintains 21,578 taxa of vascular plants representing 16,782 species. This represents some 6% of the world's flora and greatly exceeds the total number of species growing in Europe (*ca* 11,500); it is almost an order of magnitude greater than the total for the United Kingdom itself. The collections are distributed among four gardens located in various parts of Scotland, which total 117 ha in area, but most are concentrated in a 32 ha city-centre site at Inverleith, Edinburgh (WALTER & al. 1995). Botanic gardens have certainly taken to heart PURSEGLOVE's (1959) call for them to "have as large a collection of living plants as it is possible to grow, without sacrificing an attractive layout."

History

Diverse collections of plants were apparently maintained in ancient China and by the Aztecs in pre-Columbian Mexico (HILL 1915). Collections were also established in Spain by the Moors (HARVEY 1981), but the present botanic garden tradition can be traced back to renaissance Italy and the foundation of gardens at Pisa, Padua and Florence in 1543-5 (STAFLEU 1969). The idea quickly spread to Holland, Switzerland, Germany and France, with gardens at Leiden, Zürich, Leipzig, Montpellier and elsewhere (JELLICOE & al. 1986, GAGER 1938). The British, ever reluctant Europeans, gained their first botanic garden in 1621, at Oxford, with Edinburgh and Chelsea Physick Garden following in 1670 and 1673 (BATEY 1989, FLETCHER & BROWN 1970, FIELD & SEMPLE 1878, STUNGO 1993).

From the sixteenth to the eighteenth centuries, botanic gardens were generally associated with the medical faculties of universities. They were used to train physicians to recognize and use plants in the treatment of various medical conditions and diseases, and to provide the *materia medica* themselves. Around 1780, for instance, the Royal Botanic Garden, Edinburgh could boast 3000 rhubarb (*Rheum palmatum*) plants, obtained from Russian stock by the Regius Keeper and King's Botanist John Hope, which were grown in a special field for the use of physicians

(MORTON 1986). It was a short-lived episode in the alimentary and medical history of the city and its citizens.

As systematic botany emerged as an independent scientific discipline in the eighteenth century and early nineteenth century, botanic garden collections grew beyond what was necessary for supplying the needs of medicine, fed by expeditions to remote areas. Species were planted in 'order beds' to demonstrate plant diversity and relationships, according to a favoured classification, such as Linnaeus' sexual system. In Edinburgh the change from traditional physic garden to systematic plant collection took place around 1763, inspired by what John Hope had seen in Paris 15 or so years earlier (MORTON 1986).

Later, many botanic gardens in Europe took on a new role, in planning and effecting international transfers of plant germplasm as the colonial powers that owned them vied to establish hegemony over trade in valuable plant products, such as tea, coffee, spices, fruits, medicines or rubber. Indeed, the Royal Botanic Gardens, Kew, were established largely to act as a conduit for plant germplasm - a botanical entrepôt importing from plant collectors and exporting to a network of satellite gardens spread through the British Empire. In a report that was influential in persuading the British government to establish Kew as a nationally funded botanic garden and herbarium, it was argued that:

> "A national garden ought to be the centre round which all minor establishments of the same nature should be arranged . . . receiving their supplies and aiding the Mother Country in everything that is useful in the vegetable kingdom . . . From a garden of this kind, Government would be able to obtain authentic and official information on points connected with the founding of new colonies; it would afford the plants these required ..." (quoted by BROCKWAY 1979).

A similar philosophy led to the founding of the botanic garden at Calcutta (GAGER 1938). Plants were dispatched from Kew to gardens such as that at Singapore, which had as one of its main aims "to introduce and acclimatise plants of possible economic value" to the colony (CHAMBERS 1990).

The British used their world-wide web of botanic gardens to engineer profound changes in world trade in certain plant products, to the benefit of their Empire. A well-known example is the breaking of the S American monopoly in para rubber (PURSEGLOVE 1959, BROCKWAY 1979). Rubber plants were taken from S America to parts of the British Empire in S and SE Asia, via Kew. This began with the removal of thousands of *Hevea brasiliensis* seeds from Brazil in 1875 by Henry Wickham, who did not inform the Brazilian authorities about the nature of his cargo, since he feared that he might be detained by them if he did. The seeds were germinated at Kew and transferred to Ceylon, Singapore and elsewhere. The end result was the rubber plantations of Malaysia and other parts of SE Asia, still important today. Other European nations behaved similarly, an example being the introduction of the oil palm *Elais guineensis* to Indonesia and Malaysia by the Dutch, via Bogor in Java (HEYWOOD 1983). Some transfers, for example of *Cinchona* via Kew, for the production of quinine, may have been illegal (BROCKWAY 1979).

Horticultural plants have also often been introduced via botanic gardens. During the early years of the twentieth century, for example, the Royal Botanic Garden, Edinburgh, played a major role in the introduction to western European gardens of many trees, shrubs and herbaceous plants from China and the Himalayas. One of the most successful collectors was George Forrest, who worked in Yunnan and Tibet between 1904 and his death in 1932, while still collecting in China (FLETCHER & BROWN 1970, DIELS 1912-13, the STAFF OF THE ROYAL BOTANIC GARDEN EDINBURGH 1924, 1929-30). Many new species were described from this material, by I. B. Balfour, W. W. Smith and others.

Some of the plants Forrest brought back are still cultivated in Edinburgh but, while this is not hidden from visitors (indeed, it is clearly displayed on the plant labels), many people enter and leave the Garden without realizing how the collections have been brought together and why. Indeed, the involvement of European botanic gardens in international movements of germplasm can rarely have been obvious to visitors to the gardens. Transfers of plantation crops, or of horticulturally or economically valuable plants, have generally been planned and overseen by small côteries of entrepreneurs and scientists, out of the public eye.

The legacy of this period of exploitation and manipulation by the colonial European powers is an imbalance in wealth between north and south, between those that transported and exploited germplasm and those that supplied it. The embargoes now being placed on the export and movement of germplasm are therefore understandable, though in our view ultimately unconstructive and self-defeating, since they hinder the very same activities - wealth creation and advances in scientific understanding - that make the embargoes seem worthwhile. Furthermore, if the movement of germplasm is made illegal, it will simply become clandestine (contraband genes!).

Uncertain present

Most botanic gardens today belong to universities (about 30% of the total: two British examples are Oxford and Cambridge Botanic Gardens), government departments (about 27%, e. g. the Royal Botanic Gardens of Edinburgh and Kew) or cities (about 14%, e. g. Glasgow Botanic Garden). Universities no longer have any use for physic gardens and plant systematics is at a low ebb (in spite of the biodiversity crisis). The exploitation of plants for agriculture and forestry is often now overseen by specialist institutes, not botanic gardens (HEYWOOD 1983), and besides, international treaties and the break-up of empires have shackled the movements of germplasm. Furthermore, botanic garden directors are sometimes hampered in their plans because politicians, public and administrative officials often fail to understand the difference between a botanic garden and a park.

Many owners would undoubtedly like to be rid of their botanic gardens, but these expensive institutions are not without friends (in addition, of course, to the staff themselves) prepared to resist closure. The principal motivation of these supporters is often to protect a valued amenity: from polluted monochrome surroundings (for many botanic gardens are located within an urban environment), city-dwellers and visitors enter a scented Garden of Delights, an exotic kaleidoscope of colour set against textured green.

This, then, is to treat botanic gardens as high-class parks - pleasure grounds for the horticulturally minded. Amenity is an important function for botanic gardens and it can also be used as bait to attract income via gate charges, retail outlets situated in the garden, or catering concessions; there is no doubt that income from these sources will be increasingly necessary for many botanic gardens towards the millenium. In any case, gardens are offering the public things they have probably always wanted: the chance to buy literature, souvenirs and plants to remind themselves of a pleasant visit, and the chance to relax for a while with a drink or light meal in attractive surroundings. But botanic gardens cannot be justified on the grounds of amenity alone; other kinds of garden can perform this role better, at lower cost. Hercules fought Antaeus and killed the dragon Ladon to gain the golden apples in the garden of the Hesperides: we have to discover and explain what treasure it is that botanic gardens contain and how it should be looked after.

An analogy

It may be useful to explore the analogy between botanic gardens and art galleries, since both are repositories of things that delight the eye. When we visit an art gallery, the Uffizi, for example, and look at the *Adoration of the Magi* by Leonardo, or at Botticelli's *Primavera*, we know that we are looking at paintings that, were they ever to come on the market, would command millions or tens of millions of pounds. We also know that, if by some horrible misfortune these paintings were destroyed, they could not be replaced. Each is unique and has its own history and pedigree: the circumstances of its commissioning, composition and execution, its owners and their reasons for buying, keeping or disposing of it, the inspiration it has given to artists and critics, and so on. Works of art are thus parts of the national heritage and must be treated as such, to be passed down in good condition to future generations, having gained a thicker and richer patina.

In some ways we should feel the same about botanic gardens and the plants they contain. In terms of investment and as collections of *objets d'art*, botanic gardens are the equal of many art galleries. In Edinburgh, for example, we have a large rock garden (1. 5 ha) in which, helped by the cool northern climate, we are able to grow many herbaceous plants and dwarf shrubs from alpine and montane habitats in every continent except Antarctica. It has taken millions of pounds to create and maintain the rock garden and, after an early phase when a pleasing effect seems to have eluded its designers (Farrer referred to its "chaotic hideousness": FLETCHER & BROWN 1970), it has been greatly admired. Hundreds of thousands of people visit this and other parts of the Royal Botanic Garden collections each year and gain enjoyment and information from them. In addition, the plants have been collected over many years and have a pedigree. 57% of the accessions are of known wild origin (WALTER & al. 1995): there are records of who collected the plants, when and where. Some accessions have been used as the basis for taxonomic studies, some have yielded type material, some have been propagated and found their way into commercial horticulture, a few have been screened for new chemicals and pharmaceuticals. Thus, because of the data associated with them, the collections are unique and irreplaceable.

Increasingly too, botanic garden collections contain germplasm that has disappeared from the wild. *Trochetiopsis erythroxylon* from St. Helena survives only as plantings, with a few specimens in botanic gardens: it was introduced to Kew by Banks (AITON 1789) and Kew still grows one plant. *Franklinia alatamaha*, with its striking 'poached egg' flowers, became extinct in nature around 1790, within 25 years of its discovery near Fort Barrington, Georgia, USA, probably because of over-exploitation for horticulture (HARPER & Lees 1937); there are still many specimens, but only in gardens. In Edinburgh, we maintain 13 species known to be extinct in nature, including *Trochetiopsis* and *Franklinia*, but also lesser known species, such as *Bromus interruptus*. Other species held by botanic gardens are not yet extinct in the wild but may be vulnerable, such as *Rhododendron taxifolium*, restricted to one mountain in the Philippines (G. C. G. Argent, pers. comm.). Such plants can and should be propagated and distributed to other gardens and so they are not equivalent to a painting by Leonardo. But they certainly have many of the attributes of Old Masters - rarity, beauty, history, human interest.

So, anyone who has responsibility for a major botanic garden must recognize that he or she is not a park manager, but a custodian of part of the national heritage and of part of the natural heritage of all mankind.

The river of diversity

The art gallery analogy is instructive, therefore, and indeed many themes and activities are common to botanic gardens, museums and art galleries: cataloguing and labelling, display and interpretation, education and training, restoration, special collections (medicinal plants, foliage plants, succulents), and so on. HOLTTUM (1970) stated that "a botanic garden is essentially a museum of living plants" and not infrequently botanic gardens, like herbaria and museums, refer to their senior staff as curators. However, the analogy has a fatal flaw.

To the casual visitor, botanic gardens may appear to be static collections, preserved for ever like pots on a museum shelf, growing slowly as new specimens are acquired. Thus, for the Cambridge University Botanic Garden, records show that Thomas Martyn had built up the collections to around 1250 spp by 1756, shortly after the establishment of the garden, and the total rose to 1860 spp in 1794. Then, under the influence of Professor Henslow there was a rapid expansion to *ca* 5000 spp in the early 19th century; today there are 8000 spp. However, although the bald figures seem to suggest steady growth, it is unlikely that any plants in the present garden date from before 1846, when the garden moved to a new site. Most of the accessions have been made in the last 40-50 years. The Royal Botanic Garden, Edinburgh has occupied four city sites in its 325 year history, but although it is known that the collections were transferred to the new sites as old ones were vacated (FLETCHER & BROWN 1970), very few accessions predate the last move, in 1822, or are known to be lineal descendants of plants from the earlier periods; two old specimens that do remain are of *Encephalartos natalensis* and *Sabal bermudana* (RAE 1995).

The impermanence of botanic garden collections can also be illustrated by reference to the collections of Primulaceae at Edinburgh. In the first half of the twentieth century, Edinburgh was known internationally for research into the systematics of *Primula* (SMITH & al. 1977). It might be expected, therefore, that Primulaceae would be particularly well represented in the collections of the Royal Botanic Garden and this is indeed so: in 1994, there were 841 accessions (K. WALTER in RAE 1995). Examination of the plant catalogue reveals that accessions of *Primula* are dominated by wild collected material, but among these there is apparently only one accession left of the hundreds brought back by the major plant collectors associated with Edinburgh in the period when Balfour, Forrest, Smith and Fletcher were engaged in *Primula* research at the Garden; this is an accession of *Primula gracilipes*, from material collected by Ludlow & Sherriff in Bhutan (WALTER & al. 1995). Of the Sino-Himalayan species collected by Forrest for the nurserymen Bees, or of those collected by Wilson, Kingdon Ward and others (for example, see BALFOUR 1913), there is no trace. In 1936, E. E. Kemp recorded around 100 different *Primula* taxa in flower in the propagation department and frames (unpublished manuscript books of the Royal Botanic Garden archive); they all appear to have gone. The present collection is dominated by accessions from the 1980s and 1990s (Fig. 1). The explanation for this is not hard to find. Most *Primula* species are short-lived perennials and their pollen is promiscuous, so that long-term maintenance will always be difficult. In a sense, therefore, the Royal Botanic Garden does not have, and never has had, a *collection* of living *Primula*. Returning to the art gallery analogy, we might say that the Garden has no permanent displays, but stages a series of temporary exhibitions of ephemeral *objets d'art*, sometimes to brilliant effect.

The vast majority of accessions in botanic gardens are short-lived: indeed, many never successfully establish. Unfortunately, these include species of conservation importance, such as *Rhododendron chamaepitys*, which is restricted in nature to an area about the size of a tennis court and has been lost from cultivation at both Kew and Edinburgh (G. C. G. Argent, pers. comm.). On the other hand, a few species are extraordinarily persistent, most of these, of course, being woody. But even woody plants are subject to turn-over. *Trochetiopsis erythroxylon* was mentioned earlier as a species that is now extinct in nature, but survives in cultivation. This species was an early introduction to Kew and there is a plant there today, but this is not a case of long-term maintenance, as the plant has been lost and re-introduced perhaps three times during the history of Kew; no introduction of the plant appears to have been maintained for more than 30 years.

It may be best to think in terms of an exponential fall-off (an analogy being radioactive decay) and to appreciate that collections have a half-life. This may be approximately equal to the first flowering (generation time) of the plant group concerned. Figure 2 shows the fall off of accessions in the Royal Botanic Garden, Edinburgh. It is very rapid at first (equivalent to a half-life of about 4 years), but slows as robust and long-lived plants remain (source RBGE plant records on BG-BASE and RAE 1985). The continual arrival of new accessions more than compensates for the loss, however, and allows the collections to grow.

The message for botanic gardens (and one that has not fully penetrated) is that botanic garden staff are not curators in the normal sense, managing a collection - they are engineers channelling and diverting a vast river of germplasm through conduits and sluices until it is lost to the ocean of the compost heap. In addition to the flux of accessions, there is a flux of developmental stages and individual plant organs, since each plant is a population of modules, which are born, grow and die (HARPER 1977).

As our historical review demonstrates, this concept would not have been foreign to the directors of botanic gardens in earlier times - John Hope growing rhubarb for physicians, Hooker and Balfour arranging the introduction of economic or horticultural plants. However, it may be more difficult to accommodate the idea of inevitable flux and loss in a society that has come to place great emphasis on conservation and places restrictions on the movement of germplasm, believing (rightly or wrongly) that genetic resources belong to the nations and human cultures where they happen to have evolved.

Thus, to manage a botanic garden requires a quite different approach than the curation of a museum, since living plant collections are transient in space and time. Hence the question that must be asked as we approach the millenium is, what tangible and lasting result comes from the flow of germplasm through botanic gardens? In many cases, the answer must be, very little.

Managing the river of diversity

The first consequence of the flux argument is that, if any botanic garden ceases to import new material, there will be a very rapid fall in the number of live accessions. Clearly, the fall will be especially rapid if the horticultural work force is unskilled or poorly motivated. But, perversely, the fall will also be very rapid in the most enterprising and dynamic gardens, since it is only here that attempts will be made to bring into cultivation the most intractable plants, with particularly exacting requirements for soil, humidity, light, daylength and so on; failures are inevitable. A botanic garden is a training ground for horticulturists and a place where new techniques must be developed for growing plants that may never have been cultivated before. It is therefore impossible to gauge the quality of 'curation' in a botanic garden simply by measuring the rate of flux through it. Slow turn-over, far from implying competence, may well imply a moribund collection of undistinguished botanic garden 'weeds' resistant to the efforts of the worst gardener.

On the other hand, there is no doubt that in many cases the rate of loss should be minimized. This may not always be so, perhaps, since if a plant is common and easily collected in its country of origin, and genetic continuity is unimportant, it may be more cost-effective to plan for periodic replacement as stocks die than to struggle to maintain the current accessions.

For a particular group of plants the germplasm flux can sometimes be retarded by seed/spore banking or cryopreservation (though for many species of the wet tropics this is impossible). Nevertheless, it is important to remember that the river of diversity is never wholly impounded by these means. The trickle of germplasm that still escapes to the compost heap is almost certainly a biased sample of the main flow, so that what is withdrawn from the seed bank will not properly represent what was deposited. Furthermore, if the remaining seed is grown on in order to replenish the bank, there is further considerable opportunity for loss, change and contamination.

What implications does the flux analogy have for the use of botanic gardens? For amenity, education and information, flux is an expensive nuisance, but not much more. One accession can often be substituted by another with little consequence. For horticultural training flux is essential. For conservation, the principal message is that *ex situ* collections in botanic gardens are inherently insecure and unsatisfactory, though with the kind of care taken by zoos in planning breeding programmes for pandas, rhinoceros or tigers, viable populations could no doubt be maintained for long periods. Keeping one or two individuals of a species in several botanic gardens will not work as a conservation measure, unless all the plants are managed purposively as a single metapopulation, by a single competent authority.

It is probably in relation to research that our idea could have most repercussions. Living plant collections are most useful for research when they are comprehensive within a defined scope. However, as RAVEN (1981) noted, "even if a comprehensive collection of living plants has been assembled at a particular botanical garden, experience has shown that it is often not utilized much by the scientific staff." There are many reasons for this, including poor planning, the time it takes to assemble a comprehensive collection of anything, and serendipity. In addition, it is likely that, even during the most active research programme, only a small part of the collection is relevant at any given time to the hypotheses being tested. After all, most books in a library spend most of the time on the shelves.

However, while a collection is not being used it is changing and some accessions will be lost. What is vital, therefore, is that, as the river of germplasm flows inexorably on through a botanic garden, the biodiversity managers ensure that the flow is not only regulated but sampled. Any botanic garden that holds collections of plants for research purposes, whether for its own scientists or for the international community, should have an active and all-pervading programme of sampling and recording the biodiversity flux: photographing ephemera and features that cannot conveniently be preserved (such as bark and growth form), pressing or preserving specimens at different developmental stages, preserving samples containing intact DNA for molecular analysis, preserving samples for phytochemical analysis, harvesting seeds and fruits, recording phenological information, etc. This is why it is so important to have a linked herbarium and why the activities and plans of the herbarium and garden should be inseparable. Sophisticated computer record systems are also vital, to store, sort and retrieve data.

In conclusion, we would urge the botanic garden community to establish new systems of curation and collaborative research programmes fitted not to a flawed view of botanic gardens as so much museum shelving, but to what they really are: rivers of diversity.

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Figure legends

Fig. 1. Numbers of accessions of *Primula* in the Royal Botanic Garden Edinburgh in 1995, grouped by decade of accession. Only 9 accessions remain from the most active period of *Primula* research at Edinburgh (1905-1945), despite considerable care and expertise in *Primula* cultivation.

Initial year of decade of accession	Number of accessions alive in 1995
1990	360
1980	139
1970	100
1960	45
1950	11
1940	1
1930	8
1920	1

Fig. 2. Losses of accessions in the Royal Botanic Garden, Edinburgh. Squares: numbers of accessions remaining (expressed as a percentage) after different periods of time, calculated from accessions book data and computer records for 64, 20, 6, 5, 4, and 3 years ago. The figures show a rapid decline at first, slowing later, which can be compared with the curve marked by circles, which represents an exponential decay curve with a 4 year half-life